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ENERGY SHOCKS AND THE DEMAND FOR ENERGY

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Transmission channels and factor demand determinants

by

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> Since 1945 the supply of oil has frequently been threatened by conflict. In 1951 Mohammed Mossadegh nationalised BP's Iranian holdings. In 1956 the Suez Canal was blocked. In 1967 Israel attacked Egypt's massing armies, and the Arabs tried to embargo supplies to America. Another Arab-Israeli conflict caused the "first" oil shock in 1973, and the Iranian revolution led to the second in 1979. On each occasion the oil price jumped and the world economy shuddered.
>
> The Economist, 12th January 1991

Introduction

The Persian Gulf crisis and the resulting surge in the price of oil again raised the question of how energy-dependent developed economies are, especially at a time when a slowdown in economic activity (in some instances a recession) is being recorded. Indicators such as consumption of energy per unit of GDP show a general tendency for the energy intensity of output to be lower today than it was ten or fifteen years ago. Moreover, other sources of energy have helped to reduce the share of energy use met by oil as well as industrial countries' reliance on energy imports, allowing their production systems to adjust more flexibly in periods of crisis. Nonetheless, an increase in the price of oil still represents a deterioration in the terms of trade for most countries and risks sparking off a price-wage spiral unless appropriate policies are introduced.

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The purpose of this paper is to analyse some of the issues raised above. Section A discusses developments in energy consumption and oil markets since the early 1970s, highlighting the fall in energy and oil consumption per unit of output and the accompanying reduction in the industrial countries' exposure and vulnerability to energy shocks. Section B turns to the determination of aggregate output and applies a very simple model in discussing the major transmission channels of energy price shocks and the related risk of disturbances to long-run equilibrium growth. Section C focuses on investment and the capital stock and their role in the determination of energy demand and sets the stage for empirically derived energy demand equations for the seven major countries. These are presented in Section D distinguishing in each case between demand for energy in industry, transportation and the commercial and residential sectors. Section E summarises the major empirical findings and draws some tentative conclusions, while two annexes present more details with respect to energy use and the models discussed in Section C.

A. Energy demand and oil market developments

(a) Total energy consumption

Major trends in energy consumption in OECD countries and in the rest of the world are shown in Tables Ia and Ib and, in greater detail for net oil-importing Group of Seven countries in Annex I. The main features may be summarised as follows:

(i) during the 1960s total energy consumption in the industrial countries rose slightly relative to GDP and the dependence on imports from non-OECD countries almost doubled. Moreover, partly as a result of the fall in real oil prices, energy consumption grew increasingly oil-intensive as reflected in the 33% rise in oil consumption per unit of output;

(ii) the effect on energy use of the first oil shock was rather weak and protracted as energy consumption per unit of output in 1975 was only 5% below the level of 1970. The fall in oil consumption was even smaller and the dependence on imported energy products continued to grow. However, starting in around 1978 and reinforced by the second oil shock, energy consumption per unit of output began to fall and by 1990 was more than 25% below its 1973 level. Over the same period the decline in oil consumption per unit of output, at over 40%, was even sharper. Given the higher import

Table 1a
Developments in OECD energy consumption

Items	1960	1970	1975	1980	1985	1989	1990[1]
	in MTOE/GDP, indices, 1973 = 100						
Primary energy requirements	96.9	100.9	95.8	89.5	78.9	75.1	74.1
Oil consumption	71.9	95.9	92.3	80.7	62.2	60.0	59.3
Net imports of energy	48.4	89.0	91.7	78.4	49.5	54.3	55.7
Memorandum items:							
Real oil price[2]	103.8	77.0	268.5	497.0	319.7	174.7	218.7
Oil/primary energy use, %	39.7	50.9	51.6	48.3	42.3	42.8	42.8
Net import/primary energy use, %	19.2	33.7	36.6	33.5	24.0	27.6	28.7

[1] Based on data for first nine months.

[2] Crude oil price/GDP deflator, index 1973 = 100.

Table 1b
Developments in world energy consumption

Countries and country groups	1965-80	1980-88	Energy per capita[1]		Income per capita[2]
	percentage change, annual rates		1965	1988	1988
OECD countries	3.2	0.9	3,429	4,847	16,919
Low and middle-income LDCs	7.2	3.8	253	525	750
of which: Sub-Saharan Africa	5.6	2.7	71	95	330
East Asia	9.4	5.3	168	474	540
South Asia	5.7	5.5	99	182	320
Latin America	6.9	1.9	515	952	1,840
High-income LDCs[3]	5.7	3.2	1,943	3,028	8,380
Eastern Europe	3.6[4]	0.8	4,601[5]	3,890	3,150
Soviet Union	4.2[4]	2.7	4,084[5]	4,821	3,285

[1] In kilograms of oil equivalent

[2] In US dollars.

[3] Saudi Arabia, Israel, Singapore, Hong Kong, Kuwait and the United Arab Emirates.

[4] 1970-80.

[5] 1970.

Sources: OECD/IEA: Energy Balances of OECD countries; World Bank: World Development Report; United Nations: Energy Statistics Yearbook; and ECE: Economic Survey of Europe.

intensity of oil in comparison with other sources of energy, this also helped to lower the dependence on imported energy;

(iii) the growth of energy consumption in non-OECD countries was extremely fast during 1965-80, thus again pointing to a weak response to the first oil shock. In the 1980s the growth of energy consumption fell to less than 4% per year and energy use per unit of output actually declined for low and middle-income LDCs as a group, though entirely because of developments in East Asia;

(iv) for the former centrally planned economies the most striking feature is the very high levels of per capita energy consumption, which entail energy/GDP ratios four to five times those of OECD countries. This can be explained in part by climatic factors but also reflects the generally low level of productivity and the influence of heavily subsidised energy prices and ensuing inefficiencies in the use of energy.

(b) Oil consumption and developments in the oil market

While oil consumption per unit of output reacted only sluggishly to the first oil shock, the 1974-75 recession caused a marked decline in overall oil consumption in the OECD countries (Table 2). This was reinforced by the second oil shock, and between the peak in 1978-79 and the trough in 1983 the level of oil consumption in the industrialised countries fell by almost 20%. Even after the resumption of faster output growth and the fall in oil prices, oil consumption last year was still more than 10% below the earlier peak. Looking at the longer-run developments of the share of oil in overall energy use there is clear evidence of inter-fuel substitution, which may also be observed from estimated price elasticities for oil demand which tend to be twice as high as those derived for total energy. This substitution away from oil is particularly evident in the industrial sector of the OECD countries, which has reduced its share of world oil consumption by six percentage points since 1973. The electricity generating sector has also cut its share of overall oil consumption, mainly through switching to coal and nuclear power. By contrast, due to more limited substitution possibilities but reflecting also a relatively steep rise in consumption following the 1985-86 fall in oil prices, the OECD transportation sector has increased its use of oil and now accounts for almost 30% of total consumption.

These sectoral developments and the substitution of cheaper for more expensive sources of energy are also reflected in the changing

Table 2

Developments in world oil supply and demand

Items and country groups	1960-73	1973-78	1978-85	1985-89	1989-90[1]	1973	1978	1985	1989	1990[1]
	percentage change, annual rates					in percentages				
Consumption										
OECD	7.5	0.6	- 2.7	2.2	0.0	70.3	65.0	57.2	57.1	57.1
of which: Industry	6.5	- 0.9	- 5.3	0.9[2]	n.a.	15.6	13.2	9.9	9.4[2]	n.a.
Transportation	5.9	2.6	0.3	3.5[2]	n.a.	25.0	25.3	28.3	28.8[2]	n.a.
Residential	9.7	- 0.5	- 5.0	- 0.4[2]	n.a.	11.3	9.8	7.5	6.8[2]	n.a.
Electricity		0.5	- 10.9	2.9[2]	n.a.	9.0	8.2	4.0	4.0[2]	n.a.
Other		0.6	- 3.2	5.9[2]	n.a.	9.4	8.5	7.5	8.1[2]	n.a.
Eastern Europe and Soviet Union	n.a.	5.2	0.6	- 0.8	- 4.6	14.3	16.6	18.5	16.4	15.7
Non-OPEC LDCs	n.a.	5.5	2.0	5.3	2.3	12.5	14.6	18.0	20.2	20.7
OPEC	n.a.	8.0	6.6	2.1	4.9	2.9	3.8	6.3	6.3	6.5
Total	n.a.	1.4	- 1.4	2.8	0.0	100.0	100.0	100.0	100.0	100.0
Supply[3]										
OECD	3.4	0.3	2.8	- 1.8	- 0.6	23.9	22.4	29.3	24.1	23.7
Eastern Europe and Soviet Union	n.a.	3.5	0.6	0.8	- 6.5	15.4	18.7	21.3	19.3	17.8
Non-OPEC LDCs	n.a.	9.6	7.3	5.2	2.9	7.2	10.8	19.1	20.6	21.0
OPEC	n.a.	- 0.5	- 7.5	7.6	5.5	53.5	48.1	30.3	36.0	37.5
Total	n.a.	1.4	- 1.4	2.8	1.2	100.0	100.0	100.0	100.0	100.0

[1] Preliminary.
[2] Based on 1988 data.
[3] Excluding processing gains and stock changes.

Source: IEA: Annual and Monthly Oil Market Reports and World Energy Statistics and Balances.

composition of energy and oil consumption (Table 3). Firstly, the fall in the oil intensity of total output has been mainly the result of lower consumption of heavy fuels, which are mostly used for power generation and in industry. Indeed, in 1990 the consumption levels of other oil products were well above earlier peaks, especially among the lighter products, with aviation fuel being up by 13% (in North America by more than 30%). Secondly, the major substitutes for heavy fuels have been coal and - especially after 1979 - nuclear power, whereas natural gas (a close substitute for oil) shows a largely constant share of total energy consumption. These trends probably reflect the fact that the price of natural gas has been more closely linked to that of oil and that the relative prices of other goods have shown a steeper fall.

Another feature that may be observed in Table 2 is the rise in the use of oil in non-OPEC less developed countries. This development, which has taken the consumption share to over 20% from only 12½% in 1973, can be related to four main factors: (i) despite the debt crisis and severe terms-of-trade losses, overall output growth has been higher than in the industrialised countries, especially in the 1970s, when large capital inflows helped to sustain a rapid expansion of domestic demand and imports; (ii) industrialisation, accompanied by urbanisation and rising transportation needs, has tended to increase energy consumption per unit of output; (iii) due to an underdeveloped infrastructure and a lack of indigenous non-oil sources of energy, inter-fuel substitution possibilities are limited, implying not only that cutbacks in oil consumption are difficult but also that the rising consumption of energy is principally met by oil; and (iv) price subsidies combined with lower investment (especially in the 1980s) have weakened incentives to save energy and delayed the installation of a more energy-efficient capital stock.

Turning to the supply side, the most dramatic development has been the fall in the share of OPEC countries from some 55% in 1973 to a low of only 30% in 1985, followed by a recovery to 37% last year (Table 2). Non-OPEC LDCs, by contrast, have almost tripled their share. Industrialised countries accounted for around 30% of total supply until 1985, but their share has declined noticeably during the last five years as North Sea oil production stagnated and output in North America fell. The output share of eastern Europe and the Soviet Union has also tended to decline, with a particularly sharp fall taking place last year. Judging by developments in

Table 3

Composition of energy consumption in OECD countries

Year	Oil products[1]							Energy products					
	LPG/ naphtha	Aviation fuels	Gasoline	Middle distill.	Heavy fuels	Others	Total	Solid fuels	Natural gas	Nuclear	Hydro	Oil	Total
	in percentages												
1973	11.7	3.9	24.4	23.6	27.4	9.0	100.0	20.3	19.3	1.2	5.6	53.6	100.0
1979	11.3	4.3	26.4	24.6	23.3	10.1	100.0	20.9	18.9	3.2	6.2	50.8	100.0
1985	12.5	5.7	31.3	25.7	13.9	10.9	100.0	24.9	18.8	7.2	6.8	42.3	100.0
1989	12.8	6.2	31.4	25.3	12.7	11.6	100.0	23.6	18.9	8.6	6.1	42.8	100.0
1990[2]	12.5	6.3	31.5	25.4	12.1	12.2	100.0	23.8	18.3	8.8	6.2	42.8	100.0

[1] 1973 figures are estimated.

[2] Preliminary.

Source: See Table 2.

proven oil reserves (Table 4), these recent changes may be more indicative of future trends in supply shares than those observed during 1973-85. Measured in years of consumption, overall oil reserves are now larger than in 1960,[1] while the share of the Middle East in total reserves has increased to two-thirds and most of the rise in Africa and Latin America has taken place in countries that are OPEC members or closely follow OPEC pricing policies. At the same time, the share of industrialised countries has fallen to just over 5%, so that the future is likely to bring an increasing concentration of production in countries with a lower degree of political stability. Consequently, and despite the comfortable reserve position and the low probability of overall supply constraints, the outlook is less auspicious than it might appear at first glance.

How easily the market can be disturbed became evident in early August last year. Even though the reduction in world supply was only some 8% following the embargo on exports from Iraq and Kuwait, it sparked off a doubling of the spot oil price (monthly averages) and of the differential between the prices of light and heavy crudes. In assessing this disturbance it is useful to distinguish between those features of the oil market which also obtained during previous oil shocks and those that were new:

- a principal feature of the spot oil market is that demand and supply elasticities are extremely low. This means that even minor shifts in demand or supply will be accompanied by very large price fluctuations and only marginal changes in quantities.[2, 3] If unused capacities are available,

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[1] Proven reserves in the former centrally planned economies may be estimated at twenty-three years of future consumption (1989).

[2] Today most oil is sold on the spot market or on the market for future deliveries which developed after 1985-86 in response to OPEC's move from a price to an output target and the subsequent rise in price volatility. By contrast, in the 1970s the spot market accounted for only 10% of total sales and the bulk of deliveries were on a long-term contractual basis. The scope for clearing differences between supply and demand has, therefore, expanded significantly over time, which should dampen price fluctuations in the spot market (see Hubbard (1986)), although this was not apparent last year. At the same time, the virtual disappearance of longer-term contracts has shortened the lag with which spot price changes appear in final user prices.

[3] Low short-run elasticities are not confined to the spot market, but also characterise overall demand for and supply of oil. Brown and (Footnote Continued)

Table 4

Proven oil reserves

Areas and country groups	1960	1970	1975	1980	1985	1989
	in percentages					
OECD	13.0	8.9	9.5	8.4	8.0	5.5
Africa	2.7	7.8	8.0	8.7	8.2	5.9
Asia	3.6	2.1	2.4	2.6	2.5	2.1
Latin America	8.4	14.1	11.8	12.6	12.2	11.6
Middle East	61.1	52.5	56.4	55.3	57.4	66.4
Others[1]	11.2	14.6	11.9	12.4	11.7	8.5
Total	100.0	100.0	100.0	100.0	100.0	100.0
In years of consumption[2]	39[3]	35[3]	43	32	36	48

[1] Mainly the former centrally planned economies.
[2] Excluding other areas.
[3] Partly estimated.

Source: See Table 2.

operating rates will gradually increase and the demand and supply curves will flatten, with prices showing a tendency to fall. Indeed, early this year virtually all of the supply cut had been replaced by expanded production - principally by other OPEC members - and the spot price fell to about half its October peak (see Graph 1). In the longer run, as oil is replaced by other sources of energy and investment in the oil sector is stepped up, the demand and supply elasticities increase further, strengthening the downward pressure on prices;

- although prices for deliveries three to six months ahead also increased in response to the embargo, they stayed well below spot prices and were much less volatile. This suggests that market participants tended to take a longer-run view and that shifts from spot to future deliveries are likely to have relieved excess demand pressures in the spot market and dampened the price rise;

- another factor serving to dampen the price rise - in particular compared with the situation prior to the second oil shock - was the high level of oil stocks. In early August 1990 the combined level of strategic and company stocks[4] was equivalent to a forward consumption coverage of 97 days and net imports of 155 days.[5] By contrast, in 1978 stocks corresponded to only 74 days of forward coverage and the initial reaction to the revolution in Iran was a marked rise in inventory demand as companies, anticipating a continued rise in oil consumption, attempted to rebuild their inventories;

(Footnote Continued)
Phillips (1989) provide a good illustration of the low demand elasticities by observing that in the first quarter of 1981 world oil consumption was about 56 mbd at a price of $48.6 per barrel (1988 dollars), and in the first quarter of 1988 world oil consumption was also about 56 mbd, but the price only $15.5 per barrel. For the United States, the 1981 price would eventually have reduced consumption by some 40%, while maintenance of the 1981 consumption level would have required a price fall of almost 60%.

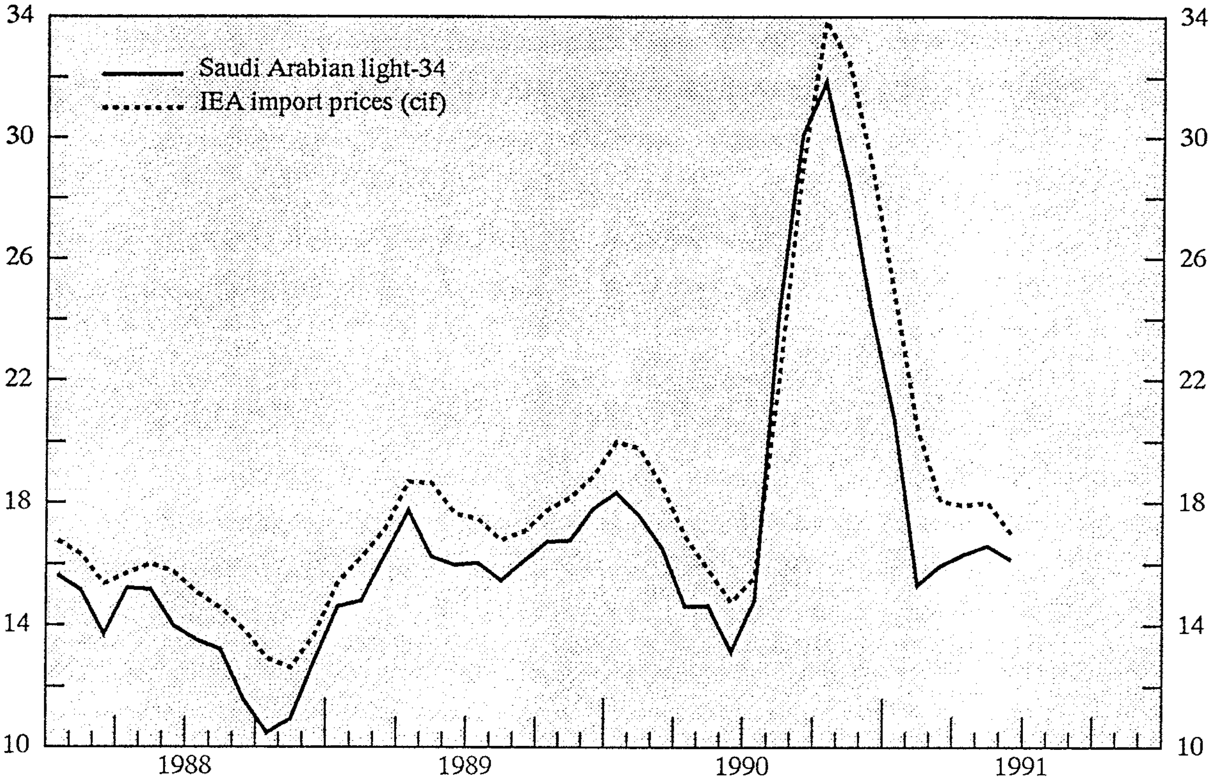
[4] Some 30% was accounted for by government held strategic stocks for emergency purposes. Since 1974 such stocks have increased from virtually zero to about 140 million tons, whereas company stocks have fallen by almost 20% as a result of higher real interest rates, tighter stock management policies and the shifting of part of the burden of holding emergency stocks to the public sector.

[5] IEA member countries are committed to maintaining stocks equivalent to at least 90 days of oil imports.

Graph 1

Spot price of Saudi Arabian light oil and average price of crude oil imported into IEA countries

In US$ per barrel



- a special feature of the recent crisis was the much larger decline in refining capacity and in the supply of lighter crudes than in overall supply, and this pushed up price differentials. This should be seen against the background of continued growth in the demand for lighter fuels (Table 3) as well as the fall in distillation capacities in OECD countries.[6] In fact, local capacity bottlenecks were already being encountered in 1989, and perceptions of future profitability in the refining sector strengthened considerably. Consequently, while the overall supply fall caused by the embargo was relatively easy to make up, it proved much more difficult to offset the loss of refining capacity and price differentials remained high almost to the end of last year.

On balance it would appear that, with the exception of the refining shortage, developments in the oil market since the early 1980s have generally helped to dampen the price effect of a given fall in supply. This has reinforced the decline in industrial countries' exposure to energy price shocks already evident in the lower net import levels (see Table 1a). Moreover, as will be further discussed in the following, certain developments in the demand determinants for energy and in the general supply structures of industrial countries have further strengthened this trend.

B. Transmission channels and the demand for energy: a simple approach

(a) Energy demand, aggregate supply and prices

The early 1970s marked a watershed not only with respect to economic performance in most industrial countries but also as regards economic analysis. In the first place, the events of 1972-74 - and especially the combination of weaker output growth and accelerating inflation - were difficult to explain within demand-oriented models and underlined a need to pay more explicit attention to aggregate supply and especially to the effect of changes in the relative prices of intermediate production factors such as energy. Secondly, the early 1970s also saw a marked rise in the share of labour income relative to profits suggesting that long-run equilibrium conditions - in particular real wage and

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[6] Since 1980 distillation capacity has fallen by more than 20%, reflecting environmental policies as well as low profits.

productivity developments - should be included as an important part of aggregate supply analyses.

The approach chosen by most analysts and model builders was to extend factor demand equations and the traditional two-factor value added production function to include energy and to incorporate real or relative factor prices in the long-run equilibrium conditions. There are numerous ways of incorporating energy and factor prices into this broader framework. However, as a starting point, we shall rely on a very simple model to derive the principal effects of higher energy prices and then, in Section C, turn to more complicated models when analysing factor price adjustments and the dependence of energy demand on changes in the size and composition of the capital stock.

A production function can be seen as an attempt to describe the transformation of factor inputs into real output using existing technologies. The aggregate production function in most earlier models was based on real value added (Y) as defined in the national accounts and included only labour (L) and capital (K) and a trend term to describe technical progress ($A\ e^{rt}$). Other inputs such as energy and non-energy raw materials were regarded as intermediate factors, which could be "netted out" in calculating value added. A particularly popular model which offered attractive analytical properties and successfully explained aggregate developments was the Cobb-Douglas function:

$$\text{(i)} \qquad Y = A\ e^{rt}\ L^{\alpha}\ K^{\beta}$$

where α and β measure the elasticity of output with respect to labour and capital respectively and - on the additional assumptions of perfect competition and constant returns to scale - also the factor shares of income. One way of incorporating energy (E) into the analysis is to extend (i) to:[7]

$$\text{(ii)} \qquad Q = Y^{1-\gamma}\ E^{\gamma}$$

where Q is gross output measured by value added plus energy inputs. When the marginal productivity of energy equals its real price (P_E/P_Q), the following condition is satisfied:

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[7] See Bruno and Sachs (1985) and Rasche and Tatom (1981).

(iii) $$dQ/dE = \gamma(Y/E)^{1-\gamma} = P_E/P_Q$$ or

$$E = Y\ (P_E/P_Q)^{\frac{-1}{1-\gamma}}\ .\ \gamma^{1-\gamma}$$

which can be interpreted as a demand equation for energy. On the further assumption that firms set their output prices as a mark-up on average costs measured as a weighted average of factor prices, P_Q becomes:

(iv) $$P_Q = P_Y^{1-\gamma}\ P_E^{\gamma}$$

and (iii) can be rewritten as:

(iii)' $$E = Y\ (P_Y/P_E)\ .\ \gamma^{1-\gamma}$$

Hence, on the assumptions made, long-run energy demand is determined by real value added and the ratio between the GDP deflator and the price of energy, with both determinants entering with unit elasticities. As regards the impact of higher energy prices on gross output, substituting (iii)' into (ii) gives:

(v) $$Q = Y\ (P_Y/P_E)^{\gamma}\ \gamma^{(1-\gamma)\gamma}$$

Using (iv) and (v) it can easily be seen that if P_E increases by 25% and the share of energy in total factor inputs (γ) is 10%, gross output declines by 2½% and gross output prices will increase by 2½%,[8] while for γ = 20% both price and output effects will double.

(b) Applications and modifications

The equations derived above can be used as a first approximation to evaluating the macroeconomic effects of energy price shocks and they underline the share of energy in total output as a key parameter in such evaluations. However, before the model can be applied to actual data a number of modifications need to be made, partly on theoretical grounds and partly for statistical reasons.

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[8] Assuming that P_Y remains unchanged. This assumption will be further discussed below.

Table 5

Direct real output effects of changes in energy import prices
(as a percentage of GDP)

Countries	Period	Energy imports/GDP	Relative price change	Real output change/GDP[1]	Memo item: Change in US$
		in percentages			
United States	1972-74	0.3	352	- 1.1	-
	1978-81	1.7	152	- 2.6	-
	1984-86	1.4	- 53	0.6	-
	1989-90[2]	0.8	15	- 0.1	-
Japan	1972-74	1.9	159	- 3.0	- 3.6
	1978-81	3.2	129	- 4.1	4.8
	1984-86	4.8	- 58	2.7	- 30.0
	1989-90[2]	1.5	24	- 0.4	4.9
Germany	1972-74	1.0	194	- 1.9	-19.0
	1978-81	2.3	145	- 3.3	12.4
	1984-86	4.1	- 56	2.3	- 24.0
	1989-90[2]	1.4	2	- 0.0	- 14.0
France	1972-74	1.5	146	- 2.2	-4.4
	1978-81	2.8	108	- 3.0	20.8
	1984-86	4.3	- 57	2.5	- 20.0
	1989-90[2]	1.4	2	- 0.0	- 14.5
Italy	1972-74	1.5	214	- 3.2	11.5
	1978-81	3.4	111	- 3.8	34.0
	1984-86	5.5	- 64	3.5	-15.2
	1989-90[2]	1.4	0	0.0	- 12.7

[1] Calculated on the basis of equation (v) and GDP of the initial year.

[2] Estimated on the assumption that the recorded rise in US$ oil import prices of 26.8% corresponds to a rise in the deflator for net energy imports (in US$) of 20%.

Sources: OECD / IEA: Energy Balances for OECD countries and OECD Trade Series C.

Table 6

Developments in exposure to energy price shocks
(in percentage points)

Countries	1972-80			1980-89		
	Real	Nominal	Total	Real	Nominal	Total
United States	0.0	2.5	2.5	- 0.8	- 1.2	- 2.0
Japan	- 0.3	5.0	4.7	- 1.5	- 3.6	- 5.1
Germany	- 0.1	3.4	3.3	- 1.1	- 1.8	- 2.9
France	- 0.1	3.3	3.2	- 1.7	- 1.6	- 3.3
Italy	- 0.3	3.9	3.6	- 0.9	- 2.8	- 3.7

Note: Exposure is defined as $\frac{E_m \cdot P_E}{GDP_V \cdot P_{GDP}}$ and measured as net energy imports in current prices relative to GDP in current prices. The real effect is measured as the change in the ratio of net energy imports (volumes) to real GDP (E_m/GDP_V) times exposure in the initial year. The nominal effect is the residual change in exposure and is dominated by the change in energy prices relative to the GDP deflator (P_E/P_{GDP}).

Source: See Table 5.

(i) Energy-producing sectors

Strictly speaking, equation (v) strictly only holds for a country which has no domestic production of energy, whereas most countries partly satisfy their energy needs through domestic sources.[9] Consequently, a rise in world oil prices will be accompanied by distributional effects as domestic producers of energy gain at the expense of the non-energy-producing sectors. However, assuming that such effects can be ignored, equation (v) still holds if only γ is measured by the share of net energy imports in GDP and not as the share of total energy use. With this modification, Table 5 presents the direct real output effects of the two oil shocks, the "reverse" shock in 1985-86 and some preliminary estimates for 1990. Three features are worth underlining in this respect (see also Hutchison (1991)):

- even though the 1978-81 oil price rise was much smaller than the 1973-74 shock, the real output effects were in all countries much larger and entirely because the share of net imports had increased;
- the real output shocks associated with the second oil shock were more equally distributed than those following the first shock. This may in part be due to a more uniform rise in oil import prices, as long-term contracts were far less common than in the early 1970s. In addition fewer countries were able to offset part of the oil price rise through appreciating exchange rates;[10]
- in no country was the real output effect following the 1990 price rise higher than 0.5% of GDP, and in the three EC countries exchange rate appreciations combined with domestic inflation kept the relative energy price virtually constant. In the United States and Japan the relatively

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[9] For the OECD area as a whole, energy consumption is about three times net imports and for the five net importing Group of Seven countries the ratio of overall consumption to net imports ranges from 6.1 for the United States to 1.1 for Japan, with Germany (1.7), France (1.3) and Italy (1.2) occupying intermediate positions (1980 figures).

[10] As can be seen from the last column of Table 5, part of the first oil shock effect in Germany was compensated by a 20% strengthening of the Deutsche Mark against the US dollar. The relative price changes are calculated for total energy imports (not only oil) and also reflect important differences in the composition of imports, with the price changes for the United States being particularly large due to a high share of oil (see section (ii) below) in total energy imports.

small price rise also limited the real output loss, but even more important was the low import share, especially as compared with 1978-81.

Against this background, Table 6 attempts to disaggregate changes in the net import share over the last two decades into nominal and real changes. Corresponding to the sluggish adjustment to the first oil shock the real changes - measured as changes in import volumes relative to GDP in constant prices - during the 1970s were small. By contrast, during the 1980s most countries managed to reduce their real import dependence by 1 percentage point or more, partly through energy conservation and partly through a greater reliance on domestic sources. Yet in most cases lower import prices accounted for more than half of the decline in exposure, implicitly suggesting that the low import ratios recorded in 1989 may be difficult to sustain.

(ii) Import prices and final user prices

The introduction of domestic sources of energy does not change the potential price response given in equation (iv) if domestic energy producers adjust their prices in step with import prices. However, this last assumption rarely holds. Firstly, a large part of the energy consumption satisfied by domestic production is met by non-oil sources of energy and the prices of these products (natural gas, coal, atomic power, etc.) tend to follow oil prices with a lag and, depending on the elasticity of substitution, may not change to the same extent. Secondly, the ratio of changes in final energy prices to changes in import prices of energy is reduced by profit margins and indirect taxes, which are usually not raised in step with import prices. The ratios also tend to vary across sectors, being somewhat higher for industrial users (where taxes are lower and/or can be deducted) than for the household sector.

These variations in the price response are illustrated in Table 7, which shows the development in import and final energy prices following the two oil shocks and the reverse shock of 1984-86. Despite the preliminary nature of the calculations some features are worth noting:

- although the world market price of oil is virtually the same for all importing countries, changes in the average import price of energy vary considerably depending on the composition of energy imports, the proportion of energy supplies on long-term contracts and movements of exchange rates. The differences were particularly large for the first oil shock, whereas

Table 7

Energy price changes by stages of production

cumulative percentage change, selected periods

Countries	Production stage	1972-74			1978-81			1984-86			Memo: Weight of energy in CPI, 1980, %
		%	e_1	e_2	%	e_1	e_2	%	e_1	e_2	
United States	Import prices	426.3	-	-	228.5	-	-	- 50.3	-	-	
	Wholesale prices	75.6	0.18	0.28	115.3	0.50	0.18	- 26.4	0.52	0.35	
	Retail prices	39.6	0.09	0.32	86.0	0.38	0.28	- 12.5	0.25	0.10	7
Japan	Import prices	266.2	-	-	152.3	-	-	- 56.5	-	-	
	Wholesale prices	120.5*	0.45	0.18	110.8	0.73	0.22	- 21.5	0.38	0.54	
	Retail prices	42.8*	0.16	0.80	50.2	0.33	- 0.22	- 12.0*	0.21	0.36	6
Germany	Import prices	233.8	-	-	177.7	-	-	- 53.6	-	-	
	Wholesale prices	28.9*	0.12	0.23	34.0	0.19	0.64	- 9.5	0.18	0.89	
	Retail prices	35.8	0.15	0.14	55.4	0.31	0.13	- 19.7*	0.37	0.19	7
France	Import prices	198.9	-	-	183.7	-	-	- 51.8	-	-	
	Wholesale prices	50.5	0.25	0.59	78.9	0.43	0.33	- 9.3	0.18	0.54	
	Retail prices	43.3	0.22	0.48	74.0	0.40	0.26	- 5.5	0.11	0.39	9
Italy	Import prices	326.1	-	-	245.7	-	-	- 57.6	-	-	
	Wholesale prices	117.7*	0.36	0.31	117.1	0.48	0.10	- 22.8	0.40	0.48	
	Retail prices	51.7*	0.16	0.65	126.5	0.51	0.16	1.5	n.d.	0.45	3
United Kingdom	Import prices	282.0	-	-	142.7	-	-	- 42.5	-	-	
	Wholesale prices	68.6*	0.24	0.86	74.4	0.52	- 0.52	- 7.2	0.17	0.32	
	Retail prices	69.4*	0.25	0.51	66.9	0.47	0.19	5.7	n.d.	0.07	6
Canada	Import prices	309.5	-	-	170.2	-	-	- 32.2	-	-	
	Wholesale prices	56.0	0.18	0.52	100.7	0.59	0.25	- 15.6	0.48	0.42	
	Retail prices	25.5	0.08	0.66	80.8*	0.47	0.18	- 2.0	0.06	0.61	5

Note: e_1 is defined as the ratio between changes in wholesale and retail energy prices respectively and changes in import prices of energy; e_2 is defined as $(dp - dp_{-i})/(dp_E - dp_{-i})$ with dp_E = % change in energy prices, dp = % change in wholesale or retail prices and i denotes lags (2 years for 1972-74 and 1984-86 and 3 years for the period 1978-81). A '*' indicates that the change in wholesale or retail energy prices was lagged one year relative to the change in import prices.

Sources: IEA Annual Oil Market Report and national data.

during 1984-86 most importing countries experienced price falls of around 50%;

- generally, the ratio of changes in wholesale energy prices with respect to import prices (the column headed e_1) is higher than that of retail energy prices, reflecting in particular the higher tax share for households' consumption of energy. In most countries the ratios increased between the first and the second oil shock (especially at the retail stage), while they fell during 1984-86, as few countries reduced energy taxes in step with the price fall, but probably also reflecting some increase in profit margins;

- the column headed e_2 was included as a crude measure of the contribution of energy price shocks to changes in the rates of wholesale and retail price inflation and shows widely different figures between periods as well as across countries.[11] Overall, however, the results suggest that the two oil shocks occurred in conditions of a generally worsening price performance, which was reinforced, but not induced, by the rise in energy prices. This is clearly evident for the first oil shock, when several countries recorded e_2 coefficients of .5 or more, whereas after the second shock most coefficients were below .2. Japan is of special interest in this respect as it recorded the highest inflationary response to the first oil shock, whereas during 1978-81 the inflation performance had been brought under control to such an extent that not even the rise in energy prices could break the decelerating trend of price inflation. In Italy, too, the adjustment improved remarkably, whereas Germany saw a

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[11] The calculations (see the note to Table 7) are based on equation (iv):

$$dp_Q = (1-\gamma)dp_Y + \gamma dp_E$$

with P_Q denoting wholesale or retail prices, P_Y non-energy costs, P_E wholesale or retail energy prices, d the first difference operator and small letters variables measured in logs. Taking only one-year lags and subtracting $dp_{Q,-1}$ on both sides, the equation may be rewritten as:

$$dp_Q - dp_{Q,-1} = a(1-\gamma)(dp_Y - dp_{Q,-1}) + \gamma\ (dp_E - dp_{Q,-1})$$

If non-energy costs had continued to increase in line with the past general inflation rate, the equation reduces to:

$$(dp_Q - dp_{Q,-1})/(dp_E - dp_{Q,-1}) = \gamma$$

where the left-hand side corresponds to e_2. Hence for $dp_Y = dp_{Q,-1}$, e_2 corresponds to the weight of energy in the general price index (see memo item in Table 7), whereas for $dp_Y > dp_{Q,-1}$ the e_2 coefficients exceed γ. On the other hand, if (see Japan for the period 1978-81) $dp_Y < dp_{Q,-1}$ and $-(1-\gamma)(dp_Y - dp_{Q,-1}) > \gamma(dp_E - dp_{Q-1})$, e_2 will be negative.

worsening at the wholesale level which may reflect the depreciation of the Deutsche Mark during the early 1980s.

(iii) Gross output, value added and real income

Gross output as defined in equations (ii) and (v) is not a concept covered in national accounts statistics, and another problem in evaluating the output effects of changes in relative energy prices is that so far possible changes in value added (Y) have been ignored. The first problem is mainly statistical and will be dealt with below, whereas the second one raises analytical issues, which may be illustrated by returning to equation (iii)'.[12] Previously (iii)' was interpreted as a demand equation for energy, taking value added and the relative energy price as predetermined variables. Alternatively, it can be seen as determining the optimal ratio of E/Y as a function of relative prices, but with the levels of the two variables left undetermined. Finding the levels of E and Y requires an additional assumption regarding the regime prevailing at the time of the price change:

- one possibility is that markets are perfectly competitive, in which case firms face a given output price and use each input factor until its marginal productivity equal its real price. This was the assumption made earlier in deriving the energy demand function, and when applied to value added it implies that Y remains constant following a rise in the price of energy if P_Y/P_Q also remains constant.[13] In other words, and using the numerical example considered earlier, if P_Q rises by 2½% in response to a rise in P_E of 25%, Y would remain unchanged if P_Y also increased by 2½%.[14] By contrast, if P_Y does not change at all, value added would increase

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[12] Statistical problems are also involved since real GDP is not an unbiased measure of real value added; see Bruno and Sachs op. cit. Especially in conditions of large relative price changes and infrequent adjustments of the base year the measurement errors become substantial.

[13] One property of the simple Cobb-Douglas model is that the marginal productivities of capital and labour in terms of value added are insensitive to changes in the prices of intermediate factors such as energy. As will be further discussed in Section C below, the assumptions required to satisfy this property are very restrictive.

[14] When allowing for the rise in P_Y the increase in P_E/P_Y is reduced to 22% and the gross output effect to 2¼%.

despite the fall in gross output, whereas when labour and owners of capital "overreact" and P_Y increases by more than P_Q, value added would fall relative to gross output;

- alternatively, firms may be selling their products in non-competitive markets and have some power to set their own prices. In this case, firms are constrained by the demand side of the economy and the levels of Y and E will mainly depend on developments in real disposable income and wealth and on policy reactions to the rise in energy prices.[15]

A priori, it is not possible to say which regime prevails and the results of empirical studies have also been rather mixed. Consequently, for the following it has been assumed that some firms are subject to a price constraint while others face a demand constraint. In such a "mixed" regime, real value added will usually change in response to higher energy prices but may, on certain assumptions (P_Y increasing at the same rate as P_Q and policy measures compensating private agents for losses in real income and wealth), remain constant.

Although these assumptions are unlikely to be met in practice, the case of constant Y may be taken to illustrate a possible solution to the first problem mentioned above. For this purpose we introduce yet another income concept (real income) defined as:

$$\text{(vi)} \qquad YR = (P_Q Q - P_E E)/P_Q = Q - (P_E/P_Q)\ E = (1 - \gamma)\ Q$$

YR may be interpreted as the income available for consumption and investment after paying for energy imports, and, since the elasticity of YR with respect to the real energy price equals that of Q, YR will also fall by some 2½% when P_E increases by 25% and the energy share is 10%. Consequently, even in conditions where real value added is unchanged, the real income available for the remuneration of capital and labour will decline. Or, to put it differently, one direct and immediate consequence of a rise in the real energy price is that it creates a "wedge" between real value added and real disposable income. Table 8 attempts to illustrate this by comparing real GDP with real income defined as nominal GDP deflated by

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[15] For further discussion of these issues see Hutchison (1991).

Table 8

Developments in real output and income per person employed

percentage changes, annual rates, selected years

Countries	Output / income	1965-72	1972-74	1978-81	1984-86
United States	Real GDP	1.1	- 0.8	- 0.1	1.1
	Real income	1.2	- 1.9	- 0.7	1.5
	Real product wage	1.6	- 0.1	- 0.0	1.5
	Real consumption wage	1.7	- 1.3	- 1.2	1.9
Japan	Real GDP	7.1	2.1	3.0	2.8
	Real income	7.4	0.5	1.7	5.0
	Real product wage	6.8	5.3	2.6	1.7
	Real consumption wage	7.1	3.8	1.0	3.8
Germany	Real GDP	3.6	2.8	1.3	1.3
	Real income	4.1	1.5	0.2	3.0
	Real product wage	3.9	4.3	1.2	0.5
	Real consumption wage	4.4	3.0	0.0	2.7
France	Real GDP	3.9	3.0	2.1	2.1
	Real income	4.2	1.1	1.1	4.1
	Real product wage	3.6	4.2	2.8	0.0
	Real consumption wage	3.9	2.3	1.8	2.0
United Kingdom	Real GDP	2.9	1.5	0.8	2.4
	Real income	3.3	- 2.7	1.9	3.5
	Real product wage	3.0	4.5	1.2	2.9
	Real consumption wage	3.3	0.7	2.4	4.0
Italy	Real GDP	5.5	0.1*	2.9	2.1
	Real income	6.0	- 1.8*	1.7	4.8
	Real product wage	5.6	1.7*	2.6	1.2
	Real consumption wage	6.1	0.0*	1.4	2.9
Canada	Real GDP	2.2	1.4	- 0.3	1.1
	Real income	2.4	1.0	0.4	1.3
	Real product wage	2.7	- 0.0	- 0.7	1.5
	Real consumption wage	2.9	- 0.4	- 0.1	1.7

* 1973-75

Source: OECD National Accounts.

the deflator for GDP plus imports.[16] Although this is only a crude measure of energy price effects, the first two lines for each country reveal a wedge opening up during 1972-74 and again in 1978-81. In the United States, for instance, where real GDP and real income had increased at approximately the same rates during 1965-72, the two oil shocks reduced real income by a cumulative 1½-2¼% relative to GDP and in Japan the wedge widened from 3¼% in 1972-74 to 4% in 1978-81. Germany also experienced a rise in the wedge between the first and the second oil shock, whereas in Italy and France, which had been particularly hard hit by the first shock, the wedge narrowed by about half. Canada and the United Kingdom are special cases as they either were or became net exporters of energy during the 1970s and thus experienced a net gain in 1978-81. The "reverse oil shock" is also evident in these crude measures, especially in Japan, France and Italy, which saw growth of real income outpacing that of GDP by more than 4%.[17]

(iv) Real wages, productivity and labour market developments

When a rise in real energy prices reduces the real income available to capital and labour, a key condition for a smooth adjustment is that labour and firms reduce their income claims in line with the fall in real income. By contrast, if wage earners claim[18] compensation for the rise in gross output prices, real wage costs (measured in terms of the value

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[16] This deflator was calculated as GDP plus imports in current prices divided by GDP plus imports in constant prices and corresponds to equation (iv) except that total imports replaces energy use:

$$P_Q = (1 - \lambda)\ P_Y + \lambda P_M$$

with P_M the import deflator and λ the share of imports in gross output.

[17] Although the United Kingdom and Canada were net exporters of energy in 1984-86, the table indicates a positive wedge for both countries. This underlines the crudeness of the measure, as real income will increase faster than real GDP whenever import prices rise less fast than the GDP deflator. During 1984-86 the United Kingdom and Canada experienced falls in relative import prices of 8¾ and 1¾% respectively.

[18] A rise in profit claims would have similar effects, but profits were squeezed after both oil shocks and most analysts have focused on wage behaviour.

added or GDP deflator) will increase relative to labour productivity and make production unprofitable for some firms.[19]

Turning to lines 3 and 4 for each country in Table 8, such a wedge became evident following the first oil shock.[20] In Japan, for instance, the real consumption wage outpaced the growth of real income by a cumulative 6.5 percentage points, causing a similar rise in real wage costs relative to labour productivity, and the United Kingdom and France experienced discrepancies of 6 and 4 percentage points respectively. Even in the United States, which apart from Canada was the only country to record a fall in the real consumption wage, real product wages rose relative to labour productivity.

Factor prices adjusted much more smoothly to the second oil shock, especially in Japan, where the real product wage fell markedly relative to productivity. In Italy and Germany, too, the real product wage rose less fast than labour productivity and in all other countries the divergence between real wage and productivity growth was much smaller than during the first oil shock.[21]

These developments can also be interpreted in terms of the aggregate supply curve, as a rise in real wages relative to productivity will increase firms' marginal costs and cause an adverse shift of the supply curve and thus reinforce the inflationary pressures generated by changes in energy prices. At the same time, the rise in real product wages reduces firms' demand for labour and leads to higher unemployment. Indeed,

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[19] If prior to the oil shocks all firms were producing below capacity because of insufficient demand, a rise in real product wages relative to labour productivity would not leave any direct output effect. As mentioned above, some firms were probably subject to a price constraint prior to the two oil shocks and thus affected by real wage behaviour.

[20] Real product wages have been measured as compensation per employee deflated by the GDP deflator and real consumption wages as compensation per employee deflated by the the combined GDP and import deflator.

[21] Oddly enough, Canada is the only country to register real product wage increases below productivity growth during both oil shocks. Apart from Canada's status as a net exporter of energy, this may reflect the incomes policies in force during the 1970s, which are likely to have affected wages much more than prices.

following the seminal work by Malinvaud (1977), a number of empirical studies have ascribed much - if not all - of the post-1973 rise in unemployment to the rise in real product wages. The more moderate wage behaviour following the second oil shock was accompanied by lower rates of inflation; nonetheless, in most countries, and especially in Europe, unemployment rose more steeply than after the first shock and it is only in recent years that unemployment rates have started to decline. Consequently, while real wage behaviour constitutes an important element of the supply-side transmission mechanism, it is clearly not the only one. Unfortunately, at this stage there is no general consensus regarding the principal causes of the persistently high unemployment rates in Europe.[22]

C. Further modifications and their implications for energy demand

The simple Cobb-Douglas function used throughout the previous section provides a useful framework for analysing the short-run price and output effects and for underlining the importance of a smooth adjustment of real wages to energy price shocks. However, since the Cobb-Douglas model rests on simplifying assumptions which can be questioned on empirical grounds, it is less useful for analysing long-run developments, including the levels and rates of growth of potential output and labour productivity, and the demand for energy. In particular, the assumption that value added is separable from energy is doubtful, implying that capital/labour ratios will be affected by energy price shocks. Moreover, the size and composition of the capital stock and its adjustment to changes in relative factor

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[22] It would go well beyond the scope of this paper to provide even a superficial review of the vast literature dealing with this subject, but among the factors mentioned as principal causes of high unemployment have been low aggregate demand growth (Bean et al. (1986)), nominal wage rigidities associated with institutional factors (Fischer (1977) and Taylor (1979)), real wage rigidities due to trade union activities (McDonald and Solow (1980)), efficiency wages (Katz (1986) and Solow (1979), unemployment compensation (Coe (1990)) and capital shortages (Malinvaud (1982)). Others have emphasised a distinction between insiders and outsiders (Lindbeck and Snower (1988)) or between short and long-term unemployed (Bean and Gavosto (1988)) in explaining why real wages do not clear labour markets and some recent studies have drawn attention to the existence of hysteresis (Cross (1988)). Readers interested in more thorough reviews of this literature are referred to Andersen (1989) and, in particular, to Blanchard (1987).

prices and aggregate demand are of crucial importance to the demand for energy and to the speed with which energy use can be adjusted in response to changing energy prices.

(a) Alternative production functions, employment and investment[23]

(i) Separability and factor substitution. One of the simplifying assumptions underlying equation (ii) on page 8 above is that energy and value added are weakly separable, which only holds when the substitution elasticities between labour and energy and between capital and energy are equal.[24] There is, however, some evidence that, while labour and energy are substitutes, capital and energy are complements according to some researchers, substitutes according to others, or complements in the short run but substitutes in the longer run according to yet a third group. Whatever the precise relation, there is little doubt that labour and energy are closer substitutes than capital and energy, implying that a rise in relative energy prices tends to lower the optimal capital/labour ratio.

Since the Cobb-Douglas function assumes unitary substitution elasticities for all factors, this finding calls for a respecification of the aggregate production function. There are several alternatives available, but one that is favoured by many analysts is based on a two-stage decision process where, in a first stage, firms determine their optimal capital stock on the basis of expected demand and factor prices. At a second and later stage firms then choose the amounts of labour and energy needed as well as the operating rate of the capital stock given the then existing prospects for demand and factor prices. Technically, these assumptions may be presented as a two-level constant elasticity of substitution (CES) production function which combines capital and energy in an "inner function" and the capital-energy bundle with labour in an "outer function".

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[23] The following is a non-technical discussion of the various modifications and their implications for the specification of factor demand equations. A more technical explanation is provided in Annex II.

[24] The condition can also be stated by the requirement that a rise in relative energy prices and a fall in the use of energy leaves the optimal capital/labour ratio unchanged.

(ii) Size and composition of the capital stock. A second assumption underlying equation (ii) is that the capital stock is homogeneous and that energy/capital and labour/capital ratios can be adjusted smoothly and continuously in response to shifts in relative factor prices. Alternatively, it might be argued that once the capital stock is installed substitution possibilities are rather limited so that factor ratios can only be changed in step with technical progress or through renewal of and additions to the capital stock.[25] This alternative view is of crucial importance to the speed with which energy consumption responds to a rise in relative energy prices and it is supported by empirical estimates relating to individual firms.[26] However, when analysing larger sectors or a whole economy, experience has shown that the assumption of fixed factor ratios is too restrictive, as factor demand is not determined by technical factors alone but also influenced by changes in the composition of final demand.[27] Consequently, models have been developed which, by including a "retrofitting" parameter, allow for some short-term flexibility of factor ratios with respect to relative factor prices.

The factor demand equations derived from a production function which incorporates both of the modifications discussed above are presented in Annex II and as regards the demand for labour there are two major changes compared with the analysis based on the simple Cobb-Douglas function. Firstly, relaxation of the separability assumption means that a rise in energy prices increases the demand for labour relative to capital so that, initially, the need for real wage restraint is somewhat smaller

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[25] According to this alternative view, the capital stock is not homogeneous but composed of different "vintages", with each vintage characterised by specific labour/capital and energy/capital ratios. Other analysts have interpreted a relative price shock as a once-for-all decline of the capital stock due to the scrapping of old and less efficient vintages (see Artus (1984)) and Baily (1981)). However, estimates of excess scrapping are very uncertain as few data are available.

[26] In one case (the Netherlands, see Annex II) a production function excluding short-run changes in factor proportions has also been used in modelling the aggregate economy.

[27] For instance, much of the fall in overall energy demand can be ascribed to changes in private and public consumption towards less energy intensive products.

Table 9

Fixed investment, real interest rates and capital stock growth

Countries	1973-75		1978-80		Capital stock[3]		
	I[1]	i[2]	I[1]	i[2]	1965-72	1972-80	1980-87
United States	- 16.2	- 2.2	- 4.6	0.6	4.6	3.9	2.1
Japan	- 10.6	- 4.1	5.3	4.8	13.8	6.0	6.2
Germany	- 14.3	2.7	10.2	3.4	5.7	2.2	1.2
France	- 5.3	- 1.4	5.8	1.4	n.a.	3.6	1.6
United Kingdom	- 5.4	- 4.8	14.9	- 4.5	3.7	2.2	0.5
Italy	- 4.3	- 7.1	- 2.8	- 3.0	n.a.	n.a.	n.a.
Canada	12.7	- 2.7	19.0	0.9	5.3	3.9	3.0

[1] Real gross fixed investment, cumulative percentage changes.

[2] Long-term bond rate less current change of GDP deflator, averages 1974-75 and 1978-80 respectively.

[3] Percentage changes (annual averages) of gross capital stock in manufacturing.

Source: OECD National Accounts and Historical Statistics.

than that predicted by the simple Cobb-Douglas model. Secondly, labour productivity tends to fall as the desired capital/labour ratio is reduced (or grows at a slower rate than in the past), implying that in the longer run the need for real wage restraint gradually increases. As discussed in Section B, the increase in relative labour demand induced by the first oil shock did not result in higher employment because real wages "overreacted" to the energy price shock, thus reducing rather than supporting labour demand. The more moderate real wage behaviour following the second oil shock helped to stabilise employment, but by then labour productivity had started to be affected by the lower level of investment and the slower growth of the capital/labour ratio. Consequently, the rate of unemployment increased further.[28] As can be seen from Table 9, there has been a marked fall in the rate of growth of the capital stock, as the first oil shock was accompanied by a steep decline in fixed investment (except in Canada) even though relative labour costs increased and real interest rates were negative in most countries. Fixed investment generally recovered after the second shock, but not sufficiently to restore earlier investment/GDP ratios and, except in Japan, the growth of the capital stock fell further.[29]

(b) Specification of the energy demand equation. Regarding energy demand and the previous demand function given in equation (iii)', the move to a two-level putty-clay CES function with retrofitting has several implications, which are also relevant to the empirical results to be discussed below. Both real value added and relative energy prices retain their roles as determinants of energy demand, but the income elasticity is no longer constrained to equal unity and can be higher or lower depending on technical factors. Moreover, the size of the expected coefficient with respect to relative energy prices is subject to several modifications. Firstly, reflecting the combination of input factors in the CES function, energy prices relative to the prices of labour and capital respectively

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[28] The slowdown in labour productivity growth, which can be seen in Table 8 and is even more evident over longer periods, gives some support to the view that the high unemployment rates of the 1980s are mainly due to capital shortages (see also note 22).

[29] The data for capital stock growth given in Table 9 only include manufacturing, but the declining trends are likely to have contributed to the fall in potential output and labour productivity growth of the aggregate economies.

enter the equations with separate coefficients. Secondly, using a capital stock composed of different vintages not only generates very long lags and a marked difference between short and long-run price elasticities but also introduces gross investment as an element influencing the relative price elasticity. Thirdly, the possibility of retrofitting creates a factor of uncertainty with respect to the exact size of the short-run price elasticity while at the same time opening up large differences between countries depending on the availability of retrofitting techniques.

D. Energy demand elasticities in the Group of Seven countries

This section attempts to estimate the energy demand equations for the G-7 countries using statistical series supplied by the International Energy Agency and distinguishing between energy demand in three sectors: industry, commerce and households and transportation. In the early 1980s Mittelstaedt (1983) found that the long-term price elasticity of industrial demand for energy was -0.40 in the major seven countries and -0.62 in seven smaller OECD countries, with an adjustment lag which could be as long as seven years. In the IEA World Energy Outlook (October, 1982) a long-term price elasticity of -0.65 was used. However, these estimates were based on observations confined to the period 1960-78, and since the last oil shock energy prices have fallen (even more so in relative terms) which might provide new evidence on these relationships. In fact, the estimates reported below tend to indicate that energy needs might be less price-sensitive than was estimated in the early 1980s but that adjustment lags might be shorter.

The econometric method applied in this section draws on the theory of co-integration, which, under certain conditions, allows a distinction between long-run relations and short-term adjustment. The basic idea behind co-integration is to search for a linear combination of individually non-stationary time series (selected on the basis of economic theory) that is itself stationary.[30] In testing for co-integration we shall

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[30] Time series which are stationary only after differencing may have linear combinations which are stationary without differencing, i.e. they have similar long-term trends which offset each other in the

(Footnote Continued)

rely on three tests: The Durbin-Watson (DW) statistic, which gives a first but not very robust indication; the Dickey-Fuller test (DF or ADF); and the sign and significance of the coefficient of the error-correction term in the adjustment equation.[31]

(a) Energy demand by industry

(i) Long-run equations

As can be seen from Annex II, the energy demand equation resulting from the theoretical discussion is non-linear and can only be estimated using a grid-search procedure. Data availability constitutes a further problem, and for the estimates to be discussed below a simpler specification was chosen. Thus, real value added was entered with a freely estimated coefficient and the energy price was only deflated by the GDP deflator. Moreover, gross fixed investment (measured as a percentage of GDP) was introduced as a separate variable and not linked to the relative energy price as a strict putty-clay model would require. Finally, to capture retrofitting as well as energy saving measures, which are difficult to quantify, all equations for industrial energy demand were estimated including a simple time trend with an expected negative coefficient.[32]

With these simplifications the long-run energy demand equation estimated for industry can be written as:

(Footnote Continued)
combination. In such a case, those variables are said to be co-integrated. A co-integrated system can be represented in an error-correction structure which incorporates both changes and levels of variables such that all the elements are stationary. The error-correction structure captures short-term movements of the variables and also provides a framework for forecasting and for testing the co-integration conditions (Engle and Yoo (1987)).

[31] Engle and Granger (1987) presented a theorem showing that co-integrated series can be represented by an error-correction formulation.

[32] As will be seen below, the coefficient was in fact significantly negative for six countries, probably as the combined result of specific energy-conserving measures and shifts in the composition of demand and industrial output towards less energy-intensive goods and sectors. However, an alternative and perhaps equally plausible interpretation of the negative time trends is also possible and will be discussed below.

(vii) $$E = a + bY + cP_e + dI + et$$

where
E = energy consumed by industry, measured in millions of tons of oil equivalent;
Y = total value added in constant prices (GDP);[33]
P_e = wholesale price of energy relative to the GDP deflator;
I = real non-residential fixed investment relative to GDP;
t = time trend

and all variables are expressed in log levels, so that the coefficients represent elasticities.

Table 10 summarises the main results, which in all countries show that the long-term demand for energy in the industrial sector is dominated by **output**.[34] However, there are wide differences in the estimated elasticities, reflecting variations in the share of industry in total output (see note 32) and in the cyclical variability of industrial output relative to aggregate GDP as well as in the energy dependence of industry across the seven countries. In the United States and Germany a 1% growth in GDP generates a rise in energy consumption of about 1 3/4%, while the output elasticity is 2-2½ in Japan and France and is close to or above 3 in the United Kingdom and Italy. Only Canada shows an output elasticity of unity.

A negative **time trend** has been identified in all countries except Canada and might reflect energy-saving measures (which are not directly included in the specification) combined with shifts in the composition of output and demand towards less energy-intensive sectors and products.

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[33] In theory, manufacturing or industrial production should be used as the explanatory variable, but in practice the results were (except for the absolute size of the coefficients) very similar and total GDP was preferred in order to obtain comparable and more comprehensive coefficients. In the late 1980s the share of manufacturing production in total GDP ranged from 19% in the United States to 31% in Germany.

[34] The results also give some support to the estimation procedure chosen. The Durbin-Watson statistics clearly reject the null hypothesis of no co-integration, whereas in some cases the Dickey-Fuller tests only reject the null hypothesis at a low level of significance. However, the error-correction equations reported in Table 11 tend to show that in most cases the null hypothesis of no co-integration can be rejected.

Table 10

Demand for energy by industry
(in log levels, annual data, 1960-88)

Country	Constant	Real GDP	Prices	Non-residential investment	Time trend	R^2 DW	DF ADF
United States	- 2.54 (- 1.8)	1.73 (4.0)	- 0.18 $(3.3)^{-3}$	0.26 (1.1)	- 0.04 (- 3.6)	0.75 0.91	- 2.50 -
Japan	- 0.34 (- 0.5)	2.48 (22.4)	- 0.21 $(-5.8)^{-1}$	- 0.64 (- 3.8)	- 0.10 (-17.2)	0.99 2.00	- 4.91 -
Germany	- 1.76 (- 2.1)	1.79 (11.6)	- 0.18 $(-2.4)^{-2}$		- 0.04 (- 8.7)	0.91 1.27	- 3.38 - 5.26
France	- 1.86 (- 2.3)	2.02 (14.7)	- 0.32 $(-4.0)^{-1}$		- 0.05 (-11.5)	0.91 1.09	- 2.96 - 3.40
Italy	- 6.61 (- 7.2)	3.25 (14.8)	- 0.31 (- 4.5)		- 0.09 (-10.8)	0.96 0.85	- 2.69 - 3.85
United Kingdom	- 4.60 (- 2.3)	2.94 (7.3)	- 0.54 $(-3.5)^{-3}$		- 0.07 (- 8.1)	0.88 0.86	- 2.69 -
Canada	0.51 (3.9)	0.99 (22.7)	- 0.10 (- 2.3)			0.97 0.72	- 2.02 -

Note: The critical values for the co-integration test (DF/ADF) as reported by Engle and Yoo for three variables at the 5% and 10% significance levels for a sample size of fifty are 4.11 and 3.73 respectively.

t-statistics are given in brackets with lags indicated as superscripts.

For Canada, adding a time trend (coefficient: -0.04, t-statistic: -7.2) changes the price coefficient to 0.05 (t-statistic: 1.5).

However, an alternative interpretation is also possible and mitigates some problems concerning the size of the estimated output elasticities. Recalling the nature of the estimated relation, the output elasticities mean that, in the long run, a 1% rise in GDP is accompanied by a 2-3% rise in energy consumption, which is difficult to reconcile with the negative trends of energy requirements per unit of output seen in Table 1a of Section A. However, because GDP and the trend are highly correlated, the negative trend coefficients are likely to reflect the net effect of energy-saving measures and trend changes in output. In such a case, with the GDP trend being largely captured by the time trend, the output elasticities should be seen in relation to variations in de-trended output and as being closer to the short-term than to the long-term adjustment coefficient of energy demand.

The problem may be solved by introducing and estimating an equation for trend GDP (Y*):

(viii) $$Y^* = f + gt$$

and substituting (viii) into (vii):

(ix) $$E = (a + bf) + (bg + e)\ t + b\hat{Y} + cP_e + dI$$

with $\hat{Y}$ representing the deviation of actual from trend GDP.

Equation (ix) is no more than a linear transformation of (vii) and when the coefficient to t was calculated using estimated figures for trend GDP growth (g), values much closer to 1 than those presented in Table 10 were found for five of the countries.[35] Hence, when GDP is moving along

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[35] The actual coefficients were: United States: 0.54, Japan: 1.18, Germany: 0.78, France: 1.12, Italy: 2.77. For Japan, we used the 1963-83 GDP trend of 4.4% (rather than the 1968-88 trend of 5.5%) which is closer to the long-term trend currently observed. For Canada this transformation was not made, while for the United Kingdom the transformed trend coefficient was negative. This odd result derives from the very large negative trend observed in Table 10 combined with a relatively low trend growth of GDP (around 2%), and might be explained by the very sharp reduction in the share of industry in total GDP over the estimation period (some 13 percentage points for both manufacturing and industry (current prices) compared with 7-8 points for other Group of Seven countries on average).

its long-run growth path, there is almost a 1:1 relationship between industrial energy use and output. By contrast, for deviations from the long-run growth path, the much higher coefficients presented in Table 10 apply. Thus an increase in production to above the long-run trend can be extremely expensive in terms of energy needs as factories or production facilities made obsolete by earlier changes in energy prices are put into operation. By the same token, and obviously important in periods of rising energy prices, short-run reductions in output can very quickly and effectively reduce energy demand.

The response of energy demand to changes in the **wholesale price** of energy is of the correct sign in all countries, but again of differing magnitudes. In the United Kingdom a 1% increase in energy prices is met by a decline of one-half of one per cent in energy consumption, whereas in the United States, Japan, Germany, France and Italy, the response amounts to about one-fifth of one per cent and in Canada to only one-tenth.[36] Despite the long-run nature of the equations, lags were necessary in some cases as substitution is extremely slow and is realised only as new equipment is put into place. In addition, in several countries administered energy prices have prevented the full and/or immediate adjustment of domestic oil prices to international levels, which may have reduced firms' incentive to cut energy demand.

Adding the ratio of private or total **non-residential fixed investment** to GDP[37] to the equations does not provide much extra explanatory power. As noted, the process whereby energy use is replaced by other factors frequently requires changes in the capital stock, so that if total investment is dominated by energy-saving investment the coefficient could be expected to be negative. In Japan, which imports almost all of its energy requirements, the equation shows a strong negative influence of non-residential investment, underlining major efforts undertaken by Japanese enterprises towards reducing energy dependence through

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[36] With Canada being a major oil producer there is a risk that the long-run price elasticity reflects both demand and supply responses. A regression of industrial energy consumption on total domestic energy production yields an R^2 of about 0.75.

[37] For Japan, France and Italy total non-residential investment; for other countries private non-residential fixed investment.

capital/energy substitution and a shift towards lighter and less energy-intensive industries. In other countries, however, the coefficient was either positive or insignificant, probably reflecting the ad hoc nature of the specification as well as the fact that in many countries the gradual rise in the capital intensity of overall output has been accompanied by higher and not lower demand for energy.[38]

(ii) Short-run adjustments

The equations reported in Table 10 only attempt to identify long-run relationships and do not allow for cyclical fluctuations around the long-term trend. Moreover, as a further step in identifying stable relations, an error-correction equation is required to determine whether deviations from the long-term trend are being corrected, and (when convergence is found) at what speed.

Consequently, as a second step, the following equations were estimated:

$$dE = a' + b'dY + c'dP_e + d'dI + e\ ECM_{-1} \qquad \text{(x)}$$

where d denotes the first difference operator and ECM_{-1} is the lagged residual of the equations estimated in levels. Table 11 summarises the results of the short-term equations and shows in all cases a significant **error-correction** coefficient of the correct sign (negative), with a large proportion (between 30% and 90%) of the error that appeared in the long-term equation being corrected within two years and in some cases within one year.

Wholesale price changes influence the short-term demand for energy with a one-year lag in Japan, France and Italy, whereas the coefficients are not meaningful for the other four countries. Moreover, in both Japan and Italy the short-run elasticities are well below the long-run coefficients, so that in all cases the scope for short-run substitution of energy appears very limited. The dominating short-run influence is **output**

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[38] One reason for the failure to identify any effects of the investment variable might be that because of the ratio form I is not an I(1) variable. However, except for the United States, the DF/ADF tests fail to reject the hypothesis of an I(1) process. On the other hand, using lagged prices in a long-term equation could in part be capturing the effects of capital stock changes.

Table 11

Short-term equations of energy demand by industry

(variables expressed as changes in log levels)

Country	Constant	Real GDP	NRFI	Prices	Error-correction term*	R^2 DW
United States	- 0.05	1.99			- 0.45	0.72
	(- 4.7)	(7.0)			(- 2.6)	2.12
Japan	- 0.08	2.14	- 0.40	- 0.20	- 0.94	0.87
	(- 5.3)	(7.9)	(- 1.7)	$(-4.8)^{-1}$	(- 4.3)	1.83
Germany	- 0.06	2.41	- 0.28		- 0.63	0.82
	(- 6.8)	(9.5)	(- 2.4)		$(-3.5)^{-1}$	2.62
France	- 0.06	2.19		- 0.30	- 0.55	0.68
	(- 3.5)	(4.5)		$(-2.9)^{-1}$	(- 2.8)	1.69
Italy	- 0.08	2.85		- 0.09	- 0.48	0.76
	(- 5.9)	(9.2)		(- 1.8)	$(-3.9)^{-1}$	1.88
United Kingdom	- 0.06	2.19			- 0.33	0.53
	(- 4.4)	(5.4)			(- 1.9)	2.14
Canada	- 0.02	1.45			- 0.40	0.55
	(- 1.4)	(4.0)			(- 2.5)	2.02

Lags are reported as superscripts to t-statistics.

* Lagged residual from main equation reported in Table 10.

and the coefficients are for most countries close to those found in the long-term equations, thus giving some support to the alternative interpretation discussed above. **Non-residential investment** has only a limited influence, with only Germany and Japan producing significant coefficients of the expected sign.

(b) Demand for energy in the commercial and residential sectors

(i) Long-run equations

In deriving the demand equation for energy use in the commercial and residential sectors we have made the assumption that consumers attempt to maximise utility subject to overall income and wealth constraints. For a broad set of utility functions, this assumption generates an equation whereby aggregate consumption is a function of real disposable income and real wealth, whereas the demand for a particular commodity i depends on aggregate consumption and the price of i relative to the aggregate consumption deflator. When applying this model to the demand for energy some additional modifications were made, partly for theoretical reasons and partly reflecting the data available:

- since the series on households' use of energy are rather short, it was necessary to combine them with energy demand in the commercial sector. As a result (but also in the interests of obtaining elasticities comparable with those derived for the industrial sector), real GDP rather than real consumption was used as the activity variable, while the price of energy (retail prices) was deflated by the GDP rather than the consumption deflator;
- since energy is normally used as an input to goods more directly serving consumer needs (heating installations, electrical equipment, etc.), the stocks of durable goods and single and multi-family houses may be more relevant than aggregate wealth. However, both variables are subject to the problem that while a rise in stocks of a given quality can be expected to boost energy demand, energy-conserving measures incorporated in either additions to the stock or in replacements will have a negative effect, thus leaving the net effect undetermined. Moreover, data series on the stock of durable goods are for some countries either short or non-existent and probably capture quality improvements to a much smaller extent than those on residential construction. As a compromise, we have adopted the same

procedure as for the industrial sector and included residential investment relative to GDP as a separate variable;

- a number of other variables which might capture specific features of energy demand (such as the rate of unemployment and changes in the overall output share of the services and commercial sectors) were also tested, but in most cases did not yield any significant results.

Given the compromises dictated by the aggregate nature of the data used and the relatively "stable" development of energy demand in the residential and commercial sectors, identification of relevant parameters is likely to be more difficult than for the industrial sector. Generally, however, because substitution possibilities are less readily available and the cyclical sensitivity is much lower than in industry,[39] both price and income elasticities may be expected to be smaller than those reported in Tables 10 and 11.

As shown in Table 12, real GDP is also the major determinant of energy demand in the residential and commercial sectors, though again with very substantial differences across countries: the coefficients range from 0.2 in the United Kingdom to 1.6 in Italy, with an average elasticity of 0.9, or less than half of that shown for industry (2.0). There appears to be an inverse relationship between the size of the intercept terms and the estimated income elasticities, possibly suggesting that the former reflect basic or incompressible levels of demand.

The table also reveals a rather weak price response of energy demand. The price[40] elasticity is one-half in Canada and Italy but falls to one-third to one-quarter in Japan and France. In the United States and Germany the price coefficients are even lower and are meaningful only for the period following the second oil shock, and for the United Kingdom the estimated coefficient has a rather low t-value. In general, the price elasticities in the commercial and residential sectors are lower than those

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[39] An additional reason for expecting a lower income elasticity might be that in industry energy is used as an intermediate input in generating total output, whereas in the commercial and residential sectors it is demanded as a final or semi-final consumption good.

[40] The energy component of the consumer price index was used in calculating relative energy prices.

Table 12

Demand for energy in commercial and residential sectors
(expressed in log levels, annual data, 1960-88)

Country	Constant	Real GDP	Prices	Residential fixed investment	R^2 DW	DF ADF
United States	1.75	0.78	- 0.04*	- 0.11	0.91	- 2.21
	(4.5)	(15.3)	(- 6.4)	(- 1.6)	0.68	- 2.22
Japan	1.19**	1.10	- 0.33		0.99	- 3.10
	(1.8)	(19.9)	(- 3.1)$^{-1}$		1.14	- 2.48
Germany	- 0.13	1.06	- 0.04*		0.94	- 3.87
	(- 0.5)	(18.8)	(- 6.6)		1.55	- 3.57
France	- 0.72	1.07	- 0.25	0.33	0.96	- 2.71
	(- 0.8)	(25.7)	(- 2.0)	(3.3)	0.95	- 3.39
Italy	- 2.08	1.55	- 0.52	0.41	0.98	- 2.38
	(- 1.5)	(13.4)	(- 5.3)	(3.1)	0.67	- 2.26
United Kingdom	5.70	0.19	- 0.11	- 0.32	0.85	- 3.45
	(8.2)	(4.8)	(- 1.3)	(- 4.9)	1.33	- 3.66
Canada	4.70	0.80	- 0.50	- 0.32	0.95	- 2.66
	(6.4)	(21.1)	(- 7.4)	(- 2.3)	0.96	- 3.16

* The coefficients apply only to prices after 1979.

** A dummy variable with 0 up to 1979 and 1 thereafter was entered with a coefficient of -0.10 (t-statistic: -2.1).

Note: The Dickey-Fuller tests reject the null hypothesis of no co-integration only at a low level of significance (see Table 10 for an indication of critical values), while the Durbin-Watson statistics combined with the existence of statistically significant error-correction terms reported in Table 13 reject this null hypothesis with more certainty.

found in industry, except in France, where they are of the same magnitude, and in Italy and Canada, where the coefficients are actually much higher than the corresponding elasticities for industry.[41] These differences in the behaviour of energy demand between the industrial and the commercial and residential sectors in the face of changing energy prices generally reflect different substitution possibilities. In some cases they might also be due to specific energy pricing policies which might have delayed or prevented the full adjustment of domestic energy prices to international levels.

Residential fixed investment has a negative influence on energy needs in the United States, Canada and the United Kingdom, suggesting that the stock of housing has gradually become more energy-efficient. On the other hand, residential investment seems to have exerted a strongly positive influence on energy demand in France and Italy, whereas for the remaining two countries no significant coefficients were found.

(ii) Short-run adjustments

The equations reported in Table 13 explain 50% or more of the short-term movements in energy consumption, except in Canada, for which the fit is very poor. The **error-correction** terms are meaningful and indicate that in the case of Germany, the United Kingdom and Japan, more than two-thirds of the error is corrected within one year.

The short-term **price elasticities** are generally higher than those reported in Table 12 and the short-term adjustment to price changes takes place without delay. Thus in all countries there appears to be some scope for short-run reduction of energy demand in response to higher energy prices.[42] However, given the nature of the adjustments captured by the equations shown in Table 13, these results do not change the earlier conclusion concerning the much reduced ability of these sectors (compared with industry) to conserve energy through substitution.

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[41] In the case of Canada this again suggests that the price elasticity for industrial energy demand is biased towards zero because of energy supply.

[42] For instance, by reducing room temperature, turning off lights (Footnote Continued)

Table 13

Short-term demand for energy in commercial and residential sectors
(expressed in changes in log levels, annual data, 1960-88)

Country	Constant	Real GDP	Energy prices	Lagged dependent variable	Error-correction term	Residential fixed investment	R^2 DW(h)
United States		0.35 (2.7)	- 0.13 (- 2.1)	0.32 (2.0)	- 0.18 (- 1.8)		0.56 0.24
Japan	- 0.02* (- 2.0)	1.15 (11.7)	- 0.58 (- 4.8)		- 0.72 (- 4.4)	- 0.31 (- 2.5)	0.91 1.69
Germany	- 0.02 (- 1.1)	1.16 (2.7)		0.23 (2.1)	- 0.94 (- 4.0)		0.52 0.14
France		1.01 (4.2)	- 0.42 (- 2.7)		- 0.46 (- 2.5)	0.39 (1.6)	0.56 1.45
Italy		1.23 (6.6)	- 0.32 (- 3.1)		- 0.31 (- 2.2)$^{-1}$		0.67 1.78
United Kingdom		0.17 (1.1)	- 0.37 (- 2.9)		- 0.79 (- 4.1)	- 0.27 (- 4.0)	0.53 1.99
Canada	0.03 (4.0)		- 0.26 (- 1.8)		- 0.38 (- 2.4)		0.20 1.89

* Applies only after 1979.

Note: Lags are reported as superscripts to t-statistics.

(c) Energy demand in transportation

(i) Long-run equations

Energy use in transportation is made up of individual and commercial use and one element common to both components is the almost complete lack of substitution possibilities.[43] In such circumstances, the price elasticity of the demand for energy can be expected to be small and substantially below the levels of the sectors discussed above. On the other hand, GDP should remain a major determinant of energy demand as commercial transport is closely and positively correlated with trade and output and personal transport depends on personal income. In some instances investment may play a role but, like investment in industry and in the personal and commercial sectors, the net effect is ambiguous: net additions to the fleet of trucks and automobiles may lead to increased energy consumption whereas replacements of existing equipment could be accompanied by improved energy efficiency.[44] Table 14 reports the main findings using the same specification as for the commercial and residential sectors, except that both wholesale and retail prices were tested (given the composite nature of the data) and investment was measured as purchases of machinery and equipment as a ratio to GDP.

As expected, the price elasticities in the transportation field are low (except for Canada and Italy), and in some cases also have a low statistical significance. In the United States and France prices appear to have had no effect in the period preceding the second oil shock and no significant effects were found in the case of Germany and the United Kingdom. On the other hand, the activity/income effects, measured by real GDP, are well-determined and generally point to a 1 - 1 1/3% increase in energy consumption for each 1% increase in output. Moreover, the

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(Footnote Continued)
earlier and, in the slightly longer run, putting in double glazing.

[43] Another common element is the lack of inter-fuel substitution possibilities. For instance, in 1988, for all seven countries taken together, petroleum products accounted for 99.3% of energy used by transportation (98.3% for the group excluding the United States), the rest being electricity, itself partly generated by oil.

[44] It should be borne in mind that in more recent years environmental policies may have reduced the energy efficiency of investment.

Table 14

Demand for energy in transportation

(expressed in log levels, annual data, 1960-88)

Country	Constant	Real GDP	Energy prices[1]	Investment in machinery and equipment	R^2 DW	DF ADF
United States	- 0.37 (- 1.6)	1.12 (20.0)	- 0.03[2] (- 5.3)		0.95 0.46	- 1.4 - 1.5
Japan	0.87 (1.5)	1.33 (14.8)	- 0.13 (- 2.2)	- 0.29 (- 5.2)	0.99 1.26	- 3.4 - 3.8
Germany	- 0.73 (- 3.8)	1.23 (71.3)		0.13 (2.1)	0.99 2.14	- 5.0 - 4.5
France	- 1.29 (-10.5)	1.29 (44.1)	- 0.01[2] (- 1.7)		0.99 0.77	- 2.5
Italy	- 1.83 (- 3.6)	1.42 (14.2)	- 0.31 (- 2.1)		0.91 1.91	- 4.9 - 4.7
United Kingdom	- 1.32 (- 2.0)	1.09 (16.9)	- 0.02 (- 0.2)		0.91 2.36	- 6.1 - 6.0
Canada	0.90 (1.5)	0.98 (17.1)	- 0.46 $(-7.9)^{-1}$	- 0.12 $(-1.5)^{-1}$	0.97 0.31	- 1.2 - 1.4

Lags are reported as superscripts to t-statistics. A time trend with a coefficient of -0.017 (t-statistic: -3.6) has been added in the case of Japan.

[1] Wholesale prices for France, Italy and the United Kingdom and retail prices for the United States, Japan and Canada.

[2] The coefficients apply only to energy prices after 1979.

Note: For Germany, Italy and the United Kingdom both the DW statistics and the Dickey-Fuller tests reject the null hypothesis of no co-integration whereas for the other four countries the Dickey-Fuller tests give very poor results. However, in all cases, the short-term equations reported in Table 15 include an error-correction term with a statistically significant coefficient of the correct sign.

coefficients are fairly homogeneous across countries, ranging from 1 for Canada to 1.4 for Italy. In Japan there is strong evidence that the capital stock has become more energy-efficient - thus supporting the results observed for industry - whereas in Germany a rise in the investment/GDP ratio appears to have increased energy demand.

(iii) Short-run adjustments

Similar to the results found for the commercial and residential sectors, the short-term equations reported in Table 15 confirm that there is some scope for short-run reductions in energy demand in response to higher prices. Except for Japan, for which no statistically significant short-term coefficient could be identified, all price coefficients are higher than in the long-run equations. On the other hand, the output elasticities are generally lower in the short run than in the long run. This was also found for the residential and commercial sectors, and probably reflects that increased energy demand partly depends on the possession of certain durable goods and pieces of equipment, the acquisition of which is subject to some lag and thus imparts a relatively low short-run income elasticity to energy demand.

The speed with which deviations from the long-run trend are being corrected shows some variation from country to country. In France, Japan, Germany and Italy between one-third and 85% of the error is corrected within one year while the adjustment process is slow in North America, with three years required to correct one-quarter of the error in the United States.[45] In the United Kingdom the adjustment process is one of damped oscillations.

(d) Energy demand in periods of rising and falling prices

The elasticities reported so far have been estimated on the assumption that energy demand responds symmetrically to rising and falling prices.[46] As can be seen from Graph 2, relative energy prices have been

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[45] The low coefficient should be seen against the poor results for the level equation.

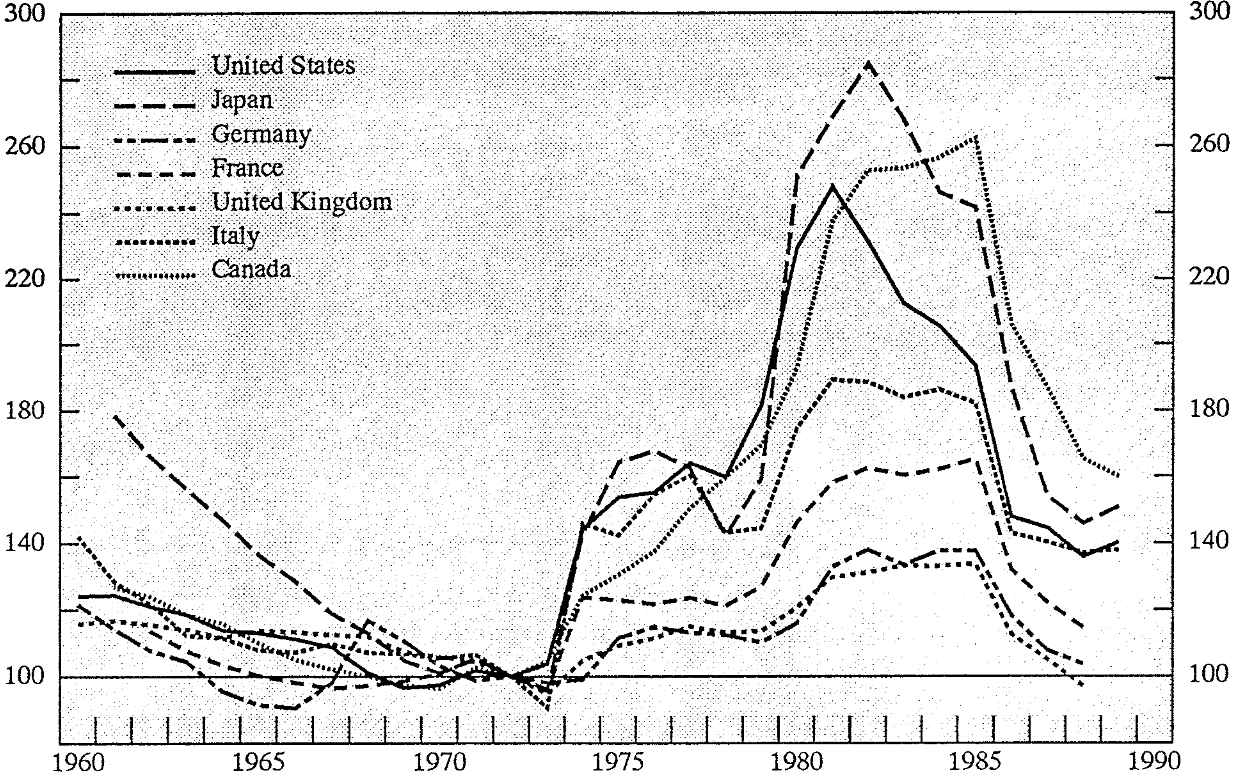
[46] It may be recalled that the equations were estimated as log-level equations, so that the coefficients equal elasticities and are (Footnote Continued)

Graph 2

Relative energy prices

In relation to the GDP deflator (1972 = 100)

Wholesale prices



Retail prices

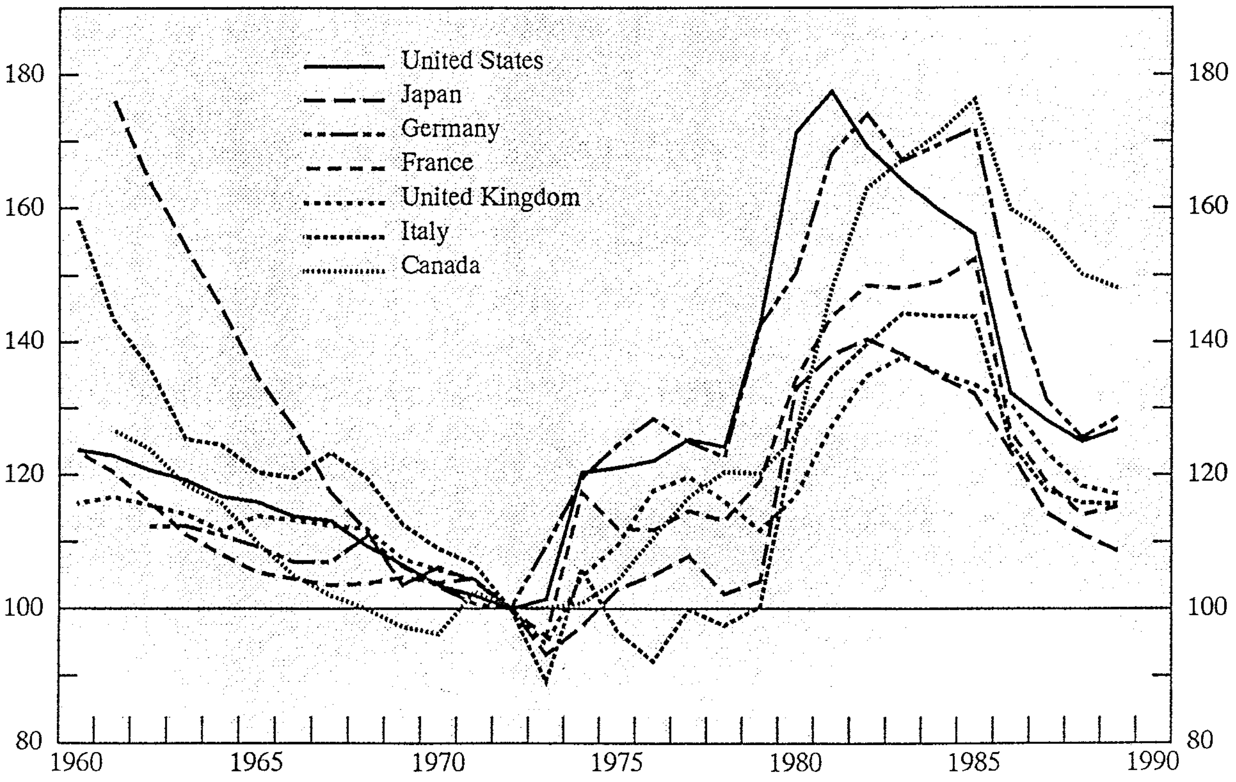


Table 15

Short-term equations of energy demand in transportation

(variables expressed as changes in log levels)

Country	Constant	Real GDP	Machinery and equipment	Prices	Error-correction term	R^2 DW
United States	0.02* (3.1)	0.55 (4.0)		- 0.16 (- 3.3)	- 0.24 (- 3.3)$^{-2}$	0.77 1.78
Japan		0.95 (17.3)		- 0.11 (- 2.2)$^{-2}$	- 0.58 (- 4.0)	0.94 1.76
Germany	0.82 (1.0)	0.93 (3.9)	0.17 (2.1)	- 0.11 (- 2.1)$^{-1}$	- 0.84 (- 3.6)	0.59 2.07
France		1.18 (11.5)		- 0.09 (- 1.7)	- 0.34 (- 2.3)	0.85 1.74
Italy		1.07 (2.4)$^{-1}$		- 1.10 (- 6.4)	- 0.80 (- 5.3)	0.72 1.49
United Kingdom		1.01 (2.2)		- 0.18 (- 0.6)	- 1.18 (- 6.0)	0.58 2.09
Canada	- 0.02 (- 1.5)	1.12 (5.4)	- 0.26 (- 2.9)$^{-1}$		- 0.27 (- 2.1)	0.81 1.57

Lags are reported as superscripts to t-statistics.

* In addition, a dummy variable with 0 up to 1979 and 1 thereafter has been entered with a coefficient of -0.02 (t-statistic: -3.2).

quite volatile over the period of estimation, with the volatility observed for individual countries depending on the share of imported energy in overall energy consumption, movements of exchange rates and the extent of administered pricing. However, in all seven countries there have been distinct phases of rising and falling prices, thus making it possible to test whether the assumption of a symmetric response is valid. A priori it may be argued that while in periods of rising prices firms and households have a strong incentive to reduce costs by installing more energy efficient capital equipment, few agents are probably prepared to scrap such equipment and replace it by less energy-efficient machinery in periods of falling prices. Thus the price elasticity is likely to be numerically lower during periods when prices are falling, and this is confirmed by Hunter and Rosenbaum (1991) in a study of US households' demand for oil.[47] At the same time, the finding of a numerically lower price elasticity in periods of falling prices does not necessarily imply that agents respond asymmetrically. In the first place, non-price conservation measures, which have mainly been introduced in periods of rising prices and are difficult to quantify in empirical estimates, may overstate the estimated response to a rise in energy prices. Secondly, to the extent that the lag structure with respect to the influence of prices on consumption is not sufficiently long, the empirical estimates will again give a false impression of asymmetry. For instance, in a study of US oil demand Brown and Phillips (1989a) allow for a total lag of about ten years and find no asymmetries when the lag structure is determined optimally,[48] whereas other studies using predetermined lags have found some evidence of asymmetric behaviour.

(Footnote Continued)
independent of the levels of energy demand, income and prices. Alternatively, the demand functions could have been estimated as linear equations:

$$E = a + b\,Y + c\,P_e + d\ldots$$

for which the partial price elasticity would be $c\,P_e/E$ and thus numerically rising (falling) in periods of rising (falling) prices and falling (rising) quantities demanded. Similarly, the partial income elasticity, measured as $b\,Y/E$), would be rising in periods when income is rising and E is falling because of rising prices.

[47] Hunter and Rosenbaum rely on equations where the dependent variable is measured as household expenditure on energy and they estimate separate equations for periods of rising and falling prices respectively.

[48] I.e. maximising the R^2.

Table 16

Demand for energy in industry in periods of rising energy prices

(expressed in log levels)

Countries	Constant	Real GDP	Prices, whole period	Prices* rising	Non-resid. fixed investment	Time trend	R^2 DW	DF ADF	Periods of rising prices
United States	- 3.92 (- 3.3)	2.30 (8.1)	- 0.11 (- 2.5)$^{-3}$	0.01 (3.4)		- 0.06 (- 6.9)	0.83 1.34	- 3.48 - 2.36	1970-81
Japan	- 0.32 (- 0.5)	2.48 (15.8)	- 0.21 (- 5.5)$^{-1}$	- 0.00 (- 0.2)	- 0.66 (- 3.2)	- 0.10 (-12.6)	0.99 2.00	- 5.00 - 3.54	1973-82
Germany	- 1.81 (- 2.0)	1.81 (10.4)	- 0.18 (- 2.5)$^{-2}$	- 0.00 (- 0.2)		- 0.04 (- 8.2)	0.91 1.29	- 3.47 - 5.58	1971-82
France	- 2.96 (- 2.2)	2.20 (9.1)	- 0.22 (- 1.7)	- 0.01 (- 1.0)		- 0.06 (- 6.9)	0.91 1.24	- 3.26 - 3.89	1973-85
Italy	- 5.23 (- 3.4)	3.02 (9.3)	- 0.41 (- 3.7)	0.01 (1.2)		- 0.09 (- 6.9)	0.96 1.06	- 3.11 - 3.54	1973-85
United Kingdom	- 3.09 (- 1.5)	2.64 (6.2)	- 0.61 (- 4.0)$^{-3}$	- 0.02 (- 1.8)		- 0.06 (- 5.6)	0.89 0.88	- 2.75 - 2.40	1973-85
Canada	0.73 (6.4)	0.94 (26.0)	- 0.12 (- 3.3)	0.02 (4.1)		-	0.98 1.13	- 3.21 - 3.33	1970-85

* Prices as defined in the previous column times a dummy with 1 in periods of rising energy prices as defined in the last column and 0 otherwise.

Table 17

Short-term adjustment equations for demand for energy in industry in periods of rising energy prices

(expressed as changes in log levels.)

Countries	Constant	Real GDP	Prices, whole period	Prices rising	Error-correction term	Non-resid. fixed investment	R2 DW
United States	- 0.06*	1.92	- 0.13	-	- 0.59	-	0.76
	(- 4.7)	(6.7)	(- 1.7)$^{-1}$		(- 3.2)		1.67
Japan	- 0.08	2.13	- 0.20	-	- 0.94	- 0.39	0.87
	(- 5.2)	(7.9)	(- 4.8)$^{-1}$		(- 4.3)	(- 1.6)	1.82
Germany	- 0.05	2.26		- 0.25	- 0.68	- 0.22	0.80
	(- 5.2)	(8.3)		(- 1.8)$^{-1}$	(- 3.2)	(- 1.7)	1.59
France	- 0.06	2.14	- 0.27	-	- 0.54		0.67
	(- 3.3)	(4.5)	(- 2.7)$^{-1}$		(- 6.5)		1.67
Italy	- 0.08	3.00	- 0.09	-	- 0.52		0.76
	(- 5.9)	(8.9)	(- 1.8)		(3.8)$^{-1}$		1.95
United Kingdom	- 0.05	2.06	-	- 0.22	- 0.40		0.54
	(- 3.7)	(5.1)		(- 0.8)	(- 2.2)		2.16
Canada	- 0.02	1.40	-	-	- 0.52		0.56
	(- 1.3)	(3.9)			(- 2.6)		2.13

* Also includes a dummy variable with 1 in periods of rising prices and a coefficient of 0.02 (1.8).

In order to preserve degrees of freedom we did not attempt to estimate energy demand functions separately for periods of rising and falling prices. Instead, we introduced a dummy variable (DUM) with a value of 1 for years of rising prices and 0 otherwise. By adding the term $e.DUM.P_e$ to the original equation (vii) the nature and strength of possible asymmetries can then be evaluated on the basis of the sign and statistical significance of the parameter e. The asymmetry hypothesis was only tested for the industrial sector and the results for the level and corresponding error-correction equations are given in Tables 16 and 17. Comparing these with the earlier Tables 10 and 11 the following main features may be observed:

- in virtually all countries the DF/ADF tests yield much more satisfactory results when the new term is added and in the two cases (United States and Canada) where the improvement is most pronounced the coefficient of the error-correction terms in Table 17 also increases significantly;
- in three of the countries (United States, Germany and France) the inclusion of the additional price term raises the income elasticity as well as the numerical value of the trend term. In the remaining countries the income elasticity falls slightly or remains unchanged;
- in the United States, Italy and Canada there is some evidence that the price elasticity is numerically lower in periods of rising prices, though for Italy the statistical significance of the additional price term is rather low. In the other four countries, the response to price changes appears to be higher in periods of rising prices, but only the equation for the United Kingdom yields a statistically significant coefficient for the additional price term;
- the error-correction equations for France, Italy and Canada remain largely unchanged except for the larger error-correction coefficient for Canada. For the United States there is a clear improvement of the statistical properties and for the United Kingdom and Germany there is some - albeit weak - evidence of price change effects in periods of rising prices.

Overall, the results reported in Tables 16 and 17 are rather mixed. On the one hand, the inclusion of the additional price term improves the statistical properties of the estimated equations. On the other hand, the asymmetry effects are small and/or statistically insignificant, suggesting that the additional price term may not be capturing an asymmetric response of energy demand but rather phenomena which appear to have played a role in years of rising prices. However, the source of these influences has not been identified and would require further analysis of the timing of policy measures and of factors particular to the industrial sectors in each of the seven countries.

E. Summary and conclusions

The main analytical and empirical findings of this paper may be summarised in five points.

1. Because of a fall in the share of net energy imports in GDP the industrial countries are now less exposed to energy price shocks than in 1973-74 and 1978-80. As a consequence, the risk to real output and inflation of such shocks has been significantly reduced. A further positive element in this respect is the very moderate real wage behaviour following the second oil shock and the continuation of modest real wage increases in the 1980s.

2. However, the decline in imports has mainly resulted from the reduction in relative energy prices since 1985, whereas energy conservation and the development of indigenous sources of energy have been far less important. Moreover, in the absence of clear signs of fundamental changes in real wage behaviour a smooth adjustment of wages and other factor prices to externally induced real income shocks cannot be taken for granted. Hence, despite the decline in exposure policy makers need to remain alert to external disturbances.

3. The empirical results presented in Section D point to total output as the key determinant of energy demand, whereas relative energy prices have only a small influence. This is especially the case in transportation and in the residential and commercial sectors, where substitution possibilities are less readily available than in industry. More specifically, for the Group of Seven countries on average a 1% fall in real output growth generates a fall in energy demand of somewhat more than 1% within the same year and of almost 1.5% in countries outside North America. For most countries long-run price elasticities are only around 0.2 for industrial energy demand and even lower for energy used for transportation and in the commercial and residential sectors. Moreover, a response of even this moderate size is only achieved in the course of several years and

requires the installation of new and more energy-efficient capital equipment.

4. Despite the lower exposure, energy price shocks - and external price shocks in general - pose several problems and there are no easy "trade-offs" for policy-makers. Firstly, the real income loss due to weaker terms of trade reduces aggregate demand and output in energy importing countries, while the rise in import prices increases inflationary pressures. Secondly, the most effective way of reducing energy demand and the dependence on oil is to lower output growth, but this is also the most costly solution in terms of foregone output and higher unemployment. Reducing energy dependence by encouraging substitution constitutes a more efficient solution but is bound to be a slow process given the low price elasticities and the crucial role of investment. Thirdly, while a quick reduction of energy demand and an effective containment of the inflationary risk call for restrictive monetary and fiscal policies, the accompanying rise in interest rates could reduce investment and thus postpone a more efficient long-run solution. Finally, measures to protect the environment often reduce the efficiency of energy use (especially in the transportation sector), thereby frustrating efforts to promote energy conservation.

5. Taking the experience gained from the first and second oil shocks as a guide,[49] the containment of the inflationary risk should be assigned the highest priority in the very short run, with the degree of policy tightening depending on the response of domestic factor prices. The behaviour of nominal and real wages plays a crucial role in this respect, but the likely response of wages to possible future changes in energy prices is not easy to evaluate. On the one hand, the real wage adjustment to the second oil shock was remarkable and gives cause for optimism. Moreover, a number of countries introduced various labour market reforms in the course of the 1980s with a view to improving flexibility, possibly suggesting that real wage moderation may be even more pronounced than after the second oil shock. On the other hand, the lack of consensus regarding the rise of unemployment in the 1980s is disturbing and leaves some important aspects of real wage behaviour unresolved. Moreover, empirical studies which attempt to identify fundamental changes in real wage

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[49] For further discussion see Hutchison, op. cit.

behaviour have so far failed to provide any firm evidence, except possibly for the United States. On balance, it thus appears that, based on the experience of the second oil shock and assuming a non-accommodating policy stance, the acceleration of wage and price inflation seen in the early 1970s is unlikely to be repeated in the future, especially if the rise in oil prices is only temporary or is expected to be only temporary. On the other hand, to count on a more favourable response than after the second shock would seem too optimistic and difficult to justify on the basis of the empirical evidence.

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Annex I

The following Tables 1-5 present time series for those Group of Seven countries which are net importers of energy and Tables 6-8 complement these series by providing comparative figures for the Group of Ten countries regarding energy consumption per unit of output, per capita energy consumption and the share of oil in total energy consumption. An important difference between the energy consumption/GDP figures presented in Tables 1-5 and Table 6 respectively is that in the former case IEA data based on GDP figures at 1985 exchange rates have been used, while in Table 6 GDP is calculated at 1987-89 prices and exchange rates.

Annex Table 1

Background table on energy: **UNITED STATES**

Period	Output[1]	Consumption[2]	Net imports[1]	Implicit import price[4]	Relative import price[5]	Exposure[6]
	Relative to real GNP/GDP[3]					
1972	52.2	59.4	7.7	1.48	3.51	0.3
1973	49.5	58.7	9.8	2.21	4.91	0.5
1974	49.0	58.0	9.5	7.79	15.86	1.5
1975	48.7	57.2	10.0	7.43	13.78	1.4
1976	47.0	58.3	11.7	8.27	14.44	1.7
1977	45.2	57.1	13.9	9.05	14.79	2.1
1978	44.0	56.2	12.5	9.02	13.74	1.7
1979	44.9	55.0	11.9	13.31	18.62	2.2
1980	45.6	53.0	8.8	24.81	31.81	2.8
1981	44.4	50.3	6.8	29.63	34.69	2.4
1982	45.2	49.7	5.5	27.84	30.63	1.7
1983	41.9	48.0	5.7	23.65	35.15	1.4
1984	42.0	46.6	5.8	23.34	24.00	1.4
1985	39.8	45.2	4.9	22.28	22.28	1.1
1986	38.5	44.0	6.2	11.60	11.32	0.7
1987	37.7	44.0	6.8	12.77	12.10	0.8
1988	36.5	43.6	7.1	10.46	9.61	0.7
1989	35.5	43.5	7.9	11.96	10.53	0.8
1990[7]	36.0	43.3	7.3	14.91	12.61	0.9

[1] In MTOE.
[2] Primary energy requirement in MTOE.
[3] 1985 prices in US dollars.
[4] Net energy imports in US dollars divided by net imports in MTOE.
[5] Implicit import price in local currency relative to GDP deflator.
[6] Net energy imports relative to GNP/GDP in current prices.
[7] Partly estimated.

Sources: OECD, IEA Energy Balances of OECD Countries and OECD Trade Series C.

Annex Table 2

Background table on energy: **JAPAN**

Period	Output[1]	Consumption[2]	Net imports[1]	Implicit import price[4]	Relative import price[5]	Exposure[6]
	Relative to real GNP/GDP[3]					
1972	5.67	38.0	34.5	2.1	12.9	1.9
1973	4.62	39.1	37.2	2.6	12.7	2.0
1974	4.97	40.0	38.0	7.7	33.5	5.4
1975	4.76	37.1	34.6	8.6	35.2	5.1
1976	4.91	37.5	34.5	9.1	34.8	5.0
1977	4.36	36.0	32.7	9.7	31.7	4.5
1978	4.44	34.8	31.3	10.0	24.4	3.2
1979	4.60	34.6	31.7	13.5	33.4	4.4
1980	4.81	32.4	29.0	21.9	54.6	6.6
1981	4.71	30.3	26.3	24.0	55.8	6.2
1982	4.71	28.8	34.5	22.7	58.5	6.0
1983	4.82	28.3	23.7	20.4	49.7	5.0
1984	4.72	28.7	34.7	19.1	46.0	4.8
1985	5.12	27.5	23.1	18.0	42.9	4.2
1986	5.09	27.1	22.8	11.7	19.4	1.9
1987	4.97	26.2	21.9	12.3	17.5	1.6
1988	4.72	26.6	22.2	11.4	14.3	1.3
1989	4.70	26.4	22.6	11.8	15.8	1.5
1990[7]	4.45	26.0	22.2	15.0	19.5	1.8

[1] In MTOE.
[2] Primary energy requirement in MTOE.
[3] 1985 prices in US dollars.
[4] Net energy imports in US dollars divided by net imports in MTOE.
[5] Implicit import price in local currency relative to GDP deflator.
[6] Net energy imports relative to GNP/GDP in current prices.
[7] Partly estimated.

Sources: See Table 1.

Annex Table 3

Background table on energy: **GERMANY**

Period	Output[1]	Consumption[2]	Net imports[1]	Implicit import price[4]	Relative import price[5]	Exposure[6]
	Relative to real GNP/GDP[3]					
1972	25.0	51.6	28.3	1.85	10.2	1.0
1973	23.9	52.7	29.6	3.04	13.1	1.3
1974	24.0	51.0	26.7	7.66	30.0	2.7
1975	24.0	48.3	27.0	7.74	27.2	2.5
1976	22.9	50.1	29.1	8.64	30.0	3.0
1977	21.8	48.4	28.3	9.36	28.8	2.8
1978	21.4	48.9	27.5	9.82	25.1	2.3
1979	21.4	49.4	28.6	15.20	34.0	3.3
1980	21.2	46.7	26.9	21.92	46.6	4.3
1981	21.8	44.4	23.0	24.20	61.5	4.8
1982	21.9	43.1	22.4	22.83	59.7	4.5
1983	20.8	42.5	21.8	20.68	55.0	4.1
1984	20.9	43.0	21.2	19.69	57.4	4.1
1985	21.6	43.1	21.8	19.30	56.7	4.2
1986	20.2	42.4	23.5	12.02	25.3	2.0
1987	19.9	41.8	22.7	12.24	20.9	1.6
1988	19.4	40.8	21.7	10.41	17.2	1.3
1989	18.5	38.5	19.9	11.67	20.0	1.4
1990[7]	17.4	37.8	20.3	15.27	21.8	1.5

[1] In MTOE.
[2] Primary energy requirement in MTOE.
[3] 1985 prices in US dollars.
[4] Net energy imports in US dollars divided by net imports in MTOE.
[5] Implicit import price in local currency relative to GDP deflator.
[6] Net energy imports relative to GNP/GDP in current prices.
[7] Partly estimated.

Sources: See Table 1.

Annex Table 4

Background table on energy: **FRANCE**

Period	Output[1]	Consumption[2]	Net imports[1]	Implicit import price[4]	Relative import price[5]	Exposure[6]
	Relative to real GNP/GDP[3]					
1972	11.86	44.4	34.0	2.26	39.8	1.5
1973	10.48	45.2	36.7	2.56	36.7	1.5
1974	10.27	43.0	35.9	7.09	98.0	3.9
1975	10.64	40.9	30.5	8.52	92.9	3.2
1976	8.95	41.1	33.9	7.95	87.0	3.3
1977	10.73	40.4	31.7	9.29	95.6	3.4
1978	10.30	41.3	31.1	9.55	82.6	2.8
1979	10.30	41.5	32.9	12.31	90.6	3.3
1980	11.24	40.9	31.3	20.41	133.9	4.7
1981	13.27	39.2	26.8	22.66	171.7	5.1
1982	12.79	37.2	24.0	22.39	183.5	4.9
1983	14.14	37.6	22.6	19.24	166.6	4.2
1984	15.86	38.1	22.7	18.34	169.5	4.3
1985	16.54	38.5	21.8	17.48	157.1	3.8
1986	17.33	38.1	21.3	11.12	73.3	1.7
1987	17.73	38.4	21.2	11.85	65.8	1.6
1988	16.72	36.0	20.2	9.94	53.1	1.2
1989	16.13	35.8	19.8	11.14	61.7	1.4
1990[7]	15.98	35.2	20.2	13.84	63.9	1.5

[1] In MTOE.
[2] Primary energy requirement in MTOE.
[3] 1985 prices in US dollars.
[4] Net energy imports in US dollars divided by net imports in MTOE.
[5] Implicit import price in local currency relative to GDP deflator.
[6] Net energy imports relative to GNP/GDP in current prices.
[7] Partly estimated.

Sources: See Table 1.

Annex Table 5

Background table on energy: **ITALY**

Period	Output[1]	Consumption[2]	Net imports[1]	Implicit import price[4]	Relative import price[5]	Exposure[6]
	Relative to real GNP/GDP[3]					
1972	9.02	44.6	38.5	1.90	7.51	1.5
1973	8.43	44.3	38.5	2.28	7.96	1.6
1974	7.85	42.2	36.5	7.26	23.60	4.5
1975	8.11	41.3	34.5	7.61	21.32	3.9
1976	7.66	40.4	34.2	7.60	22.92	4.3
1977	7.76	40.1	34.4	8.02	21.63	3.9
1978	7.30	39.4	33.2	8.56	19.47	3.4
1979	6.85	38.8	33.2	10.94	21.12	3.7
1980	6.35	36.7	31.5	18.57	30.79	5.1
1981	6.47	35.5	30.2	22.12	41.06	6.5
1982	6.78	34.3	29.3	19.76	37.27	5.7
1983	6.46	33.9	27.3	19.51	35.96	5.1
1984	6.58	33.6	28.3	17.61	33.69	5.0
1985	6.45	33.1	27.5	17.77	33.93	4.9
1986	6.73	32.8	26.8	8.80	12.19	1.7
1987	6.39	33.0	27.9	9.43	10.71	1.6
1988	6.32	31.4	24.9	8.00	8.61	1.1
1989	5.86	31.8	26.3	9.47	10.10	1.4
1990[7]	5.78	31.3	26.8	11.59	10.07	1.4

[1] In MTOE.
[2] Primary energy requirement in MTOE.
[3] 1985 prices in US dollars.
[4] Net energy imports in US dollars divided by net imports in MTOE.
[5] Implicit import price in local currency relative to GDP deflator.
[6] Net energy imports relative to GNP/GDP in current prices.
[7] Partly estimated.

Sources: See Table 1.

Annex Table 6

Primary energy consumption per unit of output

Year	United States	Canada	Germany	France	United Kingdom	Italy	Japan	Belgium	Netherlands	Sweden	Switzerland
	In MTOE per unit of GDP at constant prices and exchange rates										
1972	54.6	64.5	29.6	26.9	38.7	25.5	21.3	42.1	36.9	34.9	14.7
1973	54.0	62.8	30.2	27.4	37.4	25.3	21.9	42.2	37.4	35.7	15.8
1974	53.3	61.7	29.3	26.2	36.5	24.1	22.4	39.7	35.3	32.7	14.6
1975	52.6	61.6	27.7	24.9	35.1	23.6	20.8	37.4	34.3	33.4	16.0
1976	53.6	61.5	28.7	25.0	35.0	24.0	21.0	38.2	36.2	35.0	15.9
1977	52.5	61.0	27.8	24.4	34.7	22.9	20.2	37.5	34.1	34.9	16.8
1978	51.6	59.9	28.0	25.0	33.3	22.5	19.5	37.9	34.2	34.4	16.8
1979	50.5	60.3	28.3	25.1	34.0	22.2	19.4	38.3	35.2	34.9	16.6
1980	48.7	60.2	26.8	24.8	31.8	21.0	18.2	35.0	33.0	31.9	16.5
1981	46.2	57.3	25.5	23.8	31.3	20.3	17.0	33.0	31.2	32.9	16.2
1982	45.7	57.1	24.7	22.6	30.5	19.6	16.2	30.8	28.2	31.0	16.0
1983	44.1	55.2	24.4	22.8	29.3	19.4	15.9	30.1	29.1	31.5	16.7
1984	42.9	54.8	24.6	23.1	28.7	19.2	16.1	30.8	29.8	31.9	16.2
1985	41.5	53.9	24.7	23.4	29.4	18.9	15.4	31.5	29.5	33.5	16.5
1986	40.3	52.7	24.3	23.1	28.5	18.7	15.2	32.0	30.0	32.8	16.7
1987	40.3	52.2	24.0	23.3	27.6	18.8	14.7	32.0	30.5	32.5	16.2
1988	40.0	52.0	23.4	22.4	26.4	18.5	14.9	31.0	29.3	31.7	15.9
1989	39.9	50.7	22.3	21.7	25.9	18.1	14.7	28.6	28.9	30.2	14.6
1990*	39.7	49.8	21.9	21.3	25.2	17.8	14.5	28.0	28.2	30.1	15.1

Sources: OECD / IEA Energy Statistics and OECD National Income Accounts.

* Preliminary

Current US dollar GDP adjusted by GDP deflators rebased on 1987-89 = 100 and revalued at average 1987-89 exchange rates.

Annex Table 7

Primary energy consumption per capita

Year	United States	Canada	Germany	France	United Kingdom	Italy	Japan	Belgium	Netherlands	Sweden	Switzerland
	Tons of oil equivalent divided by total population										
1972	8.1	7.8	4.0	3.3	3.8	2.3	2.8	4.5	4.4	5.5	3.3
1973	8.3	8.1	4.3	3.5	3.9	2.4	3.0	4.8	4.7	5.8	3.7
1974	8.1	8.2	4.2	3.4	3.8	2.4	3.0	4.7	4.6	5.5	3.4
1975	7.8	8.3	3.9	3.2	3.6	2.3	2.8	4.3	4.4	5.7	3.5
1976	8.2	8.7	4.3	3.4	3.7	2.5	3.0	4.6	4.8	6.1	3.5
1977	8.3	8.8	4.3	3.4	3.7	2.5	3.0	4.6	4.6	5.9	3.7
1978	8.5	9.0	4.4	3.6	3.7	2.5	3.0	4.7	4.7	5.9	3.8
1979	8.4	9.3	4.6	3.7	3.9	2.6	3.1	4.9	4.9	6.2	3.8
1980	8.0	9.3	4.4	3.7	3.6	2.5	3.0	4.7	4.6	5.8	4.0
1981	7.7	9.0	4.2	3.5	3.4	2.5	2.9	4.3	4.3	6.0	3.9
1982	7.3	8.6	4.1	3.5	3.4	2.4	2.8	4.1	3.8	5.7	3.8
1983	7.3	8.6	4.1	3.5	3.4	2.4	2.9	4.0	4.0	5.9	4.0
1984	7.5	9.0	4.3	3.6	3.4	2.4	3.0	4.2	4.2	6.2	4.0
1985	7.5	9.2	4.4	3.7	3.6	2.5	3.0	4.4	4.2	6.6	4.2
1986	7.4	9.2	4.4	3.8	3.6	2.6	3.0	4.6	4.5	6.7	4.2
1987	7.6	9.4	4.4	3.8	3.6	2.6	3.0	4.6	4.5	6.7	4.2
1988	7.8	9.6	4.5	3.7	3.6	2.6	3.2	4.6	4.4	6.7	2.3
1989	7.9	9.6	4.3	3.7	3.7	2.7	3.3	4.4	4.5	6.4	4.0
1990*	7.9	9.3	4.4	3.8	3.6	2.8	3.5	4.5	4.5	6.4	4.2

Sources: OECD / IEA Energy Statistics and IMF International Financial Statistics.

* Preliminary.

Annex Table 8

Share of oil in total primary energy requirement

Year	United States	Canada	Germany	France	United Kingdom	Italy	Japan	Belgium	Netherlands	Sweden	Switzerland
	as a percentage										
1972	45.5	45.7	56.2	66.7	52.2	73.7	73.2	62.0	51.0	62.3	66.1
1973	44.1	45.2	55.8	68.0	50.6	74.6	75.5	60.4	49.2	59.9	64.6
1974	45.0	45.0	51.8	65.6	49.6	72.8	72.7	54.0	44.2	58.5	61.3
1975	45.7	46.1	51.9	63.3	46.2	69.8	71.8	54.8	41.6	55.0	57.5
1976	45.8	44.4	52.8	65.1	44.8	68.9	72.4	53.6	44.1	57.1	60.9
1977	48.1	43.6	52.6	61.1	45.5	68.1	73.4	54.9	43.7	52.5	58.0
1978	47.4	42.3	52.4	61.1	45.5	68.1	73.4	54.9	43.7	52.5	58.0
1979	45.9	41.8	50.7	59.3	43.2	68.3	71.0	53.2	45.9	53.1	55.2
1980	43.4	39.9	47.9	56.0	40.9	67.0	66.1	51.4	45.3	48.3	52.9
1981	41.7	38.5	44.7	51.3	38.6	66.1	63.1	49.2	43.9	45.2	49.1
1982	41.5	36.1	44.3	49.6	39.9	64.4	61.7	49.4	41.1	42.6	47.3
1983	41.1	33.5	43.7	47.6	37.7	64.5	61.4	44.9	37.8	37.4	49.4
1984	40.6	32.3	42.5	44.3	45.9	60.0	58.9	41.8	36.3	33.3	48.3
1985	40.4	30.5	41.9	42.5	38.7	59.1	55.2	41.2	34.4	32.6	46.8
1986	41.9	31.4	43.8	42.2	37.7	59.1	56.2	44.8	36.7	32.3	48.1
1987	41.2	31.7	42.3	42.0	36.5	59.5	56.0	43.0	36.2	29.7	45.7
1988	41.0	31.5	42.4	41.2	38.1	59.0	56.6	42.9	37.9	29.4	46.0
1989	41.0	33.2	41.3	42.1	39.1	58.9	56.6	44.1	37.4	30.3	46.3
1990*	39.9	33.6	41.9	41.1	40.1	57.6	56.9	43.7	38.1	29.3	47.7

Source: OECD / IEA Energy Statistics and Energy Balances of OECD Countries.

* Preliminary

Annex II

Aggregate production functions with energy

As an illustration of the two-level CES function mentioned in the text consider the case where the outer function is Cobb-Douglas, so that the elasticity of substitution between labour and the capital-energy bundle equals unity:

(i) $$Q = A.e^{rt} L^{1-a} . [(bk^{-\partial} + (1-b)E^{-\partial})^{-1/\partial}]^{a}$$

Denoting the substitution elasticity between capital and energy by $\sigma = 1/(1+\partial)$ and leaving out the productivity term ($A \ e^{rt}$), the corresponding long-run factor demand equations can be written as:

(ii) $$K = (P_{KE}/P_K)^{\sigma}(W/P_{KE})^{1-a} . Q$$

(iii) $$E = (P_{KE}/P_E)^{\sigma}(W/P_{KE})^{1-a} . Q$$

(iv) $$L = (P_{KE}/W)^{a} . Q$$

where
P_{KE} = Price of the capital-energy bundle
P_E = Price of energy
P_K = Cost of capital, and
W = Nominal wages.

Following a sustained rise in the price of energy, the long-run capital stock will be subject to two influences of opposite signs: (i) a fall in W/P_{KE}, which will reduce the desired capital stock with an elasticity corresponding to the share of labour in gross output; and (ii) a rise in P_{KE}/P_K, which will stimulate fixed investment with elasticity σ. The effect of energy prices on investment is, therefore, uncertain, though for $\sigma = 1-a$ (which is largely true in empirical estimates) and nominal wages responding more quickly than the cost of capital, investment would tend to rise. Long-run energy demand, on the other hand, will fall through substitution of capital for energy (fall in P_{KE}/P_E with elasticity σ) reinforced by substitution of labour for the capital-energy bundle (fall in W/P_{KE}, with elasticity (1-a)), while labour demand will rise, with the actual increase depending on the fall in P_{KE}/W and the share of energy and capital in gross output.

The extent to which these substitution effects can be observed in the short to medium term depends to a large degree on the composition of the capital stock. As argued in the text, substitution possibilities may be very limited once the capital stock is installed, so that the above effects will only be observed as the capital stock is increased or renewed.[1] As an illustration of the consequences for the speed of adjustment, consider the case where $\sigma = 0.6$ so that, in the long run and considering only the changes within the capital-energy bundle, a 10% rise in the price of energy relative to that of capital will cause a 6% fall in the consumption of energy. In a model with continuous substitution (putty-putty), this effect might take place within the same year, whereas for the putty-clay version the first-year reduction in energy consumption will be approximately:

$$I_g/K_{-1} \cdot \sigma$$

where I_g is gross investment (i.e. replacement investment as well as new investment) and K_{-1} is the capital stock at the beginning of the year. For most countries I_g/K is 10-15%, so that under the above assumptions the fall in energy consumption will be only 0.6-0.9% in the first year, rising to 1.2-1.8% in the second year and only attaining 6% when all of the capital stock has been replaced by new and more energy-efficient equipment.

The putty-clay model offers attractive analytical properties, but has proven too restrictive in aggregate analyses. Consequently, some recent macro-models have allowed for some short-run changes in the energy/capital

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[1] Production functions of this type are usually referred to as putty-clay. If factor ratios are totally independent of factor prices and only change in line with technical progress the production function is clay-clay. For some years a clay-clay vintage model has been part of the macroeconomic model maintained by the Central Planning Bureau in the Netherlands and used in both policy debates and medium-term predictions. A major conclusion emerging from this model is that most of the decline in employment during the 1970s can be ascribed to the scrapping of equipment made unprofitable by excessive increases in real wages relative to productivity.

ratio by incuding a "retrofitting parameter". This tends to increase the short-run price elasticity of energy demand (and thus the speed of adjustment), which can be seen from the short-run energy demand equation corresponding to (iii):

(v) $$E = E_{-1}(1-\delta-\rho) + (I_g + \rho K_{-1})[P_{KE}/P_E]^{\sigma}$$

where δ = depreciation rate and ρ = retrofitting parameter. For $\rho = 1-\delta$, the model would be putty-putty and for $\rho = 0$ the strict putty-clay version is obtained (see Helliwell et al. (1984)).

For most countries the retrofitting parameter increases the explanatory power compared with the strict putty-clay version, but the improvement is frequently obtained at the cost of transparency and less precise estimates of individual parameters.[2] Nonetheless, Table 1 below provides a useful illustration of the transmission of energy shocks as well as some perspective to the estimates given in Section D. The table is based on simulations and shows the five-year response to a 10% rise in energy prices in a model using a two-level CES function with retrofitting.[3] From the average figures it appears that a rise in energy prices lowers the energy intensity of output as well as the energy/capital ratio. The capital/labour ratio on average rises, but this is entirely due to changes in aggregate demand, as the partial elasticity of labour demand with respect to the price of the capital-energy bundle is positive. In fact, for all countries, the simulations show a fall in the desired capital stock, so that the rise in K/L merely reflects that employment is more responsive to demand-induced output changes than capital.

Turning to the channels by which energy prices affect energy consumption in individual countries, several patterns emerge:

- the largest falls are found for Japan and France but for widely different reasons. In Japan energy consumption declines mainly because of

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[2] See, for instance, the comparison between previous and revised estimates for the Seven Major countries in Jarret and Torres (1987), Table 1.

[3] It is also assumed that other factor prices stay unchanged and that monetary policy accommodates the rise in the aggregate price level. Even so, the simulation will reflect supply-side as well as aggregate demand effects.

Annex 2, Table 1

Simulated effects of a 10% rise in energy prices
(percentage change from base, five-year horizon)

	United States	Japan	Germany	France	United Kingdom	Italy	Canada	Average
Q/L	- 0.2	- 0.6	0.2	- 1.0	0.0	- 0.1	- 0.3	- 0.3
K/L	- 0.2	0.0	0.5	0.0	0.4	0.1	0.2	0.3
E/Q	- 1.0	- 4.5	- 0.7	- 1.6	0.1	- 1.3	- 0.3	- 1.3
E/K	- 1.0	- 5.1	- 1.0	- 2.6	- 0.3	- 1.5	- 0.8	- 1.7
σ_1	0.74	0.32	0.73	0.72	0.77	0.64	0.64	0.65
σ_2	0.40	0.95	0.40	0.58	0.67	0.77	0.40	0.60
ρ	0.06	0.15	0.30	0.30	0.00	0.18	0.00	0.14

Note: In the models used for the simulations both the "outer" and "inner" functions of the aggregate production function are CES, with substitution elasticities σ_1 and σ_1 respectively.

Source: Jarrett and Torres, op. cit.

capital energy substitution, which also helps to stabilise the capital/labour ratio. In France, on the other hand, retrofitting plays a major role and the stability of the capital/labour ratio is the net result of a marked fall in the capital stock matched by a demand-induced fall in labour demand;

- the smallest declines in energy consumption are found for Canada and the United Kingdom (where the energy intensity of output actually rises), for which the retrofitting parameter is 0, possibly reflecting that these countries are also major energy producers. Consequently, the speed of energy saving is entirely determined by changes in the capital stock, which tend to be relatively small;

- the remaining three countries occupy intermediate positions with respect to the degree of energy saving as well as the transmission channels. In the United States the degree of retrofitting is small and there is a clear shift towards a less capital-intensive production process and weaker labour productivity growth. By contrast, the retrofitting parameter in Germany is as high as that found for France and capital stock growth remains stable relative to developments in output and employment. Finally, the outcome for Italy is very close to the average for the seven countries regarding parameter size as well as changes in factor ratios.

All in all, the wide range of responses in energy demand shown in the table corresponds quite well to the actual developments in energy use. Moreover, the assumed close link between energy and the capital stock explains the very low short-run price elasticities of energy demand (see Nordhaus (1980) and the estimates presented in Section D) as well as the mixed results obtained with respect to capital/energy substitutability. Finally, a model in which labour is separable from the capital-energy bundle goes some way towards understanding the slow growth path observed in most countries since 1973. In particular, a rise in energy prices increases demand for labour relative to capital and reduces the long-run capital/labour ratio desired by firms. Hence, the two energy price shocks of the 1970s may be seen as one reason for the marked fall in labour productivity growth and thus further underline the importance of real wage restraint.