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Decoupling Economic Growth and Energy Use. An Empirical Cross-Country Analysis for 10 Manufacturing Sectors

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Abstract
This paper provides an empirical analysis of decoupling economic growth and energy use and its various determinants by exploring trends in energy- and labour productivity across 10 manufacturing sectors and 14 OECD countries for the period 1970-1997. We explicitly aim to trace back aggregate developments in the manufacturing sector to developments at the level of individual subsectors. A cross-country decomposition analysis reveals that in some countries structural changes contributed considerably to aggregate manufacturing energy-productivity growth and, hence, to decoupling, while in other countries they partly offset energy-efficiency improvements. In contrast, structural changes only play a minor role in explaining aggregate manufacturing labour-productivity developments. Furthermore, we find labour-productivity growth to be higher on average than energy-productivity growth. Over time, this bias towards labour-productivity growth is increasing in the aggregate manufacturing sector, while it is decreasing in most manufacturing subsectors.

Keywords: energy productivity, labour productivity, convergence, sectoral analysis
JEL codes: O13, O47, O5, Q43

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1. Introduction

Energy is an essential production factor that fuels economic growth and serves human well-being. Along with unprecedented economic growth, world primary energy use has grown enormously since the middle of the 19th century. The energy crisis of the 1970s and, more recently, the environmental problems associated with economic growth and increasing energy use have made most governments in OECD countries to strive explicitly for sustainable development, aiming to decouple economic growth and environmental pressure. In a more operational sense this implies a need for a simultaneous productivity increase of 'traditional' input factors, such as labour and capital, and of 'environmental' input factors, such as materials and energy.

Over the last decades, a growth accounting tradition has emerged measuring the contribution of various determinants to output- and productivity growth (see, for example, Kendrick 1961; Denison 1967; Jorgenson and Griliches 1967; Maddison 1991; Jorgenson 1995; Wagner and van Ark 1996; van Ark 1997; Barro 1997). This empirical research on productivity growth has focused almost exclusively on labour-, capital- and total factor-productivity growth. Among the main empirical findings are that economic growth depends on a number of interrelated factors such as an increase in the labour force and labour productivity, accumulation of knowledge and capital, institutional factors and – probably most importantly – technological change (see, for example, OECD 2003). More recently, this work has been accompanied by empirical research on energy-productivity or energy-intensity developments and its determinants (see, for example, Jorgenson 1984, 1986; Howarth et al. 1991; Schipper and Meyers 1992; Rosenberg 1994; Miketa 2001). Although this literature is rather diverse in focus, broad consensus exists that both technological change and changes in the production structure are among the most important determinants of long-run increases of energy productivity. In this paper we build upon both perspectives in the literature by simultaneously analyzing energy- and labour-productivity developments across 10 Manufacturing sectors and 14 OECD countries, for the period 1970-1997. In doing so, we put emphasis on an examination of the role of technological change in driving productivity growth of the two production factors energy and labour. Hence, we are able to explore to what extent technology-driven improvements of energy- and labour productivity performance contribute to a decoupling of economic growth and environmental pressure at a detailed sectoral level across the most important OECD countries.

For this aim, we constructed a new database to establish a link between economic and energy data at a detailed sectoral level for a range of countries. A brief description of this dataset is given in Section 2. The level of sectoral detail in our dataset allows us to trace back aggregate manufacturing energy- and labour-productivity trends to developments at the level of individual sectors. In Section 3 we document several stylised facts on the levels and trends in manufacturing energy- and labour-productivity performance, examining the role of the different manufacturing subsectors. As noted previously, observed aggregate productivity trends are not directly attributable to technological change in individual sectors, but also the result of changes in the production structure, i.e., of changes in the distribution of production factors among different sectors. The underlying reason is that some sectors produce more value added per unit of input (energy or labour) than others, because some activities require more capital, higher labour skills and/or technology than others. Our data show that across OECD countries, the manufacturing sector is characterised by a very heterogeneous production structure. Hence, understanding technology-driven productivity performance requires an assessment of productivity developments in individual sectors (see also, for example, Dollar and Wolff 1993; Wagner and van Ark 1996; Jorgenson 1984). In Section 4 we therefore decompose per country the aggregate manufacturing energy- and labour productivity growth into a part due to shifts in the underlying sectoral structure and into a part caused by technology-driven efficiency improvements in individual sectors. In several respects, our decomposition differs from other decomposition studies (e.g., van Ark 1996; Unander et al. 1999), most notably by the combination of a relatively high level of sectoral detail with a wide range of countries, a simultaneous exploration of productivity performance along the two dimensions of energy and labour, and a detailed calculation per country of the percentage contribution of each manufacturing sector to structural changes and efficiency improvements at the level of aggregate manufacturing.

Finally, by documenting the relation between energy- and labour-productivity growth rates we touch upon the issue of the direction of technological change. The idea that the nature of technological progress might be factor-augmenting, depending on relative factor prices and substitution possibilities, goes back to Hicks (1932) and received attention in the theoretical and empirical literature on technological change and factor-productivity developments ever since (see, for example, Kennedy 1962; Binswanger 1974a,b; Acemoglu 2002; Ruttan 2001). Recently, the issue has also been addressed in the context of environmental policy and energy use, examining a price- or product-standard induced bias towards energy-saving technological change (see, for example, Newell et al. 1999; Smulders and de Nooij 2003; Taheri and Stevenson 2002). An important hypothesis in this respect is that if all technological efforts are directed towards an increase in labour productivity, energy productivity improvements might slow down because of lack of resources devoted to increasing energy efficiency – and vice versa. In Section 5 we provide some empirical evidence on the existence and development of a potential bias towards either energy- or labour productivity improvements, which might reflect biases of technological change at the level of individual sectors. Section 6 concludes.

2. Data

The analysis presented in this paper is based on a newly constructed database that merges energy data from the Energy Balances, as they are published by the International Energy Agency (IEA), and economic data from the International Sectoral Database (ISDB) and the Structural Analysis Database (STAN), both published by the OECD. The main idea behind the construction of this database is to establish a link between economic and energy data at a detailed sectoral level. This results in the sector classification as described in Table 1.

< Insert Table 1 around here >

The database covers the period 1970-1997 and includes the following countries: Australia (AUS), Belgium (BEL), Canada (CAN), Denmark (DNK), Finland (FIN), France (FRA), West-Germany (WGR), Italy (ITA), Japan (JPN), the Netherlands (NLD), Norway (NOR), Sweden (SWE), United Kingdom (GBR) and the United States (USA).

We measure energy productivity by gross value added per unit of final energy consumption and labour productivity by gross value added per worker (in full time equivalents). Value added is the net economic output of a sector, measured by the price differential between the price of output and the cost of input and comprises compensation to employees, operating surplus, the consumption of fixed capital and the excess of indirect taxes over subsidies (OECD 1998). Following the IEA, energy use is defined as final energy consumption in kilo tonnes of oil equivalence (ktoe),[2] with sectoral data excluding transformation losses. Total employment is measured in the full-time equivalent number of persons, including self-employed.

[2] Hence, we do not analyse explicitly the impact of changes in fuel mix on overall energy-efficiency improvements.

The value-added data have been converted to constant 1990 US$, using 1990 expenditure purchasing power parities (PPP) as given by the OECD. In principle the theoretically most appropriate conversion factors for productivity comparisons at the sectoral level are to be based on a comparison of output prices by industry of origin, rather than on expenditure prices (e.g., van Ark and Pilat 1993).[3] The main problem in using the production or industry-of-origin approach, however, is the limited availability of producer-price based PPPs, in particular for non-Manufacturing sectors (van Ark 1993).[4] Hence, most studies including cross-country productivity comparisons use expenditure PPPs. Moreover, for an international comparison the main issue is whether there are substantial cross-country differences with respect to the drawbacks of expenditure PPPs as outlined above. We have no a priori reason to presume that these cross-country differences are substantial. Therefore, in this study we use expenditure PPPs, enabling a systematic cross-country analysis of energy- and labour-productivity performance at a high level of sectoral detail. Obviously, because of these issues, the results reported in this paper should be interpreted with caution.

In general, it holds for each analysis of productivity developments that the lower the level of aggregation the better, but that an adequate distinction between factor-intensive and factor-extensive sectors is even more important. In this respect, it is to be noted that our Chemicals sector is defined at a rather aggregated level. Chemicals is built up from the energy-intensive sub-sector Industrial Chemicals (ISIC 351, including basic industrial chemicals, fertilizers, pesticides and main plastic products) and the energy-extensive sub-sector Other Chemical Products (ISIC 352, including paints, drugs and medicines, cosmetics

[3] The drawbacks of expenditure PPPs are: (i) they exclude the part of output that is exported, while they include imported goods produced elsewhere; (ii) they take account of differences in trade and transport margins and indirect taxes between countries; and (iii) they do not cover intermediate products.
[4] This limited availability is due to some problems inherent to the industry-of-origin approach: producer prices (i.e., production values divided by output quantities) may not properly account for cross-country quality differences and imply aggregation problems for they are available only for a sample of goods (partly because of confidentiality problems), and because the production structure among countries tends to be less comparable than the consumption structure due to specialization tendencies in production according to comparative advantage (Pilat 1996).

and cleaning products). Until consistent and internationally comparable energy and economic data become available for a more detailed breakdown of the chemical sector, this problem will persist and energy-productivity figures for the sector Chemicals should be interpreted with caution.

Finally, for the USA the IEA Energy Balances unfortunately provide no sectoral breakdown for the consumption of oil products and natural gas within Manufacturing until 1995. Instead, these volumes are included in the sector Non-Specified Industry (NSI) and, hence, they are available only at the level of the aggregate Manufacturing sector. For this reason, for the different USA Manufacturing sub-sectors, we neither include data from 1995 onwards nor do we report *levels* of energy consumption. We do, however, calculate energy-productivity growth rates for the different USA Manufacturing sub-sectors, with final energy consumption defined as the sum of only Coal and Electricity consumption, under the assumption that the share of the sum of oil and gas in final energy consumption is more or less constant over time. Hence, the documented growth rates of energy productivity for the breakdown of the USA Manufacturing sector should be interpreted with caution.

3. Stylized Facts

Economic development typically involves a change in the sectoral composition of economies, with the industrialisation process inducing a shift from the Agricultural sector towards Industry, followed by a deindustrialisation phase increasing the importance of the Service sector (e.g., Baumol 1967; Maddison 1991, 1999; de Groot 2000). Moreover, in the OECD countries the Transport sector tends to overtake the Manufacturing sector as the largest consumer of final energy (Schipper and Meyers 1992). Nevertheless, within the OECD the Manufacturing sector is still responsible for about 40% of total final energy consumption and 25% of total employment (UN 2001). We start our analysis by presenting several stylised facts on the aforementioned issues, in order to illustrate the possible implications for decoupling economic growth and energy use. For this aim we plot in Figure 1 for each country in our dataset the development over time of the levels of GDP, final energy consumption and total employment in the aggregate manufacturing sector (normalised at 100 in the initial year of the sample).

< Insert Figure 1 around here >

From the figure it can be seen that in all countries manufacturing value added has increased while in virtually all countries total manufacturing employment has been declining. Concerning energy consumption the picture is diverse: in Denmark, the United Kingdom and the USA it has been falling, in Australia, Canada, Finland and Japan it has increased, while in all the other countries the level of final energy use has been more or less constant over time. Moreover, except for Norway, even in those countries showing increasing total manufacturing energy use, the growth in energy consumption has been outpaced by growth in value added, implying an increase in manufacturing energy productivity. In other words, while delinking of economic growth and energy use in the manufacturing sector is absolute (‘strong decoupling’) in Denmark, the United Kingdom and the USA, most countries show a pattern of relative delinking (‘weak’ decoupling).

To compare the development of manufacturing energy- and labour-productivity performance across the different countries, we show in Figure 2 and 3 the aggregate manufacturing energy- and labour-productivity levels over time, for each of the 14 OECD countries in our dataset. Figure 2 shows that in aggregate manufacturing two groups of countries can be identified in terms of observed levels of energy productivity. Denmark, Italy, West-Germany, France, Japan and the United Kingdom show a high level of energy productivity while the USA, Netherlands, Belgium, Sweden, Australia, Finland, Canada and Norway display a relative low energy-productivity level.[5] Figure 3, confirms again the well-known leading position of the USA in terms of labour productivity. It also shows that there is no clear pattern of catching-up by other OECD countries.

< Insert Figures 2 and 3 around here >

As previously noted, aggregate trends prevent a good understanding of sectoral dynamics, in particular in case of a high degree of sectoral heterogeneity. Hence, we continue by examining the role of the 10 manufacturing sub-sectors (see Table 1) in driving these aggregate developments. To illustrate the structure of the manufacturing sector, we first give a brief overview of their shares in Manufacturing energy consumption, employment and GDP (see Figure 4). For the 14 OECD countries included in this study taken together, the sub-sector Chemicals consumed by far most energy with a share of 40% in Manufacturing final energy consumption in 1990, followed by Iron and Steel (16%), Paper, Pulp and Printing (11%) and Non-Metallic Minerals (9%).[6]

< Insert Figure 4 around here >

In Figure 4 we compare those shares with the shares of total employment and value added.[7] This yields a different picture, with Machinery accounting for the largest share of

[5] For the same sample of countries but using energy consumption data from partly different sources, Unander et al. (1999) distinguish 3 groups of countries for Manufacturing energy-intensity, which differ slightly from our picture by classifying the Netherlands, Sweden and the USA in a medium-group.
[6] These percentages are in line with IEA data of total OECD in 1997: Chemicals: 39%; Iron and Steel: 11%; Paper: 10%; Non-Metallic Minerals: 9%.
[7] Note that Manufacturing sector shares of value added are calculated for the sum of 12 OECD countries (excluding Australia and Canada due to lack of data).

manufacturing total employment and value added (35-37%) followed by Food and Transport Equipment (each around 12%). These sectoral shares, however, differ substantially among the different OECD countries under consideration. For example, in the Netherlands, the energy-intensive Chemical sector is responsible for 67% of manufacturing energy consumption, while in the other countries this share lies between 14% and 38%. In Finland and Sweden, Paper consumes around 40% of manufacturing energy consumption, while in the other countries this share lies in between 3% and 14%. Contrary to other countries, in Italy Textiles is responsible for a large share of total employment and value added.[8] In other words, the manufacturing sector is characterised by a substantial degree of heterogeneity concerning the underlying production structure, which underlines the relevance of taking a sectoral approach in examining its development of productivity over time.

Next, in order to see which Manufacturing sectors drive the observed aggregate trends, we provide in Table 2 for all 10 Manufacturing sub-sectors a cross-country comparison of the energy- and labour productivity level relative to the weighted OECD average in 1976, 1982, 1990 and 1997.[9] The table reveals that the energy-productivity level in Germany and Japan lies above the OECD average in most Manufacturing sectors, while the opposite is true for a country like Norway. Concerning labour productivity, Table 2 again confirms the well-known leading position of the USA for most manufacturing sectors. Exceptions, however, are Non-Ferrous Metals and Non-Metallic Minerals, where the USA is lagging behind some other countries. For most countries, however, the table shows a diverse picture with considerable cross-sector variation in relative productivity performance. For example, the high energy-productivity level in Denmark, as shown in Figure 2, is due to an extremely high energy-productivity level in Chemicals and Paper, while its energy-productivity level in Food

[8] For a detailed overview of Manufacturing sector shares per country, we refer to Table A.1 in Appendix A.
[9] Note that we do not take the USA as the reference country because the USA lacks a sectoral breakdown of oil and natural consumption at this level of disaggregation (see Section 2).

is relatively low. The Netherlands are characterised by a relatively low level of energy productivity in Chemicals, but a relatively high energy-productivity level in Paper and Wood. Moreover, it shows a high labour-productivity level in Non-Ferrous Metals, while the converse holds for Transport Equipment. A few other remarkable facts are: Finland, Norway and Sweden have low levels of energy productivity in Paper and Wood; the United Kingdom has a relatively high level of energy productivity in Chemicals, Iron and Steel and Paper, while this is relatively low in Machinery; and Italy has a very high level of energy productivity in Wood.

< Insert Table 2 around here >

Looking at the standard deviation of the log of relative energy productivity in Table 2 leads to the conclusion that the cross-country differences in energy productivity are substantially larger than cross-country differences in labour productivity. Moreover, we find cross-country differences in labour-productivity performance to be slightly decreasing. Cross-country dispersion of energy productivity is increasing in the energy-intensive sectors Chemicals, Iron and Steel and Non-Ferrous Metals, while it is (more or less) constant in Chemicals, Paper and Wood and decreasing in the other sectors. All this points to considerable country specific dynamics concerning the use of energy and labour in manufacturing production.

To see what this implies for delinking economic growth and energy use at the sectoral level, we summarize in Figure 5 per country the total percentage change of the level of GDP, final energy use and total employment over roughly the period 1970-1997.[10]

[10] Note that similar to Figure 1 the exact periods differ per country, due to limited data availability. Also for this reason Australia and Canada are not included in Figure 5.

< Insert Figure 5 around here >

The figure leads to the following observations. First, absolute decoupling of economic growth and energy use is concentrated in a number of energy-intensive sectors, such as Iron and Steel (Belgium, West Germany and Denmark), Non-Metallic Minerals (Finland, West Germany, Italy) and Chemicals (Denmark, Italy); but also in Machinery (Denmark, Norway, Sweden) and Transport equipment (Finland, France, Netherlands, United Kingdom, USA). Second, all three countries that showed absolute decoupling at the aggregate manufacturing level in Figure 1 – Denmark, United Kingdom and the USA – are characterised by a relatively high increase in value added of the chemical sector. This might well be due to a pattern of specialisation away from the energy-intensive sub-sector Industrial Chemicals. Third, in these countries delinking is due to decreasing energy consumption in a range of sectors, most notably Iron and Steel, Non-Metallic Minerals and Transport Equipment; in addition, the USA shows a particularly high increase of value added in the large Machinery sector (cf. Figure 4). Fourth, the increasing manufacturing energy consumption in Finland (see Figure 1) is concentrated in a few energy-intensive industries: Chemicals, Iron and Steel, Non-Ferrous Metals and Paper. Fifth, the large increase in the Italian manufacturing value added (see Figure 1) is caused by value-added growth in a range of sectors, particularly in Chemicals and Machinery. Finally, despite considerable cross-country differences in sectoral dynamics, a few common patterns can be observed. For example, Iron and Steel and Textiles (except for Italy) are declining sectors in most countries, as can be seen from the simultaneous decrease of energy, labour and GDP levels. The next section is devoted to a further exploration of the impact of such structural changes on energy- and labour productivity growth, in comparison with the impact of efficiency improvements at the sectoral level.

4. Decomposing productivity growth rates

As we have argued in section 1, overall productivity performance not only results from technology-driven productivity performance in individual sectors, but also from the distribution of production factors among sectors. Therefore, in this section we will correct trends in aggregate energy- and labour-productivity performance for the impact of shifts in sectoral energy- and employment shares, to get a better view on the role of sector-specific technology-driven productivity improvements in driving aggregate productivity growth.

We do so by using a decomposition- or shift-share analysis, which is based on the following definitions of, respectively, aggregate energy productivity and labour productivity:

$$\frac{Y_t}{E_t} = \sum_i \frac{Y_{i,t}}{E_{i,t}} \frac{E_{i,t}}{E_t} \tag{1}$$

$$\frac{Y_t}{L_t} = \sum_i \frac{Y_{i,t}}{L_{i,t}} \frac{L_{i,t}}{L_t} \tag{2}$$

with Y_t, E_t and L_t being, respectively, GDP, final energy consumption and total employment, and the subscript i denoting the sub-sector. So, equation (1) says that aggregate energy productivity is the sum of the energy productivity of each sub-sector (the first term at RHS) multiplied by the energy share of each sub-sector (the second term at RHS). Equation (2) defines the same relationship in terms of labour productivity. Building upon equations (1) and (2), we decompose aggregate energy- and labour-productivity growth into a structural effect and an efficiency effect. The structural effect is obtained by calculating aggregate energy- and labour-productivity growth insofar as it is caused by shifts in sectoral energy- and employment shares (the second term at RHS), keeping the levels of energy- and labour-productivity performance for each individual sub-sector (the first term at RHS) constant. Vice versa, the efficiency effect is obtained by calculating aggregate energy- and labour-productivity growth insofar as it is caused by changes in the energy- and labour-productivity performance within each individual sub-sector, keeping the sectoral energy- and employment shares constant. Hence, the structural effect indicates the effect of changes in the structure of production on aggregate productivity growth while the efficiency effect points to the role of technology-driven efficiency improvements.

Many studies have measured the relative contribution of structural and technological change to aggregate productivity growth, using so-called index number decomposition or shift-share analysis. The studies differ from each other in several dimensions, including the number of sectors and countries included, the methodology (Laspyeres, Paasche, Divisia, etc.), the area of application (TFP, capital, labour, energy), the type of indicator (quantity, intensity, productivity or elasticity) and the type of analysis (time-series or period-wise). For a lucid exposition of the methodology and a survey of studies on (total factor) productivity we refer to Syrquin (1984) and Balk (2001), as well as to Ang (1995a, 1995b, 1999) and Ang and Zhang (2000) for applications in the context of energy studies.[11]

In this study we have chosen for time-series analysis, the additive technique and the so-called Refined Divisia Method (RDM). We have chosen to use the RDM because this method gives, contrary to the other methods, perfect decomposition irrespective of the pattern exhibited by the data and leaving no residual term. Moreover, this method has the advantage that it can handle the value zero in the data set effectively, while the other methods cannot. We have chosen to use the additive technique because we are interested in decomposing the absolute change in energy- and labour productivity, rather than a relative change. The main

[11] For early applications of this methodology to measure the impact of technological change and changes in labour and/or capital shares on aggregate (total factor productivity) growth see, for example, Maddison (1952) and Massell (1961). For recent applications, including cross-country comparisons, see Dollar and Wolff (1993), van Ark (1996) and Fagerberg (2000). Cross-country decomposition analyses of energy use can be found, for example, in Greening et al. (1997), Howarth et al. (1991), Schipper and Meyers (1992), Park et al. (1993), Eichhammer and Mannsbart (1997) and Unander et al. (1999).

value added of our study lies in a simultaneous exploration of productivity performance along the two dimensions of energy and labour for 14 OECD countries over about 25 years. Moreover, compared to most other studies our analysis comprises a relatively high level of sectoral detail for a relatively large number of countries, in particular in terms of energy-productivity developments. As a result, the changes in technology-driven productivity performance at the level of individual sectors reported here are relatively well specified and informative. Furthermore, our data set enables us to apply a time-series approach whereas most cross-country studies conduct a period-wise approach, using only data for the first and the last year of a specified time period. Compared to a period-wise approach, a time-series approach yields more insight into energy-productivity development over subsequent years and, moreover, the decomposition results are less sensitive to the exact functional form used and to the values in the initial- and final year.

In Figures 6 and 7 we present the results of the decomposition of the aggregate manufacturing energy- and labour productivity growth rates into a structural effect and an efficiency effect.[12] It is to be noted that one has to be careful with comparing the results between countries due to the different time periods used (because of data availability).

< Insert Figures 6 and 7 around here >

Figure 6 shows that in all 12 OECD countries energy-efficiency improvements are the main driving force behind aggregate manufacturing energy-productivity growth, although in most countries there is also a substantial effect from shifts in sectoral energy shares on aggregate manufacturing energy-productivity growth. This structural effect is mixed: it is positive in

[12] Due to limited data availability, Australia and Canada are excluded from the analysis. Moreover, for the same reason in France, Japan, United Kingdom and USA the sector Wood and in Denmark the sector Non-Ferrous Metals are excluded from the decomposition analysis.

Belgium (41%), Denmark (11%), France (47%), West-Germany (20%), Italy (37%), Japan (33%) and the USA (35%), indicating a shift towards a less energy-intensive Manufacturing structure, while it is negative in Finland (-50%), the Netherlands (-30%), Norway (-960%) and Sweden (-12%), indicating a shift towards a more energy-intensive manufacturing structure. In Norway the large structural change even dominates the energy-efficiency improvements.

This overall picture accords well with other cross-country studies decomposing manufacturing energy use in OECD countries (Greening et al. 1997; Howarth et al. 1991; Eichhammer and Mannsbart 1997; Unander et al. 1999), although our structural effects in Finland, France and Italy are relatively high as compared to these studies. This might well be due to differences in data, period and decomposition method between the other studies and ours.[13] Concerning labour-productivity growth, Figure 7 shows that in all 12 OECD countries the effect of shifts in sectoral employment shares on aggregate Manufacturing labour-productivity growth is positive, but also very small; almost all aggregate Manufacturing labour-productivity growth is to be explained from labour productivity improvements in individual sectors. This result confirms what has been known from empirical labour-productivity analyses for the Manufacturing sector (see, for example, Dollar and Wolff 1993 and Fagerberg 2000). Finally, except for Denmark and the USA, the average manufacturing labour-productivity growth is higher than manufacturing energy-productivity growth. We calculated that for the 12 OECD countries taken together the weighted average annual growth rates of Manufacturing energy- and labour productivity are, respectively, 2.25% and 2.69%,

[13] The results depend to some extent also on the level of aggregation. As noted in Section 2, the higher the level of disaggregation the better, but even more important is an adequate distinction between factor-intensive and factor-extensive sectors in order to reduce the likelihood of efficiency-performance figures being biased by the impact of intra-sectoral structural changes. However, in a European cross-country decomposition analysis of energy-efficiency in the Manufacturing industry, Eichhammer and Mannsbart (1997) concluded that, apart form data-related methodological problems, an analysis at a 2-digit level suffices to isolate the main structural effects on aggregate productivity developments. After disaggregating several energy-intensive sectors to a 4-digit level, they found intra-sectoral structural changes to be responsible for at maximum 10% of the observed aggregate energy-intensity changes.

while they drop to, respectively, 1.57% and 2.53% after being corrected for the impact of structural changes.

To see which sectors are responsible for these aggregate results, we split the percentage contribution of the total efficiency effect and the total structural effect to the aggregate productivity growth rates, as presented in Figures 6 and 7 respectively, into the percentage contribution of individual sub-sectors. The results are presented in Tables 3 and 4.

< Insert Table 3 around here >

From Table 3 it can be concluded that, except for France, the aggregate manufacturing energy-productivity improvements are to a large extent realised within the Machinery sector, followed by Chemicals.[14] Looking into the sources of structural changes yields a more diverse picture. In Belgium, the substantial positive structural effect on aggregate manufacturing energy-productivity growth is mainly caused by a shift of the energy share from Machinery, Iron and Steel, Non-Ferrous Metals and Non-Metallic Minerals towards Chemicals, Food, Transport Equipment and Paper. The small positive structural effect in Denmark is mainly the result of a relatively small increasing energy share in Food and Machinery and decreasing energy shares in Textiles, Transport Equipment, Non-Metallic Minerals and Iron and Steel, while the role of Non-Ferrous Metals is unclear due to lack of data. The substantial negative impact of structural changes on aggregate manufacturing

[14] Note that in France, Norway and in particular in the Netherlands a substantial part of the efficiency improvement is realised within the sector Non-Specified Industry (NSI). The same holds for structural changes in Italy, Norway and, again particularly, in the Netherlands. NSI contains rubber (355) and plastic products (not classified elsewhere) (356), furniture (332) and professional, scientific, measuring and controlling equipment (not classified elsewhere), photographic and optical goods (385). Furthermore, it contains energy consumption for which no sectoral breakdown can be given. Whereas NSI is rather unimportant in most countries with an average share of 2% of total energy consumption, in the countries mentioned before the share of NSI in Manufacturing GDP is on average about 12%. In sum, one should read the results with caution since an efficiency improvement and a changing energy share in NSI is partly due to developments in the above mentioned sectors (ISIC 355, 356, 332 and 385) and might be partly due to data inaccuracy.

energy-productivity growth in Finland is to a large extent caused by a shift in energy share from Machinery, Food, Transport Equipment and Textiles towards Paper, Non-Specified Industry, Iron and Steel and Chemicals. In France the positive structural effect is mainly due to a shift of energy shares from Textiles, Iron and Steel and Transport Equipment towards Machinery, Paper and Food. In West Germany an increasing energy share in Machinery and Chemicals at the cost of a decreasing energy share in Iron and Steel, Textiles and Non-Metallic Minerals mainly causes the positive structural effect. The positive structural effect in Italy has been mainly due to a shift of energy shares from Non-Metallic Minerals and Iron and Steel towards Machinery, Non-Specified Industry, Food and Textiles. In Japan the structural changes towards a less energy-intensive manufacturing structure were mainly driven by a shift towards Machinery and Transport Equipment, while energy shares decreased in Textiles, Foods, Iron and Steel and Non-Metallic Minerals. The negative structural effect in the Netherlands is the result of a shift in energy shares from Non-Specified Industry, Chemicals, Transport Equipment and Paper towards Machinery and Iron and Steel. The major negative structural effect in Norway is mainly driven by a shift in energy shares towards Chemicals and Paper at the cost of decreasing energy shares in Machinery, Food, Transport Equipment and Non-Metallic Minerals. The negligible impact of structural changes in the United Kingdom is mainly due to the fact that a slight increase in energy shares in Chemicals, Food and Paper outweighs a slight decrease in energy shares in Non-Metallic Minerals, Transport Equipment and Iron and Steel. In the USA a shift in energy share from Iron and Steel towards Machinery and Chemicals has been the main driving force behind the role of structural changes in improving aggregate Manufacturing energy-productivity improvement.

These findings confirm that in general a positive effect of total structural change on aggregate manufacturing energy-productivity growth is to a large extent driven by a shift in energy shares from low-value added (energy-intensive) sectors – such as Iron and Steel, Non-Ferrous Metals and Non-Metallic Minerals – to higher value added (capital- and/or technology-intensive) industries – such as Machinery, Transport Equipment, Textile and Food – while the opposite is true in case of an overall negative structural effect. Our results suggest, however, a few exceptions to this picture. For example, Belgium realises an overall positive effect of structural changes on aggregate manufacturing energy-productivity growth in spite of a substantial decreasing energy share in the high value added Machinery sector, while the same applies for France and Japan with respect to Textiles. Moreover, Belgium, West Germany, Japan and the USA, combine an increasing energy share in the energy-intensive Chemical sector with an overall positive structural effect while the Netherlands combine a decreasing energy share in Chemicals with an overall negative structural effect. A similar story is true for the Paper sector: Belgium and France combine a substantial increase in energy share in the energy-intensive sector Paper with an overall positive structural effect, while the opposite is true for the Netherlands, which realises an overall negative structural effect in spite of a shift away from Paper. Of course, these counter-examples can be explained from the simple fact that shifts in energy shares in one sector are sufficiently compensated by shifts in other sectors. Moreover, they might be due to data limitations, partly because in some countries (in particular Italy and the Netherlands) a significant role is played by Non-Specified Industry and partly because of the fact that the 2- and 3-digit sector definitions that were used hide heterogeneity in production structure at the 4-digit level.[15]

[15] Recall that the Chemicals sector is built up from the energy-intensive sub-sector Industrial Chemicals (ISIC 351) and the energy-extensive sub-sector Other Chemical Products (ISIC 352). Similarly, the Paper sector is built up from the energy-intensive Paper and Pulp sector (ISIC 341) and the energy-extensive Printing sector (ISIC 342. Hence, the observed shifts in energy shares might be characterised as intra-sectoral shifts. For example, it is known that in the Netherlands the share of Industrial Chemicals in the Chemical industry has been substantially reduced over time (CPB 2000: 63-68). As noted before, until consistent and internationally comparable energy and economic data become available for a more detailed breakdown of these sectors, the decomposition results should be interpreted with caution.

Finally, In Table 4 we present a similar breakdown of the total structural- and efficiency effect as in Table 3, but now for labour productivity.

< Insert Table 4 around here >

Table 4 shows that, as for energy productivity, the aggregate manufacturing labour-productivity improvements are to a large extent realised within the Machinery sector. Moreover, the table shows that, although in all countries there is only a very limited impact of structural changes on aggregate Manufacturing labour-productivity growth, this does not imply that there were no changes in employment mix. It can be seen that the main structural change consisted of a decreasing employment share of the labour-intensive sector Textiles (except for Italy) and an increasing employment share of the capital/technology intensive sector Machinery (except for Belgium). Moreover, in most countries this shift is accompanied by a shift in employment from Iron and Steel towards Chemicals, Food and Paper.

5. Sectoral biases in productivity growth rates

As a final step in our analysis, in this section we take a closer look at the relation between growth rates of energy- and labour productivity. For this aim we calculated for each manufacturing sector the average annual growth rates of energy- and labour productivity per country for the period 1970-1997. They are presented in Figure 8 together with 2 regression lines through the origin, estimating the relationship between energy- and labour-productivity growth rates for, respectively, the periods 1970-1982 and 1982-1997.[16]

[16] Note that the exact period differs for each country due to data restrictions. We refer to Tables A.2 and A.3 in Appendix A for an overview of the periods used per country, the sectoral growth rates per country (the same as in Figure 8, but then in tabular format) as well as the weighted average sectoral growth rates for the sum of the OECD countries included in this study.

< Insert Figure 8 around here >

This leads to the following three conclusions. First, overall a positive correlation exists between energy- and labour productivity growth rates, suggesting energy- and labour-productivity growth to be complements rather than substitutes. There are, however, a few exceptions. In several sectors, most notable in Transport Equipment, and Paper and Wood, several countries combine a positive labour-productivity growth rate with a negative growth rate in energy productivity. Second, labour-productivity growth is in general higher than energy-productivity growth, suggesting the existence of a bias towards labour-augmenting technological change. Third, over time, this bias towards labour-productivity growth is decreasing in all manufacturing sectors except for Paper: in this sector the regression line for the period 1982-1997 is steeper than those for the period 1970-1982. This result is in contrast with the increasing bias towards labour-productivity growth, which we found at the level of aggregate manufacturing and, hence, underlines the relevance of productivity analysis at a disaggregated level.

The overall positive relationship between energy- and labour-productivity growth rates may suggest that technological change is embodied in new capital goods which perform better than older capital goods in multiple dimensions, including a better performance in terms of both labour- and energy productivity. This hypothesis assumes that knowledge is more or less a public good as a result of which the most recent capital goods embody state-of-the art technology in different dimensions. If this is true, firms and sectors investing in new capital goods in order to expand or replace existing production facilities or to increase labour productivity, invest at the same time in energy-saving technological change. However, more precise conclusions concerning these issues require a better insight in the nature of technological change through microeconomic research (see, for example, Newell et al. 1999), which is beyond the scope of this paper.

6. Conclusions

Technological change plays a crucial role in decoupling economic growth and environmental pressure. Technology-driven productivity growth is an important source of economic growth and plays an important role in realising this decoupling, for example, through increasing energy productivity. Against this background, we empirically examined in this paper the energy- and labour-productivity performance in 14 OECD over the last decades, covering the period 1970-1997 and distinguishing 10 manufacturing sectors. A principal aim of this paper was to trace back aggregate manufacturing productivity developments to developments at the level of these manufacturing subsectors.

At the level of aggregate manufacturing we found that in all OECD countries value added has increased while in virtually all countries total manufacturing employment has been declining, implying increasing labour productivity. Our data confirm the well-known leading position of the USA in terms of labour productivity, while there is no clear pattern of catching-up by other OECD countries. With respect to manufacturing final energy consumption the picture is diverse, with energy use having increased in some countries while it has been falling in others. Nevertheless, except for Norway, in all studied OECD countries aggregate manufacturing energy productivity has increased over time (due to the relatively high growth in value added). Moreover, cross-country differences in energy productivity are found to be substantially larger than cross-country differences in labour productivity.

Delinking of economic growth and energy use was shown to be relative ('weak' decoupling) in most OECD countries, while Denmark, the United Kingdom and the USA show a pattern of absolute delinking ('strong decoupling'). These latter three countries were found to be characterised by a relatively high increase in value added of the chemical sector and by decreasing energy consumption in a range of sectors, most notably Iron and Steel, Non-Metallic Minerals and Transport Equipment; in addition, the USA shows a particularly high increase of value added in the large Machinery sector. Moreover, at the subsectoral level absolute decoupling of economic growth and energy use is mostly concentrated in a number of energy-intensive sectors, such as Iron and Steel, Non-Metallic Minerals and Chemicals as well as in Machinery and Transport equipment.

A decomposition analysis revealed that in most countries structural changes explain a substantial part of manufacturing energy-productivity growth rates while they explain only a small part of manufacturing labour-productivity growth rates. The positive structural effects are to a large extent driven by a shift of energy shares from low-value added (energy-intensive) sectors (such as Iron and Steel, Non-Ferrous Metals and Non-Metallic Minerals) to higher value added (capital- and/or technology-intensive) industries (such as Machinery, Transport Equipment, Textile and Food) – while the opposite is true in case of an overall negative structural effect. The Machinery sector is the main source for both energy- and labour productivity improvements. Finally, although the total structural effect on manufacturing labour-productivity growth is small, there have been changes in employment mix; the main shifts include a decreasing employment share of the labour-intensive sector Textiles (except for Italy) and an increasing employment share of the capital/technology intensive sector Machinery (except for Belgium). Furthermore, in most countries this shift is accompanied by a shift in employment from Iron and Steel towards Chemicals, Food and Paper.

An exploration of the relationship between energy- and labour-productivity growth rates has shown that this relationship, with some exceptions, is positive in most sectors, suggesting energy- and labour-productivity growth to be complements rather than substitutes.

Furthermore, we found labour-productivity growth rates in general to be substantially higher than energy-productivity growth while this bias towards labour-productivity growth increased in aggregate Manufacturing, but decreased in most manufacturing sectors. The latter result underlines the relevance of a sectoral approach in analysing issues concerning factor productivity and decoupling of economic growth and energy use.

Appendix A

Table A.1 **Percentage shares of total Manufacturing Energy Consumption (E), Employment (L) and GDP (Y) by sector, in 1990**

			AUS			BEL			CAN			DNK			FIN			FRA			WGR
	E	L	Y	E	L	Y	E	L	Y	E	L	Y	E	L	Y	E	L	Y	E	L	Y
CHE	17	4	--	35	10	14	--	4	--	14	5	9	17	5	7	37	7	9	36	7	10
FOD	12	12	--	6	14	15	--	12	--	27	17	21	4	12	12	9	13	13	6	9	11
IAS	12	3	--	27	5	5	--	2	--	5	1	1	11	3	3	14	4	3	22	5	5
MAC	2	19	--	3	24	21	--	20	--	8	34	30	3	26	27	8	29	26	4	37	34
MTR	1	8	--	2	10	11	--	11	--	2	5	5	0	6	5	2	12	11	4	11	12
NFM	33	2	--	3	2	3	--	2	--	3	0	0	2	1	1	4	1	2	4	2	2
NMM	12	4	--	12	5	6	--	3	--	21	4	4	9	5	5	10	3	4	9	4	4
PAP	7	10	--	3	8	7	--	15	--	7	10	11	41	18	21	8	8	8	5	5	5
TEX	2	8	--	2	12	7	--	9	--	3	7	5	1	8	4	3	10	6	2	6	4
WOD	1	5	--	0	2	1	--	5	--	4	3	2	6	8	7	2	2	2	1	2	1
NSI	0	25	--	7	8	10	--	16	--	4	13	12	8	9	9	3	11	16	7	11	12
	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----
MAN	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100

		ITA			JPN			NLD			NOR			SWE			GBR			USA	
	E	L	Y	E	L	Y	E	L	Y	E	L	Y	E	L	Y	E	L	Y	E	L	Y
CHE	34	5	7	31	3	9	67	9	15	27	5	10	15	5	7	32	6	11	--	6	11
FOD	5	8	10	4	10	11	8	17	16	6	18	16	4	9	10	10	11	13	--	9	11
IAS	14	2	3	20	3	6	8	2	3	19	2	3	9	3	3	12	3	3	--	2	3
MAC	7	26	27	6	36	38	3	31	26	3	25	25	6	35	31	10	32	26	--	27	27
MTR	1	7	8	2	8	11	1	7	5	1	8	8	2	13	11	3	10	12	--	10	10
NFM	2	1	1	3	1	2	3	1	1	23	4	6	3	1	1	3	1	1	--	1	1
NMM	18	7	7	9	4	4	5	4	4	4	3	0	5	3	3	9	4	4	--	3	2
PAP	5	5	6	8	2	3	3	12	11	14	16	17	44	14	15	5	10	11	--	12	12
TEX	5	23	16	3	7	2	1	6	3	0	4	2	1	3	2	3	10	6	--	10	5
WOD	0	3	2	--	3	1	0	2	2	3	6	5	6	6	6	0	2	1	--	4	3
NSI	9	13	13	14	22	13	0	9	14	0	10	7	4	8	9	12	12	11	--	15	15
	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----
MAN	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100

Sum sectors might differ slightly from 100 due to rounding.

Table A.2 Manufacturing sectors Energy Productivity Average Annual Growth Rates

	AUS	BEL	CAN	DNK	FIN	FRA	WGR	ITA	JPN	NLD	NOR	SWE	GBR	USA	OECD
	70-97	71-97	70-97	72-97	71-97	73-97	70-90	70-97	82-97	82-97	76-97	73-97	70-97	70-94	
MAN	0.41	1.91	0.45	2.74	1.93	0.85	1.45	3.07	1.71	1.87	-0.08	2.19	2.28	3.19	2.25
CHE	--	2.4	-1.31	6.17	1.02	2.79	0.53	6.61	0.22	4.04	1.68	3.16	3.08	2.94	2.26
FOD	--	-0.52	--	1.44	2.13	0.12	0.56	1.47	-1.16	1.63	0.65	1.38	1.62	1.42	0.64
IAS	--	1.4	-1.09	6.48	3.32	1.93	2.32	0.69	2.47	-2.38	0.97	4.33	2.16	4.48	2.67
MAC	--	3.09	--	3.23	5.62	-1.11	0.83	3.05	2.54	0.91	3.33	5.82	1.82	1.86	1.80
MTR	--	-0.80	--	-0.17	4.04	1.01	2.40	-1.37	-0.53	2.14	-1.33	0.09	1.9	2.59	1.35
NFM	--	3.61	-0.3	--	1.74	3.72	1.58	1.01	0.72	0.22	0.83	2.17	1.17	1.23	1.31
NMM	--	1.09	1.39	0.59	3.05	-0.37	1.87	3.74	1.83	1.20	1.30	2.38	3.46	-1.05	1.30
PAP	--	-2.73	-0.54	1.69	1.17	-1.12	-0.05	3.14	0.16	2.66	0.14	1.04	2.08	1.89	1.31
TEX	--	-2.90	--	3.06	1.23	1.56	-0.16	1.92	1.34	-0.05	1.06	1.07	0.87	2.46	1.59
WOD	--	0.2	--	0.14	2.07	--	1.54	-1.87	--	1.69	-1.64	-1.70	--	--	-0.01

The OECD average is weighted with each country's 1990 GDP share of total GDP per sector.

Table A.3 Manufacturing sectors Labour Productivity Average Annual Growth Rates.

	AUS	BEL	CAN	DNK	FIN	FRA	WGR	ITA	JPN	NLD	NOR	SWE	GBR	USA	OECD
	70-97	71-97	70-97	72-97	71-97	73-97	70-90	70-97	82-97	82-97	76-97	73-97	70-97	70-94	
MAN	1.06	4.29	1.79	2.09	4.84	2.92	2.26	3.93	2.98	3.03	1.60	3.19	2.82	2.39	2.69
CHE	--	3.70	3.74	3.61	3.55	5.12	3.06	7.41	3.16	5.19	5.04	2.16	4.80	4.40	4.22
FOD	--	2.99	1.34	3.21	3.12	1.99	1.63	3.46	-1.79	2.81	-0.31	2.04	2.67	1.65	1.25
IAS	--	4.63	1.56	4.83	6.77	2.80	2.44	2.44	3.53	2.82	4.05	6.22	3.44	2.72	3.03
MAC	--	3.74	1.90	1.70	6.47	2.86	1.85	4.34	6.07	2.81	2.28	4.87	2.61	5.05	4.40
MTR	--	2.70	2.54	-1.08	5.05	2.23	1.97	2.37	3.19	2.61	1.58	1.53	2.96	1.00	2.02
NFM	--	7.07	2.95	4.28	4.85	3.70	3.26	5.03	1.68	2.86	2.62	3.89	3.66	1.35	2.41
NMM	--	4.10	1.43	0.39	4.02	2.58	2.76	4.15	3.21	3.08	1.77	1.08	1.80	1.71	2.71
PAP	--	3.14	1.00	1.09	4.60	1.66	2.20	4.37	1.02	2.07	1.19	2.22	1.71	0.56	1.27
TEX	--	4.84	2.73	2.32	4.46	2.47	3.06	3.52	2.38	1.41	3.02	3.00	2.47	3.81	3.28
WOD	--	5.81	1.98	1.17	4.82	4.10	2.52	3.46	0.31	1.60	2.22	2.60	0.66	0.95	1.53

The OECD average is weighted with each country's 1990 GDP share of total GDP per sector.

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Table 1. Sector Classification

	Sector	Abbreviation	ISIC Rev. 2 code
1	Food and Tobacco	FOD	31
2	Textiles and Leather	TEX	32
3	Wood and Wood Products	WOD	331*
4	Paper, Pulp and Printing	PAP	34
5	Chemicals	CHE	351+352**
6	Non-Metallic Minerals	NMM	36
7	Iron and Steel	IAS	371
8	Non-Ferrous Metals	NFM	372
9	Machinery	MAC	381+382+383***
10	Transport Equipment	MTR	384

* WOD excludes furniture since the sector WOD in the IEA Energy Balances excludes furniture

** CHE includes non-energetic energy consumption, i.e. using energy carriers as feedstock.

*** MAC = Metal Products (BMA, 381) + Agricultural and Industrial Machinery (MAI, 382) + Electrical Goods (MEL, 383);

Table 2. Energy- and labour productivity manufacturing sectors relative to OECD average (OECD=100)

	CHE				FOD				IAS				MAC				MTR			
	Energy		Labour		Energy		Labour		Energy		Labour		Energy		Labour		Energy		Labour	
	1976	1990	1976	1990	1976	1990	1976	1990	1976	1990	1976	1990	1976	1990	1976	1990	1976	1990	1976	1990
OECD*	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100
BEL	97	149	70	78	116	115	85	97	76	58	46	80	98	118	98	94	153	134	81	106
CAN	96	64	96	92	171	--	103	87	121	55	96	76	201	--	99	86	92	--	92	93
DNK	269	434	70	53	40	67	45	61	74	96	31	54	89	116	84	55	76	91	65	54
FIN	68	88	47	55	49	74	51	65	83	50	39	69	59	94	58	82	131	161	--	63
FRA	149	168	63	77	125	120	95	89	169	129	57	63	205	100	102	98	198	193	81	90
WGR	202	175	84	63	135	162	92	86	163	127	67	65	299	215	111	85	91	111	99	89
ITA	54	141	32	62	87	168	84	107	165	128	72	96	72	102	83	95	319	335	63	91
JPN	155	176	132	113	240	226	92	76	155	154	139	137	--	179	40	91	252	171	66	102
NLD	48	66	79	89	59	76	70	89	120	70	97	85	--	100	--	90	195	106	65	74
NOR	55	58	47	64	57	54	69	48	38	18	43	55	69	61	81	66	83	69	60	58
SWE	101	147	73	53	78	90	73	67	77	85	31	48	57	68	65	64	86	96	--	57
GBR	166	230	66	73	84	114	68	81	169	130	42	62	64	68	71	65	79	142	51	83
USA	--	--	113	124	--	--	125	129	--	--	115	100	--	--	123	125	--	--	135	113
SD log	0.54[a]	0.56[a]	0.36	0.27	0.50[b]	0.42[b]	0.27	0.25	0.45[a]	0.58[a]	0.48	0.28	0.55[c]	0.36[c]	0.30[d]	0.22[d]	0.49[b]	0.41[b]	0.26[e]	0.22[e]

	NFM				NMM				PAP				TEX				WOD			
	Energy		Labour		Energy		Labour		Energy		Labour		Energy		Labour		Energy		Labour	
	1976	1990	1976	1990	1976	1990	1976	1990	1976	1990	1976	1990	1976	1990	1976	1990	1976	1990	1976	1990
OECD*	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100
BEL	143	156	126	165	46	97	79	119	265	227	55	84	328	124	82	108	145	145	39	44
CAN	87	31	171	113	157	138	136	103	54	30	88	85	--	--	107	91	130	--	100	86
DNK	--	--	46	48	93	76	92	70	611	322	74	61	130	112	95	74	129	102	95	56
FIN	111	77	80	103	68	63	65	86	33	33	47	84	176	145	66	69	41	56	65	77
FRA	133	125	174	159	222	143	126	137	341	182	82	93	151	170	118	116	--	--	83	91
WGR	196	163	117	78	148	139	107	100	290	188	68	76	149	108	107	98	185	217	111	75
ITA	113	108	99	102	119	136	93	98	229	262	59	103	191	216	115	109	803	756	89	80
JPN	249	193	227	152	121	135	63	88	--	185	66	98	85	115	55	46	--	--	48	52
NLD	111	51	256	168	115	118	--	111	360	288	72	93	131	134	108	108	402	300	134	89
NOR	35	20	137	96	65	88	100	79	83	56	56	62	90	95	62	66	87	62	90	66
SWE	112	72	92	72	86	96	84	82	37	31	58	71	112	64	105	82	76	67	109	87
GBR	100	98	67	66	123	128	79	75	290	374	65	82	106	139	91	83	--	--	88	59
USA	--	--	140	113	--	--	118	105	--	--	126	112	--	--	99	110	--	--	124	106
SD log	0.47[f]	0.68[f]	0.47	0.37	0.41[a]	0.26[a]	0.23	0.19	0.97[g]	0.97[g]	0.24	0.18	0.36[b]	0.30[b]	0.24	0.26	0.89[g]	0.85[g]	0.34	0.25

[a] excluding USA [b] CAN, USA [c] CAN, JPN, NLD, USA [d] NLD [e] FIN, SWE [f] DNK, USA [g] JPN, USA [h] CAN, FRA, JPN, GBR, USA

Average OECD is **weighted** with each country's 1990 GDP share of total GDP per sector.

Table 3. Percentage contribution of structural effect (STR) and efficiency effect (EFF) by sector to average annual growth rate (g) of aggregate energy productivity in manufacturing per country

	BEL 1971-97			DNK 1972-97			FIN 1971-97			FRA 1971-97			WGR 1970-90			ITA 1970-97		
	STR	EFF	Total	STR	EFF	Total	STR	EFF	Total	STR	EFF	Total	STR	EFF	Total	STR	EFF	Total
CHE	13.5	14.9	28.5	-2.7	20.7	18.0	1.4	5.2	6.6	8.4	25.3	33.7	12.6	3.4	16.0	-0.8	10.8	10.0
FOD	15.6	-3.8	11.8	10.9	10.6	21.4	-13.6	13.5	-0.1	17.8	2.2	20.0	0.1	5.0	5.1	4.7	5.5	10.2
IAS	-4.8	4.7	-0.1	-1.3	2.8	1.5	2.1	4.6	6.6	-12.5	9.6	-2.9	-9.1	9.3	0.2	-1.0	1.6	0.6
MAC	-24.4	39.2	14.7	7.3	31.1	38.5	-17.0	88.2	71.2	66.7	-36.4	30.3	16.3	20.0	36.3	9.8	22.5	32.3
MTR	16.5	-5.4	11.1	-4.8	1.5	-3.3	-11.6	12.0	0.4	-10.9	13.9	3.0	9.6	15.7	25.2	6.4	-3.5	2.9
NFM	-1.7	5.5	3.8	--	--	--	0.6	1.3	1.9	-5.1	7.9	2.8	1.5	2.7	4.2	0.1	0.4	0.5
NMM	-3.6	5.9	2.3	-3.1	1.5	-1.7	-5.3	5.8	0.5	0.3	-2.9	-2.5	-3.2	5.2	2.1	-2.1	8.8	6.7
PAP	12.6	-6.6	6.0	1.0	5.7	6.7	5.3	9.9	15.2	20.1	-13.1	7.0	4.2	0.0	4.2	3.8	3.8	7.6
TEX	10.2	-12.4	-2.2	-7.1	6.7	-0.4	-12.4	4.7	-7.7	-37.4	17.5	-19.9	-4.3	-0.8	-5.0	4.7	9.7	14.4
WOD	1.0	0.2	1.2	3.1	-0.3	2.9	-6.2	7.2	1.0	--	--	--	-1.0	1.6	0.5	1.8	-1.4	0.4
NSI	5.9	17.0	22.9	7.8	8.6	16.4	5.9	-1.4	4.4	0.1	28.4	28.5	-6.9	18.1	11.2	9.8	4.5	14.4
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MAN %	40.8	59.2	**100.0**	11.1	88.9	**100.0**	-50.8	150.8	**100.0**	47.6	52.4	**100.0**	19.8	80.2	**100.0**	37.2	62.8	**100.0**
MAN g	0.78	1.13	**1.91**	0.30	2.43	**2.74**	-0.98	2.90	**1.93**	0.40	0.45	**0.85**	0.29	1.16	**1.45**	1.14	1.92	**3.07**

	JPN 1982-97			NLD 1982-97			NOR 1976-97			SWE 1973-97			GBR 1970-97			USA 1970-97		
	STR	EFF	Total	STR	EFF	Total	STR	EFF	Total	STR	EFF	Total	STR	EFF	Total	STR	EFF	Total
CHE	8.4	1.1	9.4	-3.3	32.9	29.6	106.6	182.1	288.7	1.2	10.6	11.9	6.2	14.3	20.5	8.3	6.6	14.9
FOD	-6.1	-7.5	-13.6	-2.8	15.3	12.5	-342.3	140.9	-201.4	-2.1	7.1	5.0	5.4	10.0	15.4	2.7	5.0	7.7
IAS	-5.5	9.2	3.7	3.5	-3.5	0.0	-45.4	33.9	-11.5	-2.4	6.6	4.2	-3.1	3.4	0.3	-4.4	4.8	0.4
MAC	45.2	52.6	97.9	17.8	10.4	28.3	-514.5	938.9	424.4	-22.5	80.7	58.2	-2.2	29.0	26.8	27.0	19.3	46.3
MTR	12.4	-3.2	9.2	-3.4	5.7	2.3	-154.9	-171.6	-326.5	4.0	1.2	5.1	-3.3	13.2	9.9	-1.3	7.9	6.6
NFM	-0.5	0.6	0.1	-0.2	0.2	0.0	13.8	55.6	69.4	-0.1	1.7	1.6	0.0	0.6	0.6	0.1	0.9	1.0
NMM	-2.7	4.0	1.3	1.2	2.5	3.7	-126.6	80.6	-46.0	-5.3	3.4	-1.8	-3.7	5.8	2.1	2.3	-0.7	1.6
PAP	0.3	0.6	0.9	-3.1	13.8	10.7	90.6	22.7	113.3	3.1	7.1	10.2	2.9	8.6	11.5	3.3	6.2	9.4
TEX	-17.6	6.2	-11.4	-1.5	0.3	-1.2	-117.8	39.0	-78.8	-5.0	0.8	-4.1	-2.7	3.5	0.8	0.7	4.3	5.1
WOD	--	--	--	-0.6	1.5	0.9	63.5	-106.1	-42.6	6.4	-5.1	1.4	--	--	--	--	--	--
NSI	-0.6	3.0	2.4	-37.0	50.2	13.2	68.9	-357.8	-288.9	11.0	-2.7	8.3	1.4	10.6	12.1	-3.9	10.9	7.0
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MAN %	33.3	66.7	**100.0**	-29.5	129.5	**100.0**	-958.1	858.1	**-100.0**	-11.6	111.6	**100.0**	1.0	99.0	**100.0**	34.8	65.2	**100.0**
MAN g	0.57	1.14	**1.71**	-0.55	2.42	**1.87**	-0.74	0.67	**-0.08**	-0.25	2.44	**2.19**	0.02	2.26	**2.28**	1.11	2.08	**3.19**

Table 4. Percentage contribution of structural effect (STR) and efficiency effect (EFF) by sector to average annual growth rate (g) of aggregate labour productivity in manufacturing per country

	BEL 1971-97			DNK 1972-97			FIN 1971-97			FRA 1971-97			WGR 1970-90			ITA 1970-97		
	STR	EFF	Total	STR	EFF	Total	STR	EFF	Total	STR	EFF	Total	STR	EFF	Total	STR	EFF	Total
CHE	7.8	13.2	20.9	6.4	14.3	20.7	2.0	4.1	6.1	2.1	13.7	15.8	1.8	11.6	13.4	-0.6	9.6	9.1
FOD	3.0	11.5	14.5	-5.3	27.9	22.6	-0.9	7.9	7.1	5.8	9.7	15.5	-1.3	8.7	7.4	0.1	10.4	10.5
IAS	-3.5	6.3	2.8	-0.7	2.3	1.6	0.5	3.9	4.5	-1.6	3.5	1.9	-4.2	6.5	2.3	-1.5	3.1	1.6
MAC	-0.2	17.9	17.7	16.3	24.3	40.7	11.4	35.1	46.5	2.1	25.3	27.4	7.9	27.6	35.5	2.7	28.2	30.9
MTR	4.0	6.3	10.3	-3.3	-2.6	-5.9	-2.2	5.5	3.2	0.1	9.0	9.1	11.7	8.2	19.9	-0.9	4.9	4.0
NFM	-1.2	4.2	3.0	--	--	--	0.3	1.2	1.5	-0.3	2.4	2.1	0.9	2.5	3.4	-0.7	1.3	0.7
NMM	-1.2	5.5	4.3	-5.3	1.3	-4.0	-0.7	3.3	2.5	-1.4	3.8	2.3	-2.4	5.2	2.8	-0.6	7.3	6.7
PAP	1.4	5.0	6.5	-1.6	6.6	5.0	-2.3	20.0	17.7	3.1	4.2	7.3	0.0	4.4	4.4	0.7	6.6	7.2
TEX	-5.8	9.6	3.7	-8.8	6.8	-2.0	-4.6	4.2	-0.4	-6.8	6.0	-0.9	-8.3	6.9	-1.4	-0.1	15.0	15.0
WOD	0.1	0.9	0.9	1.1	1.7	2.7	-1.9	6.6	4.7	0.0	0.0	0.0	-0.8	1.7	0.9	-1.2	2.0	0.9
NSI	3.2	12.0	15.3	5.8	12.9	18.7	5.0	1.7	6.7	3.0	16.4	19.4	4.2	7.4	11.6	1.6	11.8	13.4
MAN %	7.6	92.4	**100.0**	4.6	95.4	**100.0**	6.6	93.4	**100.0**	6.0	94.0	**100.0**	9.2	90.8	**100.0**	-0.3	100.3	**100.0**
MAN g	0.33	3.96	**4.29**	0.10	2.00	**2.09**	0.32	4.52	**4.84**	0.18	2.74	**2.92**	0.21	2.05	**2.26**	-0.01	3.94	**3.93**

	JPN 1982-97			NLD 1982-97			NOR 1976-97			SWE 1973-97			GBR 1970-97			USA 1970-97		
	STR	EFF	Total	STR	EFF	Total	STR	EFF	Total	STR	EFF	Total	STR	EFF	Total	STR	EFF	Total
CHE	0.3	8.8	9.2	-1.8	25.9	24.1	0.2	20.9	21.0	4.6	6.0	10.6	0.4	18.3	18.7	1.0	15.9	16.8
FOD	4.5	-7.1	-2.7	-2.0	16.5	14.6	10.9	-3.3	7.6	-0.3	6.8	6.5	1.2	13.9	15.1	-0.4	7.1	6.7
IAS	-2.8	7.7	4.9	-1.5	2.6	1.1	-4.3	6.7	2.4	-2.5	6.6	4.0	-3.2	4.1	1.0	-4.5	3.8	-0.7
MAC	4.0	66.7	70.6	2.8	24.7	27.5	10.0	35.5	45.5	4.5	45.4	49.8	2.1	24.8	26.9	0.8	52.2	53.0
MTR	-0.7	10.1	9.4	-1.0	4.4	3.5	-12.9	8.1	-4.8	1.2	6.2	7.4	-2.6	13.0	10.3	1.4	4.0	5.4
NFM	-0.2	1.1	0.9	-0.7	1.1	0.5	-0.7	9.4	8.6	-0.4	1.9	1.6	-0.8	1.4	0.7	-0.3	1.0	0.7
NMM	-1.6	3.9	2.3	0.2	3.5	3.6	-2.1	4.2	2.0	-1.3	0.9	-0.4	0.0	2.4	2.4	-0.6	1.9	1.2
PAP	1.2	2.5	3.6	3.4	7.5	10.9	10.8	11.0	21.8	0.9	10.6	11.5	5.2	6.2	11.4	6.4	2.4	8.8
TEX	-8.3	3.7	-4.6	-1.0	1.4	0.4	-5.8	4.5	-1.2	-4.1	2.2	-1.9	-4.2	6.1	1.9	-3.0	8.0	5.0
WOD	0.0	0.0	0.0	0.4	0.7	1.1	-3.6	6.9	3.4	-1.9	4.8	2.8	0.0	0.0	0.0	0.0	0.0	0.0
NSI	2.5	3.8	6.4	0.7	12.2	12.8	2.3	-8.6	-6.3	2.8	5.3	8.1	5.9	5.9	11.7	5.1	-2.0	3.1
MAN %	-1.2	101.2	**100.0**	-0.5	100.5	**100.0**	4.7	95.3	**100.0**	3.4	96.6	**100.0**	4.0	96.0	**100.0**	5.8	94.2	**100.0**
MAN g	-0.04	3.94	**2.98**	-0.01	3.04	**3.03**	0.08	1.52	**1.60**	0.11	3.08	**3.19**	0.11	2.70	**2.82**	0.14	2.25	**2.39**

Figure 1. Evidence of Decoupling: Development of Manufacturing GDP, final energy consumption and total employment per country. (Index, initial year with data available =100)

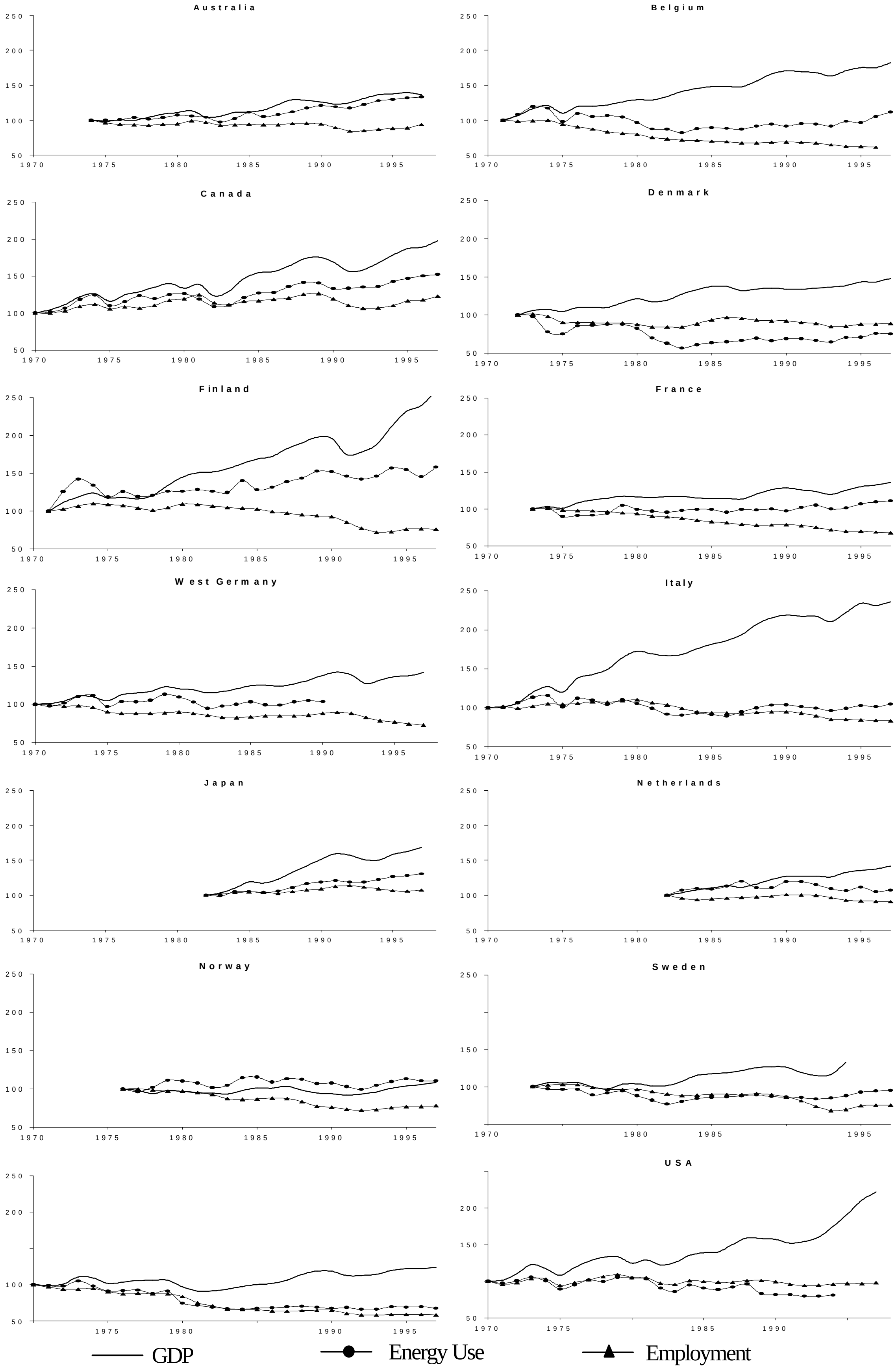

Figure 2. Trends in manufacturing energy productivity development

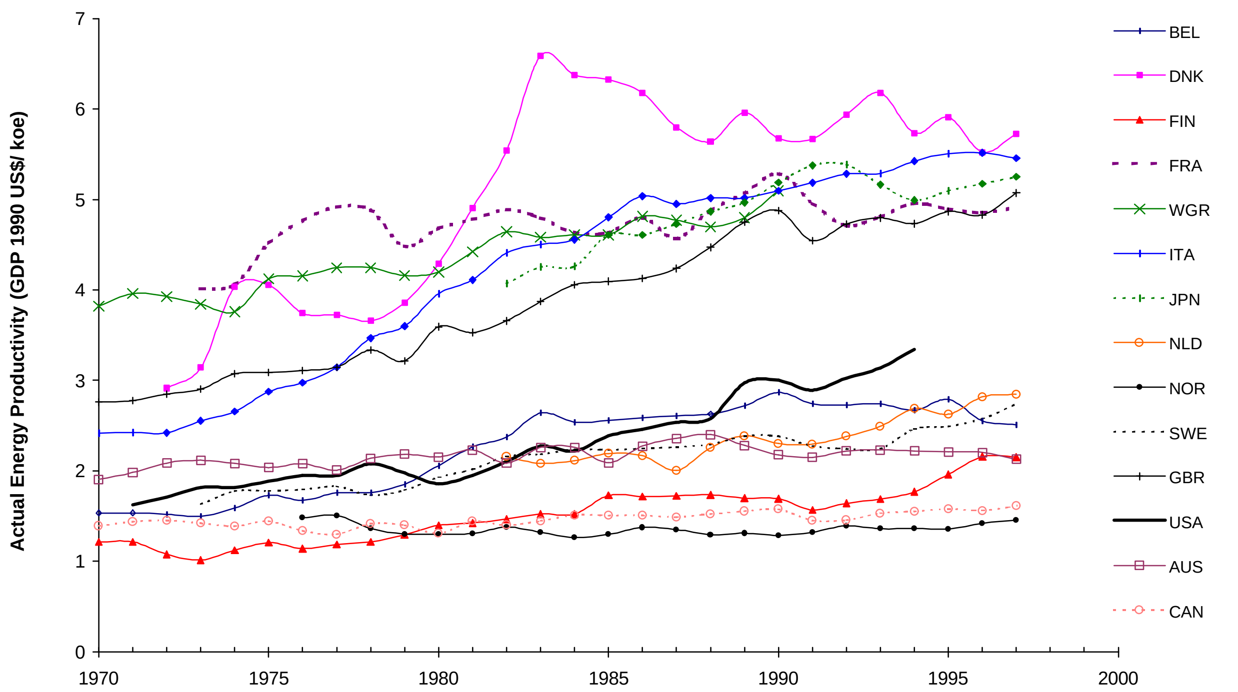

Figure 3. Trends in manufacturing labour productivity development

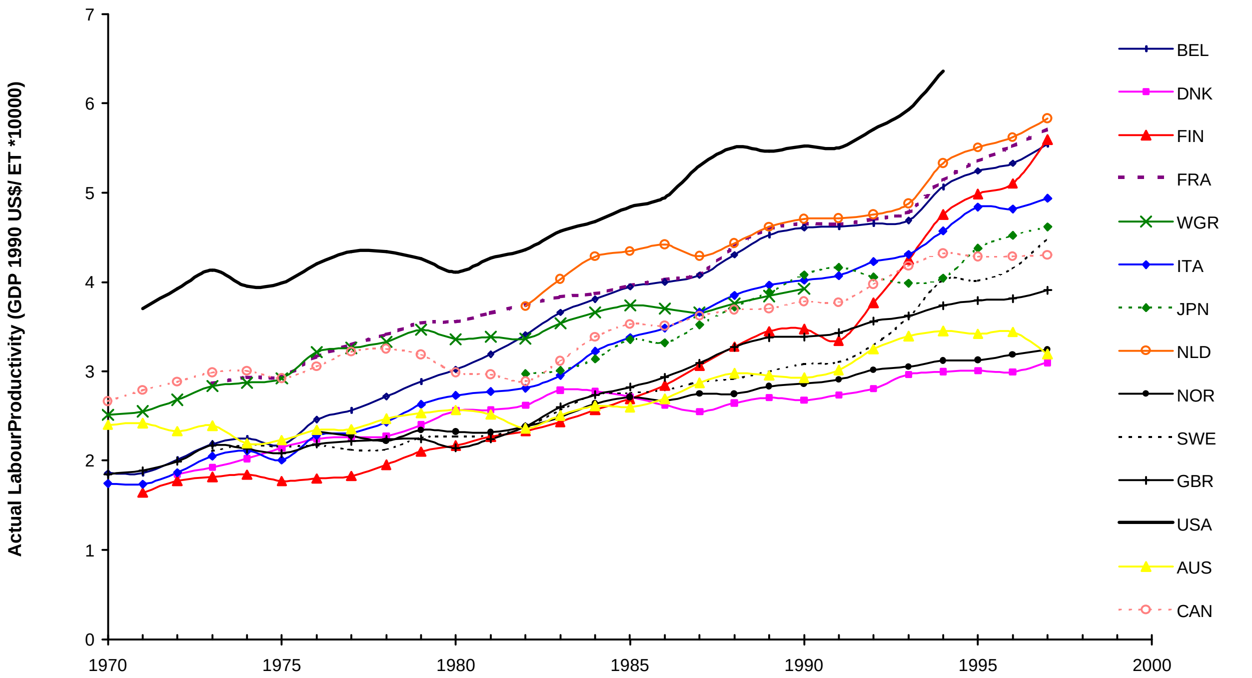

Figure 4. Percentage shares of manufacturing final energy consumption, total employment and value added by sector in 1990. Sample of 12 OECD countries.

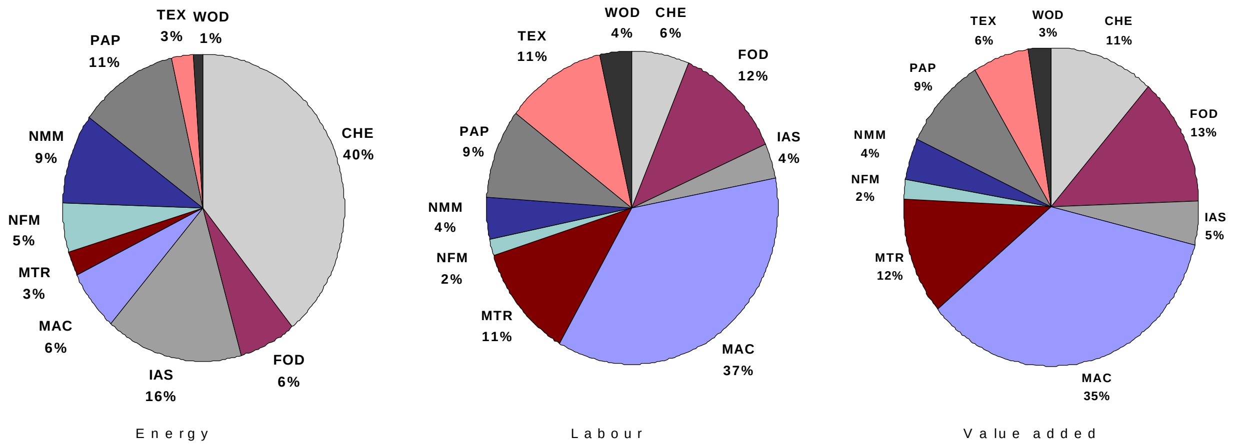

Figure 5. Decoupling at the sector level: Total percentage change of sectoral GDP, final energy consumption and total employment per country. (Index, initial year with data available =100)

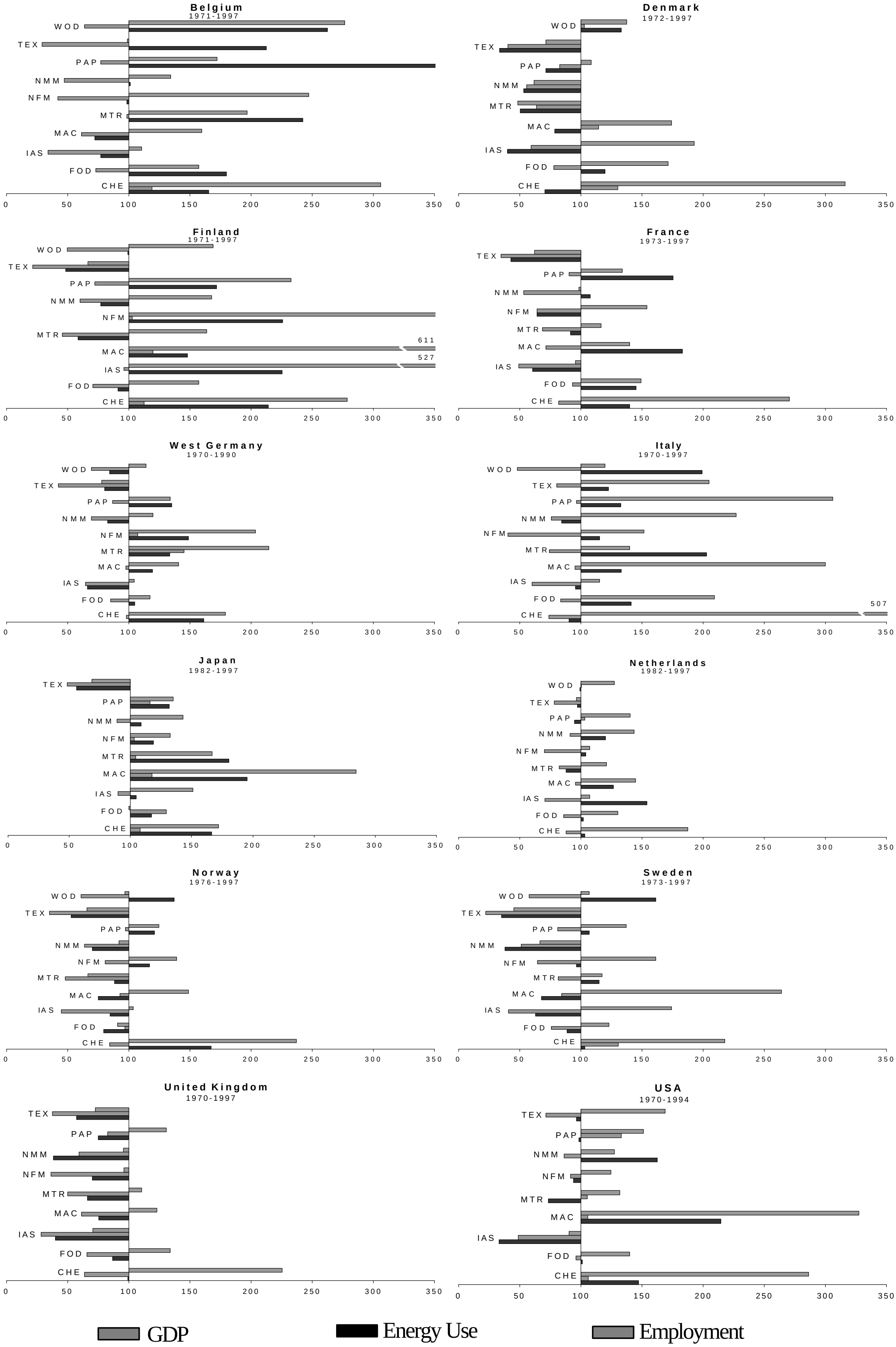

Figure 6. Decomposition of average annual growth rate of macroeconomic energy productivity

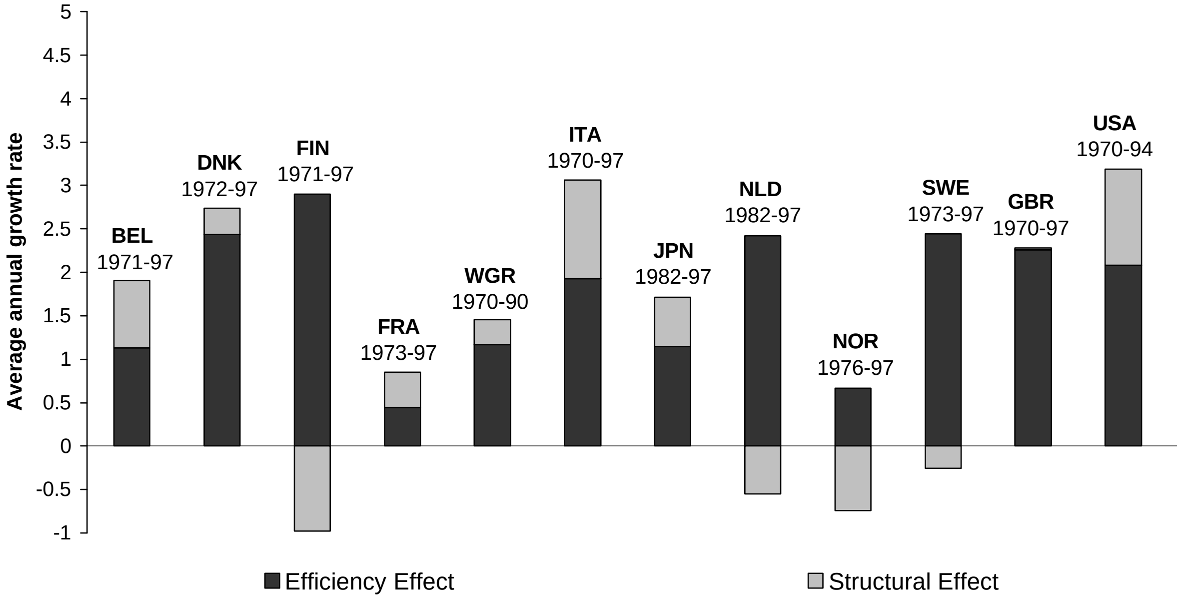

Figure 7. Decomposition of average annual growth rate of macroeconomic labour productivity

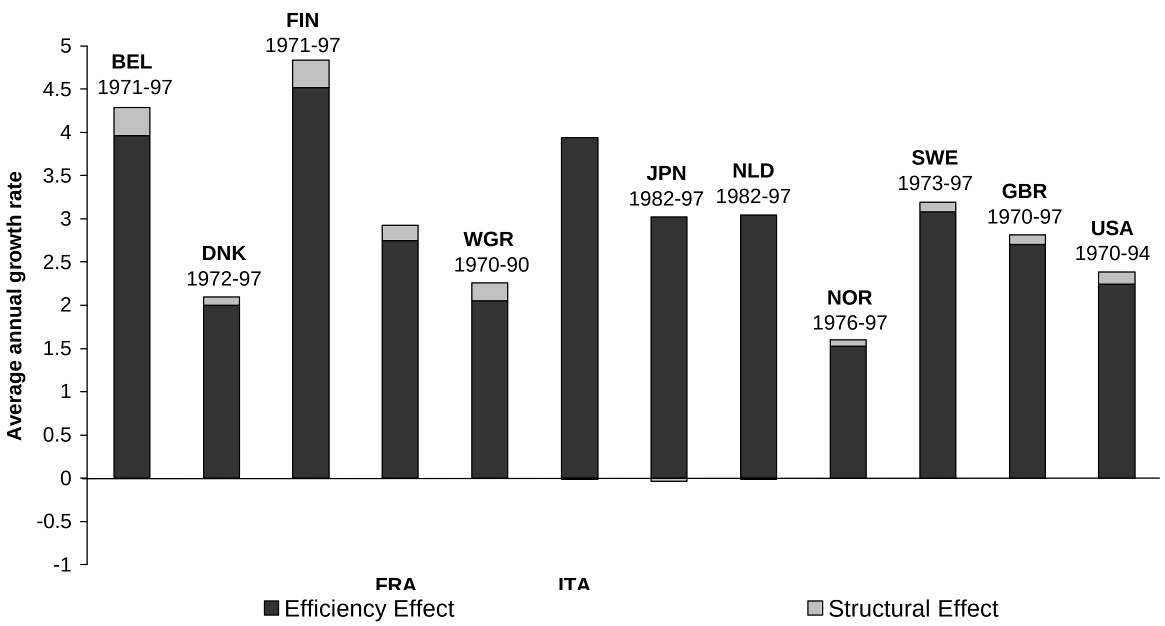

Figure 8. Energy- and labour productivity main sectors. Average annual growth rates