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# INTERNATIONAL COMPARISON OF THE SOURCES OF PRODUCTIVITY SLOWDOWN 1973-1982

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## ABSTRACT

This paper uses an integrated model of aggregate supply to analyze the post-1973 slowdown in productivity growth in the seven major OECD economies. Factor substitution, unexpected demand changes, profitability, and inventory disequilibrium all contribute to the explanation, which is based on a three-factor nested aggregate production function, including energy, and postulating Harrod-neutral disembodied technical progress. The model is first applied separately to the seven countries assuming constant (though country-specific) rates of technical progress. This model provides empirical evidence that this rate of progress has in fact slowed down for several of the faster-growing countries, even after adjusting for factor substitution and cyclical factors. The model is therefore re-estimated, and the sources of productivity decline recalculated, on the hypothesis that rates of efficiency growth in other countries are converging to those in the United States.

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# INTERNATIONAL COMPARISON OF THE SOURCES OF PRODUCTIVITY SLOWDOWN 1973-1982

## 1. Introduction*

What happened to productivity in the 1970s? Why has post-1973 growth in output per employed person in the major OECD economies been so much slower than it was between 1962 and 1973? These are key questions in economic history, and their answers have important implications for economic policy. Among the many papers devoted to this topic, analysing the problem either at an aggregate level or for disaggregated industries, most have concluded that there is a large residual to be explained, or have had to use rough guesses and often inconsistent methods to allocate the blame among a large variety of possible causes. Our study is based on the assumption that enough post-1973 history is now on record to permit using a more consistent and systematic approach, in which a comparable yet fairly simple analytic framework is applied to data from a number of countries. Errors in the explanation generated by this framework will show the size of the remaining puzzle requiring appeal to other models or additional influences.

In our analysis of the post-1973 slowdown in labour productivity growth in the seven major OECD economies, we apply an aggregate three-factor model of production behaviour that treats factor substitution, unexpected demand changes, deviations from desired inventory levels and profitability in an integrated and consistent manner. We proceed in two stages in a way that illustrates two distinct elements of comparative macroeconomics: the first is the use of comparable theory and data to assess productivity growth in a number of countries, and the second is the development of an international framework to explain the inter-country differences and possible future evolution of long-term productivity growth.

In the first stage, we apply our model separately to comparable sets of data for each of the countries, and use the results to disentangle the effects of energy price changes from those of unexpected changes in demand and profitability in explaining each country's post-1973 slowdown in the rate of growth of output per employed person. The model used has a nested long-term production function in which capital and energy are combined in a vintage CES inner function, and this bundle then enters a Cobb-Douglas outer function with efficiency units of labour. At the first stage of the research long-run technical progress is taken to be Harrod-neutral, occurring at a constant annual rate. Actual production is determined by a behavioural utilization rate equation in which the ratio of actual output to that determined by the production function (with given technical progress and normal utilization rates for employed factors) is explained by unexpected changes in final demand, abnormal profitability, and the discrepancy between actual and target inventory levels. For all countries there is strong evidence that changes in demand and profitability have led to important declines in the rate of utilization of employed factors, and hence in the rate of growth of measured total factor productivity and output per employed person, between 1973 and 1982. The post-1973 factor mix has also changed substantially, to use more labour and less energy, thus leading to further reductions in the rate of growth of output per employed person.

The first stage of our research also showed large international differences in the underlying rate of Harrod-neutral technical progress, with evidence of a slow-down in its rate of growth, even after adjusting for factor mix and cyclical factors, in those countries with initially lower but rapidly rising levels of labour efficiency. We also found evidence of some significant increases in labour income as a share of total factor payments in countries where the cost of labour had risen faster than the rate of Harrod-neutral technical progress, thus suggesting that the elasticity of substitution between labour and the capital-plus-energy bundle may not be as high as assumed by the use of a Cobb-Douglas outer function.

These results led us to a second stage of research in which the initial model was further developed, on the basis of the first stage results, to include an explanation of the international transmission and convergence of technical progress. As a separate development, we have also applied the two-level production structure using the CES form at both levels, and including simultaneous estimation of the derived factor demand equations (Helliwell, Sturm and Salou, 1984). In this paper, we shall concentrate on the convergence model using the Cobb-Douglas outer function, with references where appropriate to the two-level CES results. This marks a second distinct phase of comparative international macroeconomics, where the uniform modelling and comparison of production in national economies leads to a more general framework in which increasing trade in goods and services, and especially information and technology, tends toward international convergence of rates of growth of labour efficiency. Since the United States shows the highest level and the slowest rate of growth in Harrod-neutral technical progress of all of the seven countries (except for the United Kingdom), and does not show evidence of decline from the 1960s to the 1970s and 1980s (after adjusting for changes in cyclical position), its experience is used to approximate the rate of growth of technical progress to which other countries are converging.

The logic of our approach suggests that we present the first stage results in some detail, including the evidence that led us to proceed to the second stage. This will permit the second-stage results to be presented more concisely, since their underlying framework and basic pattern are similar, and will permit a clearer view of what is at stake in moving from a constant to a variable rate of technical progress.

## 2. Empirical and Theoretical Background

Table 1 shows the average annual growth of output per employed person, GDP per capita, and changes in various input and factor price ratios, in each of the seven major OECD countries between 1973 and 1982, with the growth rates between 1962 and 1973 given for comparison. The average annual growth of output per employed person fell by 2.5 percentage points from the pre-1973 to the post-1973 period. In all cases the average growth was less than half as high over the 1973-1982 period as over the 1962-73 period. In the United States and Canada, the countries with the lowest rates of growth of output per employed person 1962-1973, there was almost no growth in output per employed person from 1973 to 1982. Reference to statistics for productivity growth in industrialised countries over a century or more cautions that the twenty-five years of high productivity growth prior to 1973, especially outside North America, may be the exceptional performance (1). Thus any satisfactory explanation of the post-1973 slowdown that implies a return to 1962-73 average growth rates of output per employed person should also be consistent with the permanent transition to these growth rates from those experienced in the first half of the century.

How has economic research responded to the problem of explaining the large and pervasive slowdown in labour productivity growth since 1973? Nelson (1981, pp 1029-30) describes contemporary research on productivity as showing evidence of schizophrenia, with one set of studies characterised by neo-classical production functions applied under the assumption of continuous equilibirum, and a variety of other more eclectic approaches not relying on a formal analytical framework. Attempts to disentangle cyclical factors from other determinants of productivity growth are generally lacking from both sets of studies (important exceptions are Mohr (1980) for U.S. manufacturing and Kouri, de Macedo, and Viscio (1982) for French manufacturing), except insofar as cyclical factors are included among the reasons for productivity slow-down in some studies of the second type (e.g. Giersch, 1982; Denison, 1982; Lindbeck, 1982).

The presumption underlying our research is that this schizophrenia is unnecessary and costly, since any robust explanation of the post-1973 changes must deal in a coherent way with major changes in relative factor prices as well as large and sustained departures from long-run macroeconomic equilibrium. The neo-classical production framework is necessary to deal consistently with the effects of changes in factor prices, while the assumption of continuous equilibrium must be dropped if cyclical elements are to be treated properly. The production framework applied in this paper is based on the assumption that the explanatory power of the neo-classical model of production can best be harnessed by using it to provide an equilibrium towards which the system tends to move, but from which there may be many systematic departures. The likely pervasiveness of these departures means that it is necessary to avoid econometric procedures (such as the usual cost share equations used for deriving substitution parameters in translog production functions) that are only valid under conditions of continuous equilibrium.

Our approach has some similarities with that of Bruno in his comparative studies of productivity slowdown in manufacturing (1984) and in the private economy as a whole (1982). Like us, he assumes an underlying three-factor model of production, and permits short-term deviations of actual output from normal output. He does, however, not use his production structure to define a normal output series, and hence is not able to separate cleanly the effects of factor substitution from those of factor utilization. From his cross-section equation, he concludes (1982, p. 99) that about half of the slowdown in private-sector productivity growth was due to import price increases and half to demand slowdown. His estimated import price effect combines the influence of factor substitution with the impact of profitability on utilization which is separately estimated in our model.

Sylos-Labini (1984) explains productivity growth in Italy and the United States in terms of output growth, changes in the wage rate relative to the price of machinery, and current and lagged investment rates. The first term probably captures mainly cyclical effects, while the wage ratio probably combines some factor substitution with some profitability effects. By treating the production decision and the definition of potential output in a more explicit way, we are able to disentangle these separate influences more clearly, and then later to use our integrated framework to test for the possibility of general slowdown or country-specific catch-up effects in the rate of growth of labour efficiency.

We turn now to our model and its results.

## 3. The Two-Level Production Structure and the Influence of Energy Prices

The basic production structure employed in the first stage of our research is explained in detail in the technical annex. It consists of a three factor nested aggregate production function. The inner CES function combines capital and energy into a vintage capital-energy bundle which is combined with efficiency units of labour in an outer Cobb-Douglas function to define potential output. Estimates of the relevant production function parameters are presented in Table 2. Energy is singled out for treatment as a separate factor of production, in addition to capital and labour, since its relative price moved so differently in the pre-1973 and post-1973 periods, leading to changes in output per employed person that need to be disentangled from the other causes of changes in labour productivity. Since energy is treated as a separate factor of production, the output concept has to be enlarged to include net energy imports (2).

Our choice of a nested structure with capital and energy combined in the inner function follows earlier research conclusions (e.g. Berndt and Wood 1979) that the separability assumptions implied by this nesting are more plausible than the alternatives. We restricted our choice to production function structures that can be represented explicitly by their primary forms, as well as by their dual cost functions, so that we are able to have an explicit factor-based measure of potential output, and hence can decompose output per employed person into two key ratios:

$$Q/NE = (Q/QSV).(QSV/NE) \qquad (1)$$

Where:

Q = actual output,

NE = number of employed persons, and

QSV = output defined by the production function, with all quantities of employed factors operating at normal utilization rates.

We employ a flexible vintage structure for the capital and energy bundle. Some vintage structure is likely to be required since much capital equipment and many buildings are designed to embody a certain energy requirement. However, it would not be appropriate to apply a rigid vintage model, in which energy requirements were held fixed at their initial levels until the capital is scrapped, because there is much in the way of adjustment and retrofitting that can be done to change the energy use of the existing capital stock. We therefore designed our vintage model so that the degree of retrofitting should be a parameter to be estimated simultaneously with the long-term elasticity of substitution between capital and energy in the CES bundle. The distribution parameters in the inner CES bundle are derived from the assumption that the actual and desired energy/capital ratios are equal on average over the sample period, and by scaling the mean of KEV to have the same mean as K, so that the derived CES dual cost index for capital and energy:

$$PKE=(b^{s}.PK^{(1-s)} + c^{s}.PE^{(1-s)})^{1/(1-s)} \qquad (2)$$

measures the cost (after vintage effects have been worked out) of owning and providing energy for one unit of the capital stock. For any given pair of values for the retrofitting parameter (R1 in Table 2) and the elasticity of substitution (s) between capital and energy, equation 8 in the technical Annex defines the vintage energy requirement EV (3). Using EV as a predictor of E, Table 2 shows the maximum likelihood pairs of R1 and s for each of the seven countries. The long-term elasticity of substitution ranges from .6 to .95 (the highest value considered). If those values seem high, it should be remembered that they refer to energy as it is priced for final users, including all taxes and distribution charges, and that those prices have moved less than proportionately in response to changes in world crude oil prices, even in those countries where world crude oil price changes were passed on immediately to final users. There is wider variation in values for the retrofitting parameter, which in some countries is not very precisely determined statistically, and in any case is likely to get confused with the numerous non-price policies that several countries adopted to speed the conservation of energy, and especially of crude oil, following the world oil price shocks of 1973-74 and 1979-80. These latter policies may, for example, have combined with the increasing availability of natural gas service to explain the estimated high speed of the U.K. response.

Examination of the various country panels in Figure 1 shows why the elasticity of substitution and the retrofitting parameter both tend to be high, and also why there is a trade-off between R1 and s in the likelihood surfaces for several countries. In all seven countries there were matching decreases in relative energy prices and in capital/energy ratios prior to 1973, with the trends reversed thereafter.

How big were the effects of energy price changes on factor substitution, and hence on the rate of growth of output per employed person? The answer to this question depends on the properties of each country's production function. So far we have explained the method for obtaining the parameters of the inner CES function, and for defining the quantity and price of the bundle of capital plus energy. The higher price of energy leads to a substitution of capital for energy and also to a rise in the price index for capital plus energy, leading to substitution of labour for the bundle of capital and energy. The size and speed of this substitution depend on the parameters of the outer function and on the speed with which actual employment and the capital stock respond to changes in desired factor proportions.

The Cobb-Douglas form for the outer function implies a unit elasticity of substitution between efficiency units of labour and units of the capital - energy bundle. The exponents of the outer function are based on average nominal income shares over the entire sample period. The labour efficiency index and the constant term are defined from the requirement that QSV, the value of normal output defined by the production function at normal utilization rates and steady trend increases in labour efficiency, should have the same mean and trend as actual output Q over the entire sample period. The implied constant rates of growth of the labour efficiency indexes for each country are shown in Table 2.

To compute the substitution effects of energy prices on labour productivity, it matters what is held constant, and on the time lags involved in adjusting capital/labour ratios. Since our first stage research does not otherwise require estimated equations for employment and investment, we shall report results on the basis of full adjustment, and shall therefore refer only to the effects of the two long movements in energy prices relative to the prices of capital and labour: down from 1962 to 1973 and up from 1973 to 1982. Table 3 shows the results for each country, under the assumption of given levels of output and full adjustment of relative factor inputs. The first column shows by how much lower was 1973 equilibrium employment as a consequence of energy prices following their actual paths rather than staying at their 1962 values relative to the price of capital goods. The second column shows the amount by which equilibrium employment in 1982 increased because of the increase in relative energy prices between 1973 and 1982. The third column shows the combined effect of these two changes in terms of the reduction they imply in the average annual rate of increase in output per employed person from the first sub-period (1962-1973) to the second (1973-1982).

## 4. The Importance and Explanation of Variations in Factor Utilization

If it is true, as we assume, that there are systematic changes in the rate of utilization of employed factors, and hence in output per employed person, then it should be possible to estimate an output equation, including cyclical variables, that substantially improves on the prediction of output by the production function on its own.

The regression results reported in Table 4 show that this condition is very easily met for all of the seven countries, as the cyclical variables explain a significant proportion of any variations in output not already explained by variations in QSV. For each country the ratio Q/QSV is significantly reduced when average unit costs are high relative to the output price and significantly increased when final sales are high relative to what firms were expecting them to be when they made the factor demand decisions whose results are embodied in QSV.

Do these systematic departures from the long-term production function mean that firms are getting something for nothing when utilization rates are high, or being heedlessly wasteful when utilization rates are low? Before interpreting the results it might be useful to explain why not, by sketching a short-term optimization process that would lead producers, in the aggregate, to respond in the way revealed by the equations reported in Table 4.

It is costly and time-consuming to adjust capital, employment, and energy-intensity, and the size and profitability of future sales cannot be forecast with any precision. Firms deal with this situation by planning their productive capacity -- buildings, equipment, production schedules, marketing facilities, supply contracts, and so on -- to support an expected level of sales at some average desired rate of utilization. They recognize the inevitability of unexpected changes in demand and cost conditions by investing in short-term flexibility until the point where the expected costs of more flexibility start to exceed the expected benefits. Many of the devices that individual firms use to provide short-term flexibility, through contracts that transfer the extra demands to other suppliers, or by arrangements to purchase goods or services at short notice from other firms, are not available to the economy as a whole, except through the more limited extent permitted by additional imports of goods and services. Given whatever margin of spare capacity firms provide for themselves, they react to an unanticipated increase in final demand by some combination of: increases in capital, labour, and energy inputs (thereby inceasing QSV), running down inventories, raising prices, and increasing the utilization rate of employed factors. The feasible set of points for the short-term production function is a band about the longer-term function with given, or only slightly variable, quantities of employed factors.

The optimal choice of the current production level can be thought of as the selection of a fourth factor input, "factor utilization" which is not independently measurable except partially through data for working hours, number of shifts, and so on. The preferred rate of utilization will depend on its own cost relative to the costs of alternative means of dealing with changes in demand or cost conditions. The cost of higher utilization rates is not precisely measurable, but comprises some combination of increased risk of production failure (from human or mechanical stress, neglected maintenance, or control procedures ignored in the search for higher output levels), lower quality of output, and lack of time to plan for future innovations and investment. The costs of the alternatives -- inventory destocking, increased imports, price increases, and hence foregone sales -- cannot be measured precisely either, but it is possible to find measured variables that influence them. For example, the marginal cost of running down inventories may be expected to increase as inventory stocks fall further from their target levels, and the opportunity cost of foregone sales will be inversely related to unit costs and positively related to the output price. Thus the CQ variable (which represents current unit costs divided by the output price) will negatively affect the demand for utilization as a short term factor of production, as will the stock of inventories at the beginning of the period. Changes in these variables not only influence how the firm will respond to a change in demand conditions, but will also lead to the choice of a new short-term utilization rate. Thus the inventory and cost terms enter in log-linear form with the unexpected or temporary sales variable, which in turn is defined as final sales divided by QSV since QSV represents that portion of final sales that was forecast to be sufficiently permanent and profitable to be provided for by domestic factors operating at normal utilisation rates.

Since any deviation of the short-term utilization rate from unity is a measure of macroeconomic disequilibrium, it may be expected to have an important explanatory role elsewhere in the macroeconomic system, influencing imports, prices, wages, and factor demands. In the macroeconomic framework of which this explicit production model is a part (Helliwell et al, 1984), inventory change is determined as production plus net imports minus final sales, and the ratio of actual to desired inventories itself plays an important role in determining the path of macroeconomic adjustment, chiefly through its effects on prices, exports, and production.

One advantage of a direct explanation of the short-term production decision in relation to an explicit long-term production function is that it permits a consistent allocation of the proximate causes of productivity slowdown between cyclical elements and factor substitution. To get to the bottom of the matter, of course, requires an explanation of what causes sales, costs, relative prices, and inventory stocks to take the values they do. This would require complete and comparably specified macroeconomic country models, so that shock-free histories could be constructed for each of the countries and then actual external shocks and internal policies added to assess their individual and collective importance in determining the extent and timing of the productivity slowdown. This has so far only been done for the Canadian case (Helliwell 1984); to undertake that work on a comparative basis would take us beyond the scope of this paper.

We shall restrict ourselves in this paper to a comparison of the proximate causes of the productivity slowdown. Table 5 splits the overall decline in the annual rate of growth of output per employed person (Q/NE) into two components, normal output per employed person (QSV/NE) and the utilization rate (Q/QSV), which is the ratio of actual output to what it would be if all employed factors were utilized at normal rates. The growth of normal output per employed person is dominated by the rate of growth of the labour efficiency index, but is also influenced importantly by price-induced factor substitution, as evidenced especially by the effects of changes in energy prices. The first stage results assume a constant rate of increase in labour efficiency, so that the change in the average annual growth of QSV/NE from the pre-1973 to the post-1973 period is due to changes in relative factor prices.

The remaining columns of Table 5 disentangle the various causes of the changes in Q/QSV. In equilibrium growth, Q/QSV is always equal to 1.0, because there are no surprises to stop the planned increases in factors being just sufficient to produce the desired level of output at normal utilization rates. In a period of normal growth, therefore, changes in Q/QSV would contribute nothing, either positively or negatively, to changes in output per employed person. But things were not normal in either of the subperiods. There were abnormal increases between 1962 and 1973 in the main determinants of capacity utilization, followed by abnormal decreases from 1973 to 1982.

Figures 2, 3 and 4 show, respectively, the sales, cost, and inventory variables for each of the seven countries, and Table 5 shows the amount by which changes in each of these variables contributed to the slowdown in the average annual rate of growth of output per employed person from the 1962-1973 period to the 1973-1982 period. What do the results show? First, some common elements. In all countries, 1973 was a year of greater capacity utilization than either 1962 or 1982, so that changes in capacity utilization increased the average annual rate of growth of output per employed person in the first sub period and lowered it in the second. In all countries, the demand and cost variables both contributed importantly to the drop in capacity utilization from 1973 to 1982, the former usually more than the latter. This was quite different from the earlier period, where the increase in capacity utilization from 1962 to 1973 was almost entirely due to sales not matched by increases in normal output, with the cost variable usually playing a slightly negative role. If one then looks at the difference between the two sub-periods, the sales term thus appears to have much the greatest importance, as it was the primary positive contributor during the first sub-period and a substantial negative contributor during the second.

What are the major differences in the country results? First, cyclical factors have been much more important in the United States and Canada than in the other countries. Second, the production equation fits best for the United States, and least well for Germany. Only in Germany is the unexplained residual a substantial proportion of the overall productivity slowdown. Inventories play an important buffer role in most countries (the sales coefficient being significantly less than 1.0) except for the United Kingdom where the sales coefficient is above 1.0, suggesting that desired inventory stocks move substantially in response to current sales. The coefficient on the cost variable is fairly well identified in the range -.16 to -.35. The contribution of the cost variable to productivity slowdown is less uniform since, as shown in Figure 3, the variable has behaved rather differently in the seven countries, although generally moving in an adverse direction for all countries since 1973. Finally, as shown in Table 2, the underlying rate of Harrod-neutral technical progress differs very much from country to country, being less than half as high in the United States, the United Kingdom, and Canada as in any of the other four countries.

As a check on our results from the first stage research, we tested for constancy of the underlying rate of Harrod-neutral technical progress by adding a quadratic trend term to the regression used to define the technical progress index. We found a significant negative coefficient for all countries. When we added a calculated utilization rate (using exogenous instrumental variables for all right-hand side variables) to provide a rough cyclical adjustment, we found that the quadratic term became insignificant for the United States, Italy, and Canada, but remained significant elsewhere. The apparent decline in the rate of technical progress in some countries, combined with the very large intercountry differences in the average rates of technical progress suggested the need for a framework that would permit technical progress to be linked between countries, and possibly to converge. This further development is described in the following section, after which we shall summarise our overall results and search for suitable conclusions.

## 5. International Convergence of Technical Progress

Our first stage results provided evidence that, for most of the seven countries, though not for the United States, some decline in the rate of Harrod-neutral technical progress has occurred during the period 1962-1982, even after due allowance for factor substitution and the effect of cyclical changes in total factor utilization.

Since the United States showed the highest level of output per employed person throughout the observation period, and the least evidence of any decline in productivity growth, after accounting for factor substitution and utilization effects, it was used as the basis for testing the convergence hypothesis. We chose a simple form for the hypothesis, with the rate of change of labour efficiency being related to the previous period's ratio of the U.S. to the domestic labour efficiency variable. Under this hypothesis, the rate of change of labour efficiency eventually converges to the same rate in all countries, although the unconstrained logarithmic constant term permits the level of output per employed person to be different among countries (e.g. because of differing social structures, hours of work, resource endowments and education levels) even after convergence is achieved in the rates of change.

The use of a country-specific constant means that we are estimating separate dynamic models for each country, with or without the constraint that the catch-up coefficient be the same for each country. This differs from the equations tested by Lindbeck (1983, p. 33) and by Giersch and Wolter (1983, p. 40) which use only cross-section data, with the implicit assumption that in equilibrium each country would have the same productivity growth rate and level (4). The Giersch and Wolter equations also differ from ours in not adjusting the variables to reflect the effets of factor substitution. Nordhaus (1982) includes catch-up effects as one of the elements of his 'depletion' factor, to which he attributes a large part of the post-1973 reduction in productivity growth. His estimates are not comparable to ours, however, as he does not separate catch-up effects from other elements of his depletion factor.

Table 6 shows the precise form of the equations estimated, and estimation results when applied to pooled 1961-1982 data for Germany, France, the United Kingdom, Italy, and Canada. It is applied separately to Japan, for which the available data cover only the 1967-1982 period. For the pooled data, four versions of the equation are estimated and compared with two versions of a competing hypothesis that the rate of change of labour productivity, after adjustment for factor substitution, is a linear function of time. The nul hypothesis is that the efficiency index rises at a constant rate, which would mean that none of the equations in Table 6 would have any explanatory power except through contamination by correlation between the included variables and the excluded cyclical variables.

The equations shown in Table 6 are all based on the two-level nested Cobb-Douglas/CES production function and are thus directly comparable with the production structure used in the first part of the paper. We have also estimated equations based on the two-level nested CES structure with an 0.6 elasticity of substitution in the outer function, and found them to be almost identical, and that is why we need present only the first set in Table 6.

The four pooled catch-up equations use alternatively the logarithm of the U.S. efficiency index and the logarithm of the productivity ratio data on which it was estimated, and either do or do not impose the constraint that the catch-up coefficient is the same for all countries. Of the two regressions assuming a quadratic time trend for the efficiency index, one applies the constraint that the coefficient be the same for all countries, and the other does not.

There are two Japanese equations, one using the actual data for U.S. output per employed person (after adjusting for other factor inputs, as shown in Table 6) and the other using the estimated efficiency index (with a constant rate of growth) based on those data.

What do the results show? First, all of the pooled equations have significant explanatory power relative to the nul hypothesis that the labour efficiency index grows at a constant rate. Second, the constraint that all countries have the same response coefficients is generally not easily accepted, although the catch-up coefficients are quite similar among countries in the equation based on the estimated U.S. efficiency index. Third, none of the equations explain a very high proportion of the year-to-year variations in the dependent variable. This is not surprising since the latter is defined to remove the effects of long-run factor substitution, but not to remove the short-run cyclical effects. Finally, and probably as a consequence of the cyclical variance, the best fit is provided by the equation using the actual U.S. data, the second best by the time trend, and the third best by the computed U.S. labour efficiency index. Since the former two are more likely to be contaminated by cyclical variance and its international simultaneity, and since quadratic time trends for efficiency indexes have no theoretical foundation and have forecasting properties that eventually imply negative technical progress, we use the catch-up equations based on the computed U.S. efficiency index as a basis for the estimated and forecast labour efficiency indexes for each country shown in Figure 5.

In Tables 7 and 8 we present the results of integrating the catch-up hypothesis in the overall model of production behaviour, based on a unit elasticity of substitution between the capital-energy bundle and efficiency units of labour. Table 7 shows the parameters of the re-estimated production equations, and Table 8 shows the revised model's allocation of the factors leading to changes in output per employed person from the pre-1973 to the post-1973 period. Table 8 is like Table 5 for the first stage production model, but also decomposes the change in normal output per employed person (QSV/NE) into two parts, one due to growth in the efficiency index and the second due to changes in factor substitution.

The catch-up model increases the share of the productivity slowdown (outside the United States) that is due to slower growth of QSV/NE, and correspondingly reduces the amount requiring explanation by cyclical factors or left as an unexplained residual. The catch-up effect is especially important for Japan, Italy, France and Germany, in that order, as in each case it suggests that one-third of the slowdown of average annual increase in output per employed person could be due to the catch-up effect. There is not, except in Germany and the United Kingdom, any substantial increase in the overall ability of the model to explain production and the productivity slowdown, as both versions of the model have rather small residuals. We turn now to a comparison of the results of the two versions of the production model.

## 6. Summary and implications for future productivity growth

In Table 9 we draw together and compare the results from both stages of our research. The left-hand column shows the total slowdown, in each country, of the rate of growth of GDP per employed person. The second column shows the change in net energy imports, and the third column (equal to col. 1 minus col. 2) is the slowdown in the rate of growth of output per employed person, the variable directly explained by both versions of our model of production. The remaining columns then show how the two versions of the model explain the declining rate of productivity growth.

Figure 5 shows the implications of the catch-up model for the past and future growth of the labour efficiency index in each of the seven countries, based on purchasing-power-parity exchange rates and cyclically-adjusted labour income from two alternative base years, 1970 and 1982 (5). For reasons explained below, we think that the current version of the catch-up model overstates the degree of catch-up and hence understates future efficiency growth in Japan and some of the other countries with high rates of growth of constant Harrod-neutral technical progress in the Model I results reported in Table 2.

Figure 6 shows the rates of utilization of employed factors, Q/QSV, for both versions of the model. The catch-up model, by markedly slowing the recent rates of growth of potential output for several countries, has the effect of reducing the amount of underutilization at the end of the sample period, and hence the size of future increases in output per employed person as utilization rates eventually return to normal. We should emphasise that QSV measures the level of output, at normal utilization rates, of employed factors, and is not intended to measure what the economy could produce if there were increases in employment or the capital stock. In general, anything that increases Q/QSV, if it signals profitable future output, leads to subsequent increases in investment and employment, and hence to increases in QSV.

By reducing the recent growth of QSV, and hence tilting the series for Q/QSV and S/QSV, the catch-up model has the effect, for several countries, of transferring much of the explanation of productivity slowdown from unexpected changes in sales to unavoidable catch-up. We turn now to a brief country-by-country comparison of the results from the two versions of the model.

For the United States, the total decline to be explained is the smallest, (1.87 per cent), and there is only one version of the model to be consulted, since there was no evidence of slowdown beyond that which could be explained by cyclical factors. More than three-quarters of the total was explained by unexpected or temporary sales changes, with more than half of that amount due (as shown in Table 5) to unexpectedly rapid (or temporary) increases in sales up to 1973, illustrating once more the point that the pre-1973 period was itself an abnormal one. The remaining change in U.S. productivity growth was due to increases in costs, offset slightly by a fall in the level of actual relative to desired inventories. Factor substitution plays a relatively small aggregate role in the United States (as in France, the United Kingdom and Canada) (6).

The Japanese slowdown is the largest of all, (5.4 per cent) and is the most affected by application of the catch-up model. In both versions of the model, more than 2 per cent of the 5.4 per cent is due to factor substitution, and this amount, as in the other countries, is not materially altered by the choice between the two models. Application of the catch-up model cuts the estimated impact of changes in unexpected sales from 3.2 per cent per year to about 1.2 per cent per year, while changing the effect of the cost variable much less, reducing its contribution from .34 per cent to .24 per cent. The unexplained residual in the catch-up model is larger than in the initial model, but is less than .2 per cent per year in either case, a very small fraction of the total slowdown. Which set of results is more likely to be correct? It is most important to answer this question for the Japanese case, for here the gap between the two sets of results is largest. We have deliberately set up the two models so that they are likely to bracket the right answer. The first stage model understates the catch-up effect by forcing it to be zero, while model II overstates it because of the collinearity between the included catch-up variable and the excluded cyclical variables in the estimated equations reported in Table 6. This is especially likely to lead to an overstatement of the catch-up effect for Japan, where the data period is several years shorter than for the other countries. Although it is possible to try to identify more precisely the relative impacts of the catch-up and cyclical variables, it will be difficult to do so with much precision without application of cross-country restrictions in regressions that pool time-series and cross-country data.

The German slowdown is of about average size (2.4 per cent), with about one-third due to factor substitution. Germany is the only country for which the profit squeeze was worse during the pre-1973 period than during the subsequent one; even though the unit cost ratio (relative to the output price) rose after 1973 (as shown in Figure 3) it did so at a slower rate than before, so that the cost factor reduced the slowdown by .1 per cent per annum. In either model, the effects of unanticipated sales changes were smaller in Germany than in any of the other countries. In both models, the unexplained residual is larger than in any of the other countries, and is almost one-third of the total slowdown.

The French slowdown of 2.2 per cent is explained in model I by sales and profits, with the former three times as important as the latter. Model II shifts 1.5 per cent of slowdown to the catch-up effect, drawing most of it from the unexpected sales term, whose importance is cut by a factor of three. The unexplained residuals are small for the two models.

The United Kingdom slowdown was fairly large (2.6 per cent), but not much affected by the choice between models. Sales changes remain the most important determinant, and the catch-up effect is small. This is to be expected, as the U.K. had the slowest average productivity growth 1962-1973.

Italy has a large slowdown (4.4 per cent), of which almost 2 per cent is attributed to catch-up in model II. Factor substitution is responsible for more than 1 per cent in both models, and most that is not due to catch-up or factor substitution is traced to sales. Profits effects are about average, and the residuals are small in both models.

Canada has a moderately large slowdown (2.5 per cent). The catch-up effect is the smallest since it was estimated to have been largely complete by the mid-1970s. The contribution from the profits variable is larger than for any other country reflecting (as shown in Figure 3) the sharpest post-1973 rise in costs relative to output prices.

What do the results suggest about the usefulness of our approach, and about the prospects for future productivity growth? Our work is still progressing, but thus far appears to confirm our view that it is practicable and informative to analyse and make international comparisons of growth in aggregate labour productivity in a way that consistently accounts for factor substitution, factor utilization, and long-run increases in labour efficiency.

In our modelling of production and productivity, we found substantial effects from energy prices and from cyclical forces in all seven countries in explaining the slowdown in productivity growth since 1973. These effects were exaggerated by the fact that the pre-1973 and the post-1973 periods were both unusual. Relative energy prices in all countries declined substantially prior to 1973, causing energy to be substitued for other factors, and hence raising the average rate of growth of output per employed person. After 1973, the process was reversed, and caused the growth of output per employed person to be substantially less than if energy prices had remained constant, or had continued to fall as they had prior to 1973. Given the post-1973 rises in energy prices, that part of the productivity slowdown due to substitution of labour for energy represents an improvement in efficiency, since it is required to produce any given level of output at least cost. It is therefore important to separate these substitution effects when analysing and forecasting the rate of increase in output per employed person. This factor substitution exaggerated the underlying rate of productivity growth before 1973, and reduced it afterwards; future relative energy price changes are likely to be smaller and hence to produce intermediate results.

The pre-1973 and post-1973 periods were also both abnormal with respect to cyclical effects on output per employed person. Profitability and unexpected sales, especially the latter, were on average adding to utilization rates between 1962 and 1973 and reducing them between 1973 and 1982. Since 1982 was an abnormally bad year for profitability and sales in most of the seven countries, eventual restoration of normal operating rates (which may result from reduction in factor inputs as well as from increases in output) will mean that increases in output per employed person will be abnormally high during the adjustment period.

Thus, both energy prices and cyclical factors caused the 1962 to 1973 growth of output per employed person to be unusually high and the 1973 to 1982 growth to be unusually low. If real energy prices remain fairly constant over the rest of the decade, then energy substitution is not likely to be very important, although the full substitution effects of the pre-1982 energy price increases are still being worked out. Starting from 1982, the cyclical effects on labour productivity are bound to be positive as normal utilization rates are restored. Putting cyclical and energy price effects together, output per employed person is likely to rise faster than normal in all countries over the next few years.

But what is the normal rate of growth of productivity? This was the key question addressed in the second stage of our research. In the first stage, we assumed a constant rate of increase in long-run labour efficiency.

Two features of our results suggested further work. First, we found large international differences in the average rate of Harrod-neutral technical progress, being just above 1 per cent in the United States, Canada and the United Kingdom, and above 3 per cent in Japan, Germany, France and Italy. This led us to ask what caused those differences, and to question whether they provided a useful basis for forecasts of the future growth of supply potential. Second, we tested for evidence of decline in the growth rate of the underlying rate of technical progress, and found it, even after adjusting for factor substitution and cyclical factors, in most of the countries except the United States and the United Kingdom.

These results from the first stage of our research led us to develop and integrate into our production model an international catch-up hypothesis whereby all countries eventually converge to the U.S. rate of technical progress, which itself is unaffected by the convergence process. We are considering extensions of this hypothesis where the convergence could be to some rate other than that of the United States, with that central rate subject to stochastic evolution rather than being fixed. Any extensions of this sort would require that cyclical and factor substitution effects be taken into account in the pooled regressions.

We are also including the investment/capital ratio in the catch-up equations to test the hypothesis that there is an important element of capital-embodiment in harnessing the benefits of technical progress. To facilitate these extensions, we are planning to apply the model to a larger group of OECD countries. This will provide a stronger empirical base for determining the appropriate split between cyclical and catch-up effects in the explanation and projection of productivity trends.

The projections in Figure 5 of future growth in labour efficiency in each country, based on the catch-up model, should be treated with caution as the results of preliminary work. As we suggested above in our discussion of the Japanese results, our current estimates of the catch-up effect are probably biased upwards by correlation between the catch-up variable and cyclical factors. Thus the most likely estimate of the future rate of growth of labour efficiency in each country but the United States is probably more than shown in Figure 5 but less than implied by the constant rates of Harrod neutral technical progress reported in Table 2. Further refinements are not likely to alter our conclusion that it is difficult but important to consider the evolution of aggregate technical progress within a model, such as the one we have presented, which treats long-run technical progress consistently with factor substitution and cyclical effects.

We have so far found the framework useful for assessing and comparing the proximate causes of the observed productivity slowdown. It has permitted the residual element to be sharply reduced, and provides a coherent aggregate supply model that can, in the context of a more complete macroeconometric model, be used to go behind the changes in profitability, sales, and factor prices to provide a macroeconomic analysis of the underlying domestic and international sources of the productivity slowdown.

# NOTES

* We are grateful for helpful comments on earlier versions of this paper presented at INSEAD (Fontainbleau), INSEE (Paris), the Seminaire d'économie monétaire internationale in Paris, the OECD, l'Université Libre de Bruxelles and the Central Bank of Switzerland. This version also reflects helpful suggestions by our discussants and other participants in the Perugia meeting of the International Seminar on Macroeconomics. Any opinions expressed in this paper are those of the authors and do not necessarily represent the official view of the OECD.

(1) For example, in none of the 16 OECD countries studied by Maddison (1982, page 96) was the average annual rate of growth of GDP per man hour in excess of 3 per cent in either of the 40-year periods prior to 1950, and for the group of countries it averaged 1.6% annually from 1870 to 1913 and 1.8% from 1913 to 1950. By contrast, the growth of GDP per man-hour averaged 4.5 per cent annually for the group between 1950 and 1973 and it exceeded 3.0% in 14 of the 16 countries. From 1973 to 1979, it grew much less rapidly than 1950-73 but at an average rate of 2.7%, and in most countries outside North America it grew by more than in either of the sub periods between 1870 and 1950.

(2) The inputs of capital and labour have not yet been correspondingly adjusted to remove capital and labour employed in the production and distribution of energy. Earlier applications of the framework to adjusted Canadian data have shown the employment adjustment to be small and without consequence. The adjustment of the capital stock is large

in the Canadian case, and influences the results, since investment in energy was a significantly larger fraction of total investment in the 1970s than in the 1960s. The same is likely to be true for the United States and the United Kingdom. Adjustment of capital stock data for the other countries in the big seven is less likely to influence the results significantly. Efforts to adjust the capital stock data for all seven countries are underway.

(3) The recursive formulation requires an initial value for EV, provided by making it equal to E at the beginning of the data period. Since relative energy prices were moving fairly smoothly and predictably in the early 1960s, this assumption of initial equilibrium is not likely to cause problems.

(4) Marris (1982) also applies an implicit catch-up model to cross-section data for a number of OECD economies by explaining each country's 1965-73 *per capita* GDP growth rate by an equation that includes positive effects from export growth and the investment ratio, and a negative effect from the level of GDP *per capita* at the beginning of the period. This formulation implies the implausible equilibrium property that productivity growth is approaching zero in all countries, including the United States. (It is, however, to be preferred in this respect to the quadratic trend model, which implies productivity changes eventually turning negative). When used to attribute the reasons for the 1973-79 productivity slowdown, it therefore combines catch-up effects with a general slow-down, thus overstating the catch-up effects.

(5) The efficiency indicators plotted in Figure 5 have been computed from national GDP figures in U.S.-\$ purchasing power parities for 1970 and 1982 as published in OECD (1984, p. 98). These output figures were first adjusted for deviations from normal factor utilisation rates (dividing them by Q/QSV), then multiplied by the equilibrium labour share (1-a), and divided by the number of employed persons. The 1970 figures were then expressed in 1982 prices. The resulting base year figures for 1970 and 1982 were multiplied by the base-year-compatible labour efficiency index computed in the second stage of our research. Level differences between the efficiency indicators based on 1970 and 1982 U.S.-\$ purchasing power parities are due to terms-of-trade changes as well as to changes in inter-country differences in capital and other resource endowments per employed person. The country ordering according to labour efficiency levels in 1973 implicit in Figure 5 corresponds closely to a country ordering according to total factor productivity levels in an earlier study by Christensen et al (1980). Level differences in labour efficiency between the U.S. and other countries are, however, much bigger in our study compared to Christensen et al, mainly because the latter adjust their productivity measure also for hours worked and labour quality.

(6) At least in part this is because the energy capital stock data are not yet available to permit their exclusion from the total capital stock. Experiments with the Canadian data, where this adjustment has been made for other work, show that the effect can be important.

# Annex

## INITIAL NESTED PRODUCTION STRUCTURE

This structure features a Cobb-Douglas outer function, constant Harrod-neutral technical progress, and a vintage CES inner function for the capital/energy bundle.

### A) The Cobb-Douglas outer function

$$QSV = A.KEV^{a}.(PI.NE)^{1-a} \qquad (1)$$

where QSV = potential output at normal rates of factor utilisation
A = scale factor
KEV = vintage capital-energy bundle (see below)
a = non-labour share in gross output
PI = labour efficiency index
NE = total employment.

The factor share a was computed as the average non-labour income share in gross output (including net energy imports), excluding the imputed labour income of the self employed members of the labour force.

The measured labour efficiency index, PIM, which includes cyclical effects, was obtained by inverting equation (1) after substituting actual output (Q) for potential output (QSV):

$$PIM = (Q/(KEV^{a}))^{1/(1-a)}/NE \qquad (2)$$

The efficiency bundle PIM was used as the dependent variable for estimation of the rate of Harrod neutral technical progress as well as for the various tests of the time invariance of the rate of technical progress and the catch-up hypothesis. The scale parameter A is determined by normalising the calculated efficiency index PI to have the value 1.0 in 1971.

## B) The Inner CES function.

The inner function which bundles energy and capital has the form:

$$KEV = KEV(-1).(1-R1-RSC) + [I+R1.KNE(-1)] \,.\, [b+c(c.PK/(b.PE))^{s-1}]^{s/(s-1)}$$
(3)

where KEV = vintage capital-energy bundle
R1 = retrofitting parameter
RSC = scrapping rate
I = gross fixed investment
KNE = gross fixed capital stock
PK = user cost of capital
PE = energy price applicable to final user
b,c = distribution parameters in the inner CES function
s = elasticity of substitution between energy and capital.

In this equation the gross capital stock (KNE), energy consumption (E), gross investment (I), the energy price (PE) and the scrapping rate (RSC) are observed variables.

The user cost of capital PK is computed as

$$PK = PIB(RSC + RHOR) \tag{4}$$

where PIB is the (observed) investment good deflator and RHOR (the long-term supply price of capital) was defined as a constant, with a value such that on average total factor earnings exhaust total output over the sample period.

Assuming that the energy/capital ratio (EK) is optimal (subject to prevailing relative prices PE/PK) on average over the sample period implies that

$$c/b = (MEAN(EK)/MEAN\ [(PK/PE)^{s}])^{1/s} \tag{5}$$

which allows direct computation of c/b from observed variables for any given value of s, the elasticity of substitution between capital and energy. Thereafter b can be computed from

$$b = 1/(1+(c/b)^{s}\ MEAN\ ((PE/PK)^{1-s}) \tag{6}$$

The elasticity of substitution (s) and the retrofitting parameter (R1) are determined by estimating the energy demand function

$$\ln(E) = \ln(EV) \tag{7}$$

where EV is the vintage energy requirement needed to operate the capital stock KNE subject to prevailing relative energy prices PE/PK. EV is defined by the recursive equation

$$EV = EV(-1).(1-R1-RSC) + (I+R1.K(-1)).((c.PK)/(b.PE))^{s} \qquad (8)$$

To obtain a starting value, EV is set equal to E at the beginning of the sample period, on the assumption that no large and surprising changes in energy prices have occurred over the preceding few years.

The parameter pair (s, R1) which maximised the likelihood function of regression (7) was chosen as the preferred parameter combination, and results for this double grid search as well as other relevant production function parameters are depicted in Table 2 in the main text. The estimated values for the capital/energy ratios, KNE/EV, are plotted in figure 1 along with the actual ratios, KNE/E, and the relative price ratios.

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## Table 1: Changes in Output, Factor Inputs and Factor Costs

(Average annual rates, per cent)

| | Real GDP | | Output (Q) | Fixed Capital | Final Energy use | Fixed capital per unit of final energy use | Final energy price relative to user cost of capital | Units of capital/ energy bundle per employed person | Labour cost relative to price of capital/energy bundle |
|---|---|---|---|---|---|---|---|---|---|
| | Per capita | Per employed person | (Per employed person) | | | | | | |
| **United States** | | | | | | | | | |
| 1962-1973 | 2.92 | 2.00 | 2.03 | 1.55 | 2.46 | -0.91 | -1.00 | 1.43 | 2.26 |
| 1973-1982 | 0.87 | 0.19 | 0.15 | 1.46 | -1.46 | 2.92 | 7.04 | 1.19 | -1.16 |
| **Japan** | | | | | | | | | |
| 1967-1973 | 7.70 | 7.99 | 8.19 | 9.22 | 8.69 | 0.53 | -1.98 | 9.87 | 10.73 |
| 1973-1982 | 2.70 | 2.89 | 2.82 | 5.86 | -0.32 | 6.18 | 9.12 | 4.38 | 3.21 |
| **Germany** | | | | | | | | | |
| 1962-1973 | 3.50 | 4.20 | 4.40 | 5.14 | 6.73 | -1.59 | -0.98 | 5.18 | 4.93 |
| 1973-1982 | 1.70 | 2.17 | 2.00 | 3.99 | 0.75 | 3.24 | 4.83 | 3.42 | 0.95 |
| **France** | | | | | | | | | |
| 1962-1973 | 4.39 | 4.55 | 4.56 | 2.88 | 7.23 | -4.35 | -1.26 | 2.97 | 5.15 |
| 1973-1982 | 1.95 | 2.40 | 2.35 | 3.66 | 0.28 | 3.39 | 6.87 | 3.29 | 2.33 |
| **United Kingdom** | | | | | | | | | |
| 1962-1973 | 2.80 | 3.07 | 3.19 | 3.61 | 3.65 | -0.04 | -2.12 | 3.75 | 3.10 |
| 1973-1982 | 0.65 | 1.33 | 0.55 | 3.32 | 0.18 | 3.15 | 4.75 | 2.95 | 0.88 |
| **Italy** | | | | | | | | | |
| 1962-1973 | 4.06 | 5.38 | 5.42 | 5.26 | 8.40 | -3.14 | -2.93 | 5.44 | 5.73 |
| 1973-1982 | 1.59 | 1.27 | 1.00 | 2.43 | 0.23 | 2.20 | 5.12 | 2.22 | -0.10 |
| **Canada** | | | | | | | | | |
| 1962-1973 | 4.01 | 2.66 | 2.57 | 1.65 | 3.88 | -2.22 | -2.18 | 1.82 | 3.06 |
| 1973-1982 | 0.85 | 0.02 | 0.05 | 2.56 | 0.40 | 2.17 | 5.05 | 2.33 | 0.14 |

## Table 2

## PRODUCTION FUNCTION PARAMETER VALUES

| Country | Rate of Harrod-neutral technical progress | Retrofitting parameter R1 | Elasticity of substitution s | Share of capital plus energy a |
|---|---|---|---|---|
| United States | 0.012 | 0.18 | 0.60 | 0.36 |
| Japan | 0.034 | 0.65 | 0.92 | 0.38 |
| Germany | 0.030 | 0.05 | 0.95 | 0.41 |
| France | 0.042 | 0.05 | 0.95 | 0.41 |
| United Kingdom | 0.010 | 0.95 | 0.70 | 0.38 |
| Italy | 0.034 | 0.18 | 0.95 | 0.35 |
| Canada | 0.015 | 0.20 | 0.88 | 0.40 |

## Table 3

## ESTIMATED EMPLOYMENT EFFECT OF ACTUAL CHANGE IN ENERGY PRICES (a)

| | Cumulated effect | | Contributions of energy price changes to the reduction in the growth of normal output per employee |
|---|---|---|---|
| Country | 1962-1973 | 1973-1982 | Per cent per annum |
| United States | -0.50 | 3.10 | 0.39 |
| Japan | -1.48* | 5.30 | 0.84 |
| Germany | -0.58 | 2.33 | 0.31 |
| France | -0.67 | 2.98 | 0.39 |
| United Kingdom | -1.37 | 2.53 | 0.40 |
| Italy | -1.71 | 2.40 | 0.42 |
| Canada | -1.10 | 2.07 | 0.33 |

* 1965 1973

(a) Assuming full adjustment of both capital and labour to optimal levels. and using Cobb Douglas outer functions and the CES inner function elasticities of substitution shown in Table 2.

## Table 4
## OUTPUT EQUATIONS I

Equation specification:

$$LN(Q/QSV) = a_0+a_1\ LN(CQ) + a_2\ LN(S/QSV) + a_3\ LN(KIB(-1)/QSV)$$

Where: Q = GDP plus net energy imports (at constant prices).

QSV = Output with employed factors used at normal utilisation rates. (with Harrod-neutral technical progress occuring at a constant rate).

CQ = Unit cost (including normal returns to capital) relative to the output price.

S = Final sales (excluding inventory change) (at constant prices).

KIB(-1) = Inventory stock level, beginning of period.

Estimation technique: Two Stage Least Squares.

| Country | Estimated coefficients (t statistics) $a_0$ | $a_1$ | $a_2$ | $a_3$ (1) | Estimation Period | Regression Statistics $R^2$ | DW | SEE |
|---|---|---|---|---|---|---|---|---|
| United States | -0.148<br>(-92.0) | -0.170<br>(-17.7) | 0.951<br>(32.9) | -0.07 | 62-82 | 0.987 | 1.85 | 0.0031 |
| Japan | -0.148<br>(-35.1) | -0.242<br>(-8.0) | 0.900<br>(17.0) | -0.07 | 67-82 | 0.965 | 1.10 | 0.0076 |
| Germany | -0.203<br>(-9.9) | -0.345<br>(-3.86) | 0.687<br>(5.42) | -0.07 | 62-82 | 0.590 | 0.61 | 0.0180 |
| France | -0.242<br>(-52.6) | -0.292<br>(-14.8) | 0.941<br>(29.6) | -0.07 | 62-82 | 0.978 | 1.74 | 0.0065 |
| United Kingdom | -0.256<br>(-13.3) | -0.319<br>(-7.7) | 1.166<br>(9.0) | -0.07 | 62-82 | 0.799 | 1.11 | 0.0154 |
| Italy | -0.195<br>(-32.3) | -0.165<br>(-7.36) | 0.804<br>(19.2) | -0.07 | 62-82 | 0.957 | 1.25 | 0.0108 |
| Canada | -0.231<br>(-47.1) | -0.256<br>(-22.1) | 0.627<br>(27.0) | -0.07 | 62-82 | 0.983 | 1.78 | 0.0052 |

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1 The coefficient for the inventory variable (KIB(-1)/QSV) is not well determined statistically in the Q/QSV regressions except in the case of the United States. Given the importance of this coefficient for the dynamic behaviour of a complete model in which the Q/QSV equation is imbedded, an intermediate value of --0.07 for $a_3$, falling between the estimates obtained for the two alternative U.S. equations reported in Tables 4 and 7, was imposed on all countries.

## Table 5: Factors contributing to changes in output per employed person

(Based on Harrod neutral technical progress proceeding at a constant rate)
(Average annual rate, per cent)

| Country/period | Change in normal output per employed person (QSV/NE) | Change in rate of capacity utilisation (Q/QSV) | Cyclical factors influencing Q/QSV | | | | | | Unexplained Residual Change in Q/QSV |
|---|---|---|---|---|---|---|---|---|---|
| | | | Unanticipated (or temporary) changes in sales | | Unit costs relative to output prices | | Ratio of desired over actual inventories | | |
| | | | Change in Variable | Contribution to change in Q/QSV | Change in Variable | Contribution to change in Q/QSV | Change in Variable | Contribution to change in Q/QSV | |
| United States | | | | | | | | | |
| 1962-1973 | 1.29 | 0.74 | 0.89 | 0.85 | 0.19 | -0.03 | 0.95 | -0.07 | 0.01 |
| 1973-1982 | 1.20 | -1.05 | -0.67 | -0.64 | 2.15 | -0.37 | -0.38 | 0.03 | -0.07 |
| Japan | | | | | | | | | |
| 1967-1973 | 5.95 | 2.24 | 2.72 | 2.45 | 0.04 | -0.01 | 1.95 | -0.14 | -0.06 |
| 1973-1982 | 3.88 | -1.06 | -0.90 | -0.82 | 1.45 | -0.35 | -1.12 | 0.08 | 0.03 |
| Germany | | | | | | | | | |
| 1962-1973 | 3.87 | 0.54 | 0.97 | 0.67 | 1.22 | -0.42 | 1.18 | -0.08 | 0.37 |
| 1973-1982 | 3.16 | -1.15 | -0.42 | -0.28 | 0.64 | -0.27 | 0.09 | -0.01 | -0.59 |
| France | | | | | | | | | |
| 1962-1973 | 3.69 | 0.87 | 1.59 | 1.50 | -0.07 | 0.02 | 8.12 | -0.57 | -0.08 |
| 1973-1982 | 3.81 | -1.41 | -0.79 | -0.74 | 2.47 | -0.72 | 1.18 | -0.08 | 0.13 |
| United Kingdom | | | | | | | | | |
| 1962-1973 | 2.06 | 1.13 | 1.32 | 1.54 | 1.25 | -0.40 | 0.48 | -0.03 | 0.02 |
| 1973-1982 | 1.75 | -1.20 | -0.21 | -0.24 | 2.01 | -0.64 | 0.26 | -0.02 | -0.30 |
| Italy | | | | | | | | | |
| 1962-1973 | 4.08 | 1.34 | 1.82 | 1.46 | 0.70 | -0.12 | -0.05 | +0.00 | -0.00 |
| 1973-1982 | 2.96 | -1.96 | -1.51 | -1.21 | 3.02 | -0.50 | 2.88 | -0.20 | -0.05 |
| Canada | | | | | | | | | |
| 1962-1973 | 1.61 | 0.96 | 1.58 | 1.04 | 0.08 | -0.02 | 0.07 | -0.01 | -0.05 |
| 1973-1982 | 1.81 | -1.76 | -1.41 | -0.93 | 3.71 | -0.93 | -0.62 | 0.04 | 0.06 |

## Table 6

### Estimation Results for Alternative Non-constant Technical Progress Specification
(assuming Harrod-neutral technical progress)

Estimated Equations (1961-1982)

i) quadratic time trend: $LN(PI/PI(-1)) = a_0 + a_1 \, TIME$

ii) catch-up hypothesis : a) $LN(PI/PI(-1)) = a_0 + a_1 \, LN(PIUS/PI(-1))$ (synthetic US-PI)

b) $LN(PI/PI(-1)) = a_0 + a_1 \, LN(PIMUS/PI(-1))$ (measured US-PI)

| Country | $a_1$ (quadratic time trend) | | $a_1$(PIUS) | | $a_1$(PIMUS) | |
|---|---|---|---|---|---|---|
| | Constrained | Unconstrained | Constrained | Unconstrained | Constrained | Unconstrained |
| Germany | -0.00287<br>( 6.5) | -0.00190<br>( 2.0) | 0.1131<br>(6.0) | 0.0945<br>(2.0) | 0.1406<br>(7.7) | 0.1219<br>(2.8) |
| France | -0.00287<br>( 11.3) | -0.00345<br>(-6.2) | 0.1131<br>(10.0) | 0.0985<br>(6.0) | 0.1406<br>(11.8) | 0.1052<br>(6.7) |
| United Kingdom | -0.00287<br>( 6.3) | -0.00180<br>(-1.8) | 0.1131<br>(5.6) | 0.1393<br>(1.2) | 0.1406<br>(7.1) | 0.4247<br>(3.0) |
| Italy | -0.00287<br>(-4.8) | -0.00393<br>(-3.0) | 0.1131<br>(4.4) | 0.1416<br>(3.2) | 0.1406<br>(5.7) | 0.1663<br>(3.8) |
| Canada | -0.00287<br>(-7.6) | -0.00326<br>(-3.9) | 0.1131<br>(5.5) | 0.1099<br>(1.1) | 0.1406<br>(7.3) | 0.3865<br>(3.8) |
| System $R^2$<br>$CHI^2$ (D.F.) | 0.597<br>20.007 (1) | 0.720<br>27.984 (5) | 0.569<br>18.537 (1) | 0.654<br>23.372 (5) | 0.599<br>20.085 (1) | 0.828<br>38.761 (5 |
| Japan (a) | n.a. | -0.00505<br>(-2.3) | n.a. | 0.236<br>(3.9) | n.a. | 0.194<br>(3.5) |
| $R^2$ | | 0.23 | . | 0.49 | - | 0.43 |
| F-stat. (1 14) | . | 5.45 | - | 15.29 | - | 12.1 |

(a) Estimated separately because of shorter sample period (1967 1982).

## Table 7

## OUTPUT EQUATIONS II

Equation specification:

$$LN(Q/QSV.CU) = a_0 + a_1\ LN(CQ) + a_2\ LN(S/QSV.CU) + a_3\ LN(KIB(-1)/QSV.CU)$$

Where: Q = GDP plus net energy imports (at constant prices).
QSV.CU = Output with employed factors used at normal utilisation rates. (with Harrod-neutral technical progress occuring at a decelerating rate).
CQ = Unit cost (including normal returns to capital) relative to the output price
S = Final sales (excluding inventory change) (at constant prices)
KIB(-1) = Inventory stock level. beginning of period.

Estimation Technique: Two Stage Least Square.

| Country | Estimated coefficients (t statistics) $a_0$ | $a_1$ | $a_2$ | $a_3$ (1) | Estimation Period | Regression Statistics $R^2$ | DW | SEE |
|---|---|---|---|---|---|---|---|---|
| Japan | -0.143<br>(-42.5) | -0.172<br>(-7.2) | 0.808<br>(16.8) | -0.07 | 67-82 | 0.950 | 1.12 | 0.0056 |
| Germany | -0.182<br>(-15.3) | -0.203<br>(-3.3) | 0.546<br>(7.3) | -0.07 | 62-82 | 0.767 | 1.06 | 0.0113 |
| France | -0.232<br>(-51.7) | -0.214<br>(-10.1) | 0.864<br>(26.8) | -0.07 | 62-82 | 0.982 | 2.06 | 0.0044 |
| United Kingdom | -0.267<br>(-10.7) | -0.314<br>(-10.0) | 1.244<br>(7.3) | -0.07 | 62-82 | 0.833 | 1.21 | 0.0152 |
| Italy | -0.178<br>(-20.1) | -0.103<br>(-4.2) | 0.651<br>(9.6) | -0.07 | 62-82 | 0.835 | 1.51 | 0.0110 |
| Canada | -0.224<br>(-45.4) | -0.254<br>(-23.3) | 0.596<br>(25.5) | -0.07 | 62-82 | 0.983 | 2.02 | 0.0049 |

1. The coefficient for the inventory variable (KIB(-1)/QSV) is not well determined statistically in the Q/QSV regressions except in the case of the United States. Given the importance of this coefficient for the dynamic behaviour of a complete model in which the Q/QSV equation is imbedded, an intermediate value of -0.07 for $a_3$, falling between the estimates obtained for the two alternative U.S. equations reported in Tables 4 and 7, was imposed on all countries.

## Table 8: Factors contributing to changes in output per employed person

(Based on Harrod-neutral technical progress proceeding at a decelerating rate)
(Average annual rate, per cent)

| Country/ period | Change in normal output per employed person (QSV.CU/NE) | Of which due to: | | Change in rate of capacity utilisation (Q/QSV.CU) | Cyclical factors influencing Q/QSV.CU | | | | | | Unexplained Residual Change in Q/QSV.CU |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | Unanticipated (or temporary) changes in sales | | Unit costs relative to output prices | | Ratio of desired over actual inventories | | |
| | | Growth of labour efficiency (a) | Factor substitution | | Change in Variable | Contribution to change in Q/QSV.CU | Change in Variable | Contribution to change in Q/QSV.CU | Change in Variable | Contribution to change in Q/QSV.CU | |
| Japan | | | | | | | | | | | |
| 1967-1973 | 6.96 | 3.29 | 3.67 | 1.23 | 1.68 | 1.36 | 0.04 | -0.01 | 0.93 | -0.06 | -0.06 |
| 1973-1982 | 2.78 | 1.13 | 1.65 | 0.04 | 0.20 | 0.16 | 1.44 | -0.25 | -0.03 | 0.00 | 0.13 |
| Germany | | | | | | | | | | | |
| 1962-1973 | 4.08 | 2.01 | 2.07 | 0.32 | 0.74 | 0.41 | 1.22 | -0.25 | 0.95 | -0.07 | 0.23 |
| 1973-1982 | 2.57 | 1.19 | 1.38 | -0.57 | 0.16 | 0.09 | 0.64 | -0.13 | 0.68 | -0.05 | -0.48 |
| France | | | | | | | | | | | |
| 1962-1973 | 4.24 | 3.07 | 1.17 | 0.31 | 1.02 | 0.88 | -0.07 | 0.02 | 7.25 | -0.51 | -0.08 |
| 1973-1982 | 2.87 | 1.53 | 1.34 | -0.46 | 0.16 | 0.14 | 2.44 | -0.52 | 2.12 | -0.15 | 0.07 |
| United Kingdom | | | | | | | | | | | |
| 1962-1973 | 2.51 | 1.07 | 1.44 | 0.68 | 0.86 | 1.07 | 1.24 | -0.39 | 0.04 | -0.00 | 0.00 |
| 1973-1982 | 1.95 | 0.82 | 1.13 | -1.40 | -0.41 | -0.50 | 1.99 | -0.63 | 0.07 | -0.00 | -0.27 |
| Italy | | | | | | | | | | | |
| 1962-1973 | 5.00 | 3.16 | 1.84 | 0.42 | 0.88 | 0.57 | 0.70 | -0.07 | -0.97 | 0.07 | -0.15 |
| 1973-1982 | 1.97 | 1.21 | 0.76 | -0.97 | -0.53 | -0.34 | 2.98 | -0.31 | 3.83 | -0.27 | -0.05 |
| Canada | | | | | | | | | | | |
| 1962-1973 | 1.73 | 1.01 | 0.72 | 0.84 | 1.45 | 0.86 | 0.08 | -0.02 | -0.04 | 0.00 | 0.00 |
| 1973-1982 | 1.74 | 0.82 | 0.92 | -1.69 | -1.34 | -0.80 | 3.65 | -0.93 | -0.55 | 0.04 | 0.00 |

(a) Figures shown are computed as the average annual growth rate of the labour efficiency index (over the period specified) multiplied by the equilibrium labour income share (1-a). This implies that labour input and cost are defined in natural rather than efficiency units in the analysis of inter-factor substitution. Defining labour input and cost in efficiency units would result in allocating all of the labour efficiency growth to Column 2, reducing the figures in Column 3 correspondingly.

Table 9: Alternative explanations of the slow-down of the growth of labour productivity between 1962-73 and 1973-82

MI : Model I with technical progress at country specific constant rates.
MII : Model II with technical progress at converging rates.

| | Total slow-down in the average annual rate of growth of GDP per employed person | Of which due to : | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Change in Relative Net Energy Imports | Change in gross output per employed person | | | | | | | | | | | | | | | | | |
| | | | Total slow-down in annual growth of Q/NE | Explained by: | | | | | | | | | | | | | | | | |
| | | | | Change in growth of normal output per employed person | | | | | | Change in rate of capacity utilisation | | | | | | | | | | |
| | | | | Total | | Explained by : | | | | Total | | Explained by : | | | | | | | | |
| | | | | | | Change in growth of labour efficiency | | Factor Substitution | | | | Unanticipated Changes in Sales | | Changes in unit cost/price ratio | | Changes in ratio of desired to actual inventories | | Unexplained Residual Change in Q/QSV | | |
| | | | | MI | MII | MI | MII | MI | MII | MI | MII | MI | MII | MI | MII | MI | MII | MI | MII |
| United States | 1.81 | -0.06 | 1.87 | 0.08 | - | 0 | - | 0.08 | - | 1.79 | - | 1.48 | - | 0.33 | - | -0.10 | - | 0.08 | - |
| Japan* | 5.10 | -0.27 | 5.37 | 2.07 | 4.18 | 0 | 2.16 | 2.07 | 2.02 | 3.30 | 1.19 | 3.24 | 1.20 | 0.34 | 0.24 | -0.21 | -0.07 | -0.07 | -0.18 |
| Germany | 2.03 | -0.37 | 2.40 | 0.71 | 1.51 | 0 | 0.82 | 0.71 | 0.69 | 1.69 | 0.89 | 0.95 | 0.32 | -0.20 | -0.12 | -0.08 | -0.02 | 1.02 | 0.70 |
| France | 2.15 | -0.00 | 2.15 | -0.13 | 1.38 | 0 | 1.54 | -0.13 | -0.16 | 2.28 | 0.77 | 2.23 | 0.75 | 0.73 | 0.54 | -0.46 | -0.36 | -0.22 | -0.16 |
| United Kingdom | 1.74 | -0.90 | 2.64 | 0.31 | 0.56 | 0 | 0.25 | 0.31 | 0.31 | 2.33 | 2.08 | 1.77 | 1.58 | 0.24 | 0.23 | -0.02 | 0.00 | 0.34 | 0.27 |
| Italy | 4.11 | -0.31 | 4.42 | 1.12 | 3.03 | 0 | 1.95 | 1.12 | 1.08 | 3.30 | 1.39 | 2.67 | 0.92 | 0.38 | 0.24 | 0.20 | 0.34 | 0.05 | -0.11 |
| Canada | 2.64 | 0.12 | 2.52 | -0.20 | -0.01 | 0 | 0.19 | -0.20 | -0.20 | 2.72 | 2.53 | 1.87 | 1.66 | 0.91 | 0.91 | -0.05 | -0.04 | -0.01 | -0.00 |

* First period covers 1967 to 1973 only.

*Figure 1* **PRICE AND FACTOR RATIOS FOR CAPITAL AND ENERGY**

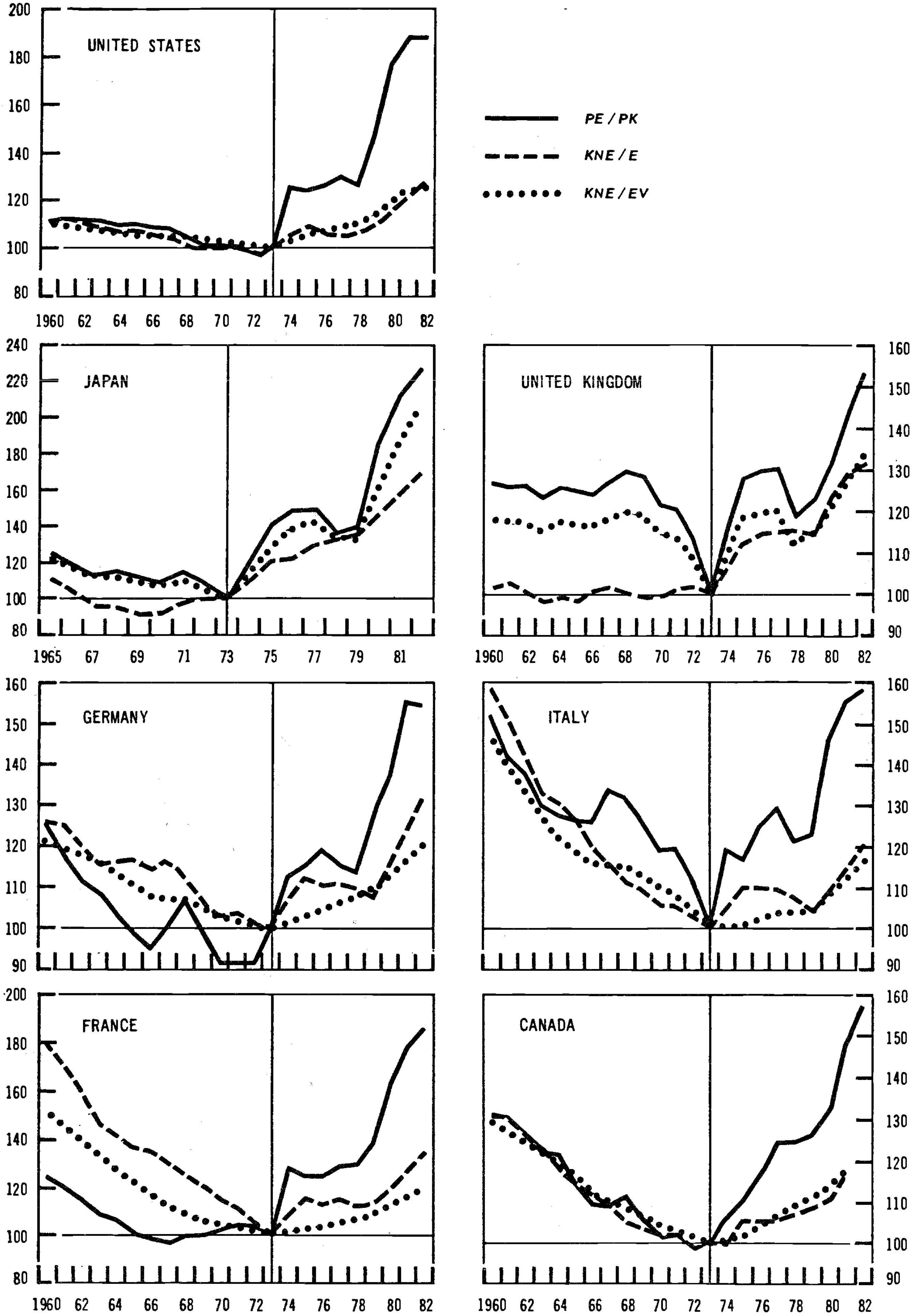
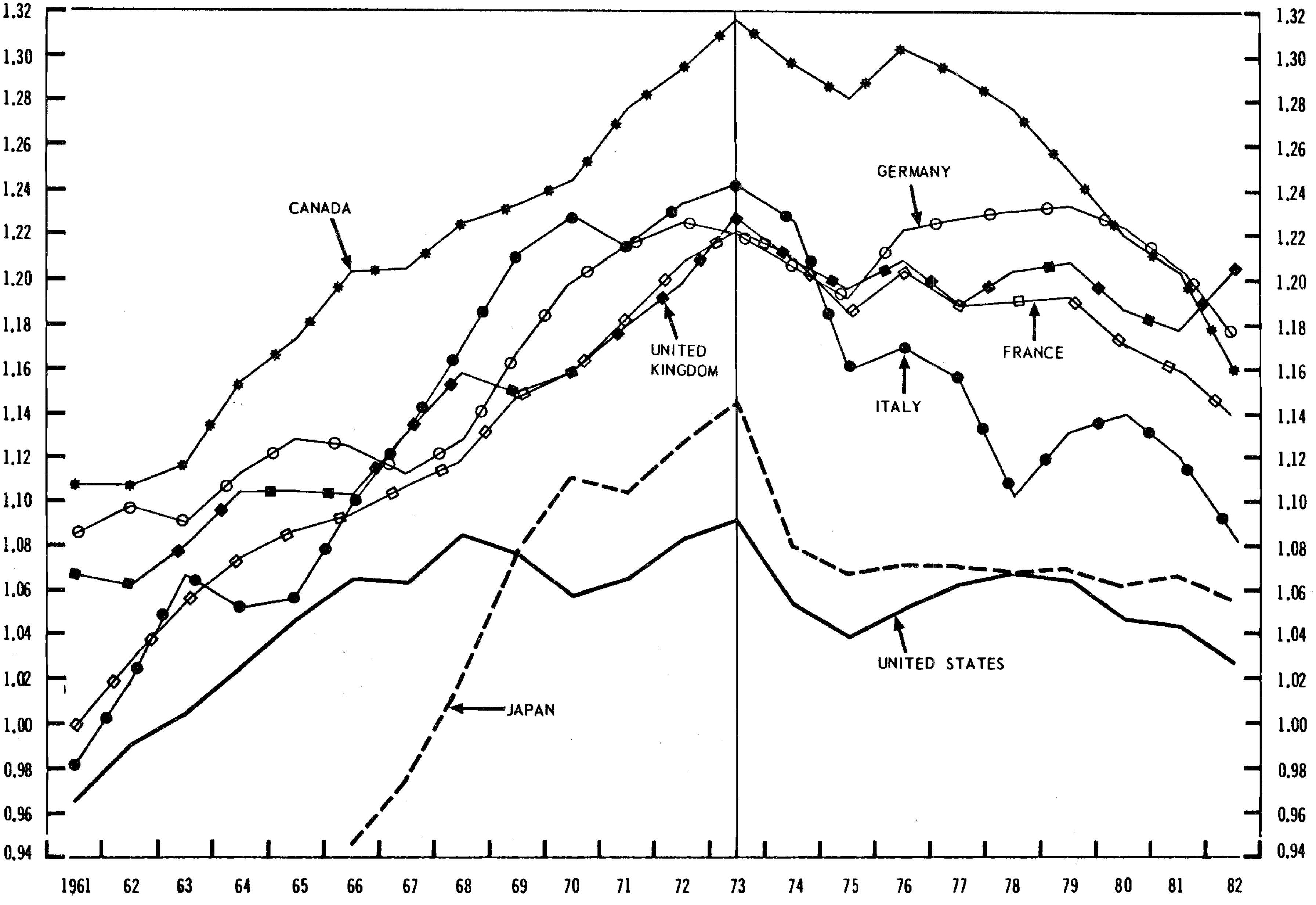


*Figure 2* **RATIO OF SALES TO NORMAL OUTPUT**



## Figure 3 RATIO OF UNIT COSTS TO OUTPUT PRICE

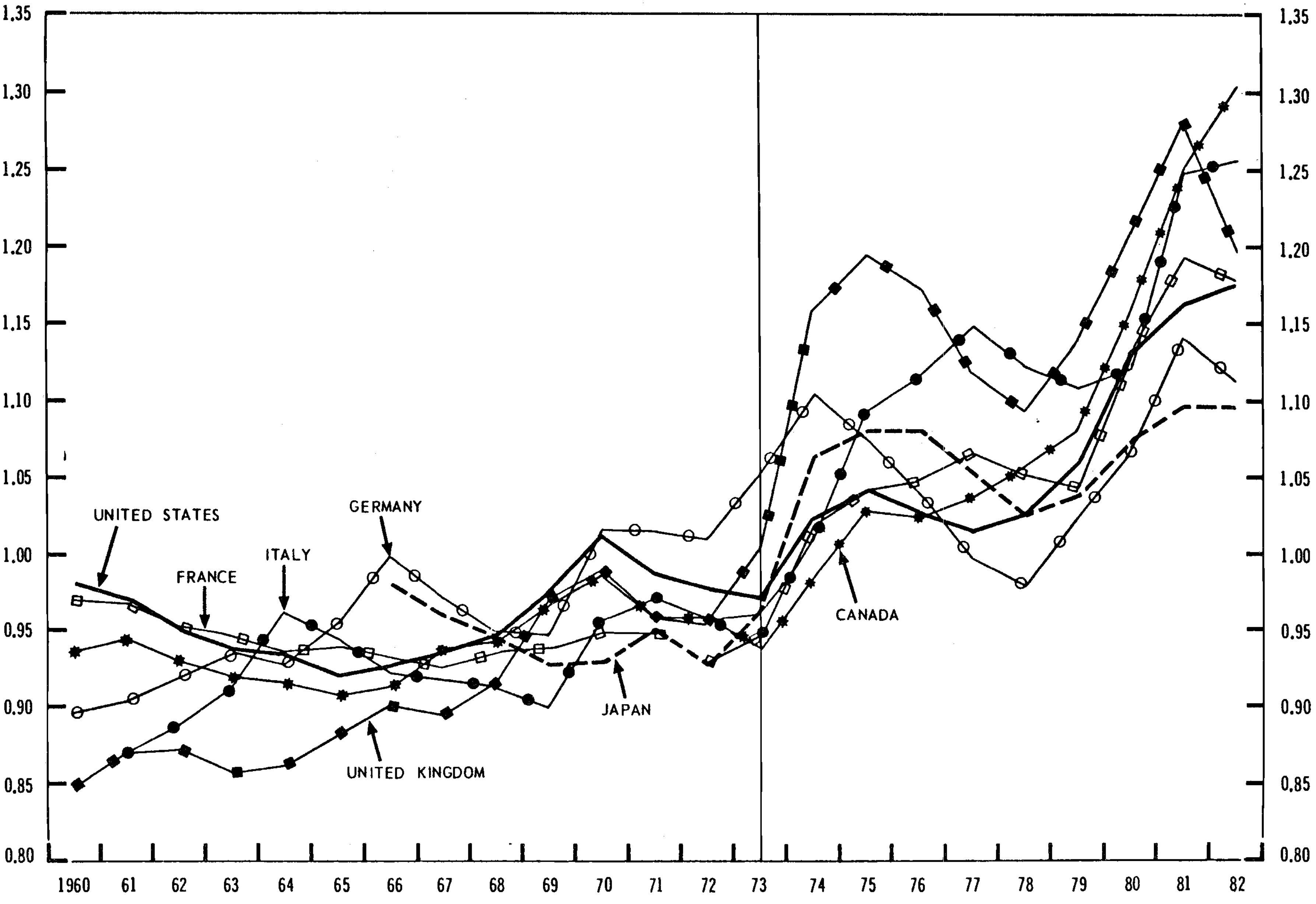
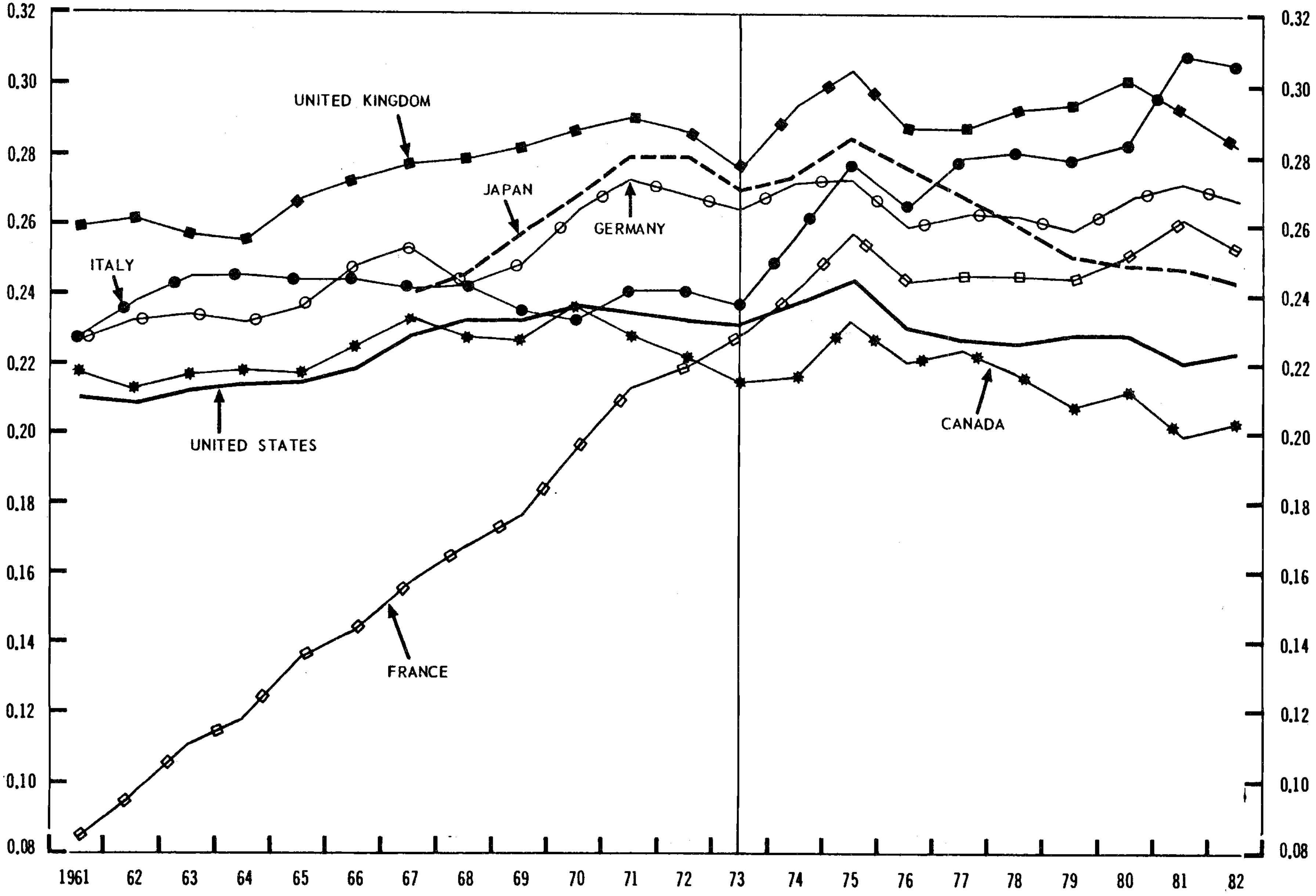


Figure 4 RATIO OF INVENTORIES TO NORMAL OUTPUT



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