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International Comparisons of Sectoral Energy- and Labour-Productivity Performance: Stylised Facts and Decomposition of Trends

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Abstract
This paper addresses the interplay between economic growth, energy use, change in sectoral composition and technological change, by exploring trends in energy- and labour productivity development for 14 OECD countries and four sectors over the period 1970-1997. A cross-country decomposition analysis reveals that in some countries structural changes contributed considerably to macroeconomic energy-productivity growth while in other countries they partly offset energy-efficiency improvements. In contrast, structural changes only play a minor role in explaining macroeconomic labour-productivity developments. We also find labour productivity growth to be higher on average than energy productivity growth. Over time, this bias towards labour productivity growth is increasing in Transport, Agriculture and Manufacturing, while it is decreasing in Services.

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

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1. Introduction

Economic growth depends on a number of interrelated factors such as an increase in labour force and labour productivity, accumulation of knowledge and capital, the availability of natural resources and energy, the quality of government and institutions and – probably most of all – technological change (e.g., OECD 2003). Ever since Solow (1957) held his famous 'residual' responsible for most of the observed economic growth, broad consensus exists that long-run economic growth is caused by technology-driven (total) factor productivity growth. This led economists to focus on the role of productivity and technology in their quest for understanding economic growth. The quest has not been confined to economic theorizing about growth and technological change, but also includes empirical work on the sources of economic growth. Over the last decades, a growth accounting tradition emerged measuring the contribution of various determinants to output- and productivity growth (e.g., Kendrick 1961; Denison 1967; Jorgenson and Griliches 1967; Maddison 1991, 1999; 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.

However, over the last decades increasing attention is paid to the role of energy in production processes and economic growth. Energy is an essential factor that fuels economic growth and serves human wellbeing. The energy crisis of the 1970s and, more recently, the environmental problems associated with economic growth and increasing energy use have induced empirical research on energy-productivity or energy-intensity developments and its determinants (e.g., Jorgenson 1984, 1986; Howarth et al. 1991; Schipper and Meyers 1992; Miketa 2001). Moreover, it 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 that not only labour productivity, but also energy productivity should increase.

At the same time, economic development is typically associated with a change in the sectoral composition of economies – with emphasis shifting from Agriculture, via Industry towards Services – as well as with increasing trade and international specialisation, and of course technological progress (e.g., Baumol 1967; Grossman and Helpman 1991; Maddison 1991,1999; de Groot 2000). Obviously, this bears important implications for both economic growth and its impact on the environment.

Against this background, we explore in this paper simultaneously levels and trends of macroeconomic energy- and labour-productivity performance among 14 OECD countries, for the period 1970-1997, examining the role of the Manufacturing, Services, Transport and Agricultural sectors. More specifically, we document several stylized facts, we decompose for each country macroeconomic productivity growth rates into a part due to structural changes and a part due to technology-driven efficiency improvements, and we provide some empirical evidence on the existence and development of a potential bias towards either energy- or labour productivity at the sectoral level.

In doing so, we build upon insights from the traditional empirical growth literature as well as from the literature on energy-intensity developments. In several respects, our paper differs from previous empirical analyses of productivity developments. First, we provide a simultaneous exploration of productivity performance along the two dimensions of energy and labour, which allows us to present a multidimensional examination of the productivity performance across a range of advanced economies in view of the aim to decouple economic growth and environmental pressure. Second, our analysis is not – like most other studies, particularly in the field of energy productivity – confined to the Manufacturing sector, but focuses on a decomposition of macroeconomic productivity growth rates. Third, we identify for each country the percentage contribution of Manufacturing, Services, Transport and Agriculture to macroeconomic structural changes and efficiency improvements, in terms of both labour and energy use. Hence, we are able to answer a number of important questions concerning the interplay between economic growth, energy use and technological change. Are there considerable cross-country differences in productivity performance within the OECD? To what extent are macroeconomic productivity trends to be explained from, respectively, shifts in the underlying sectoral structure and efficiency improvements in individual sectors? And to what extent do these results vary accross the various countries? Do patterns of energy-productivity growth resemble those of labour-productivity growth, or is there evidence for the one being substantially higher than the other? And are they positively or negatively correlated?

The paper proceeds as follows. In section 2 we give a brief description of the data used in this study. Section 3 provides the different analyses as previously mentioned. Section 4 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 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 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.

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

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

[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).

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.

3. Comparing productivity performance in OECD countries

This section proceeds in four steps. Section 3.1 provides a first exploration of the four sectors that we consider in this paper, viz. Agriculture, Manufacturing, Transport and Services and their contribution to macroeconomic employment, production and energy use. In section 3.2, we study the development of macroeconomic labour and energy productivity in OECD countries for the period 1970-1997. Section 3.3 decomposes these macroeconomic developments in a part due to changes in the structural composition of the economy and a part due to changes in efficiency of energy- and labour-input use. Finally, in section 3.4 we consider how energy and labour productivity have developed relative to each other.

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3.1 An exploration of the four sectors

In this subsection we document some stylised facts concerning the shares of Manufacturing, Services, Transport and Agriculture in macroeconomic energy consumption, employment and GDP.[5] The Manufacturing sector used to be the most important sector from an energy-point of view, accounting for about 50% of the world's energy use (Schipper and Meyers 1992). In

[5] It is to be noted that in this paper 'macroeconomic' refers to the sum of the Manufacturing, Transport, Services and Agriculture sectors, and thus excludes the Construction and Energy Production sectors, as well as Households.

the OECD the Transport sector is nowadays at least as important as Manufacturing in terms of energy consumption. For the sum of the 14 OECD countries included in this study, the share of macroeconomic final energy consumption in Transport accounted for 43% in 1990, closely followed by Manufacturing with 42%, while Services accounted for 15% and Agriculture for 2% (see Figure 1).

< Insert Figure 1 around here >

In Figure 1 we compare those shares with the sector shares of total employment and value added. Our data confirm the well-known fact that for industrialised countries the highest share of total employment and value added can be found in the Service sector (60-63%), followed by Manufacturing (27-29%), while Transport and Agriculture are responsible for the remaining 8-13%. These shares are more or less similar for all of the 14 OECD countries included in this study (see Table A1 in Appendix A). In sum, the Service sector plays a major role in terms of value added and total employment, while most energy is consumed in Transport and Manufacturing. Particularly in the Transport sector, there is a large contrast between the share of total energy consumption on the one hand and the share of total value added and employment on the other hand.

Within the OECD, the absolute level of energy consumption and employment grew over the last decades, but so did economic activity. In this paper we take this volume effect into account by using energy- and labour productivity as indicators to relate, respectively, final energy consumption and employment to the level of economic activity.[6] In the remaining part of this section we provide a cross-country comparison of energy- and labour-

[6] Note that most studies analysing energy-efficiency developments use energy intensity as an indicator, being the inverse of energy productivity. We prefer to use energy productivity simply because it establishes a direct link with (the empirical literature on) labour-productivity developments.

productivity *levels*, followed by a cross-country comparison and decomposition of energy- and labour-productivity *growth rates*.

3.2 Comparing energy- and labour-productivity levels

To compare cross-country energy- and labour-productivity performance at the macroeconomic level, we calculated for each country the energy- and labour-productivity levels for the sum of the Manufacturing, Transport, Services and Agriculture sectors. In Figure 2 and 3 we plot the development of these macroeconomic energy- and labour-productivity levels over time.

< Include Figure 2 and 3 around here >

Figure 2 reveals a diverse picture for energy productivity with substantial cross-country differences. The highest energy-productivity levels are to be found in Italy and Japan while Canada, Finland, Norway and Sweden show the lowest levels of energy productivity. All other countries form a medium group. The USA tends to leave the group with low levels of energy productivity over time to catch-up with the medium group. Figure 3 shows the well-known picture for labour productivity with a leading position for the USA and other OECD countries showing a tendency to catch-up.

These macroeconomic pictures raise two important questions. First, are there similar cross-country productivity patterns to be found at a lower level of aggregation? Second, does a country's productivity performance differ substantially across its sectors? To answer these questions, we present in Table 2 a cross-country comparison of the energy- and labour-productivity levels relative to the USA for the years 1976 and 1990, for the Manufacturing, Transport, Services and Agriculture sector.

< Insert Table 2 around here >

Concerning energy-productivity performance we find that the high energy-productivity level of Italy is mainly due to its high energy-productivity level in Services.[7] Japan shows a relatively high level of energy productivity in all four sectors while Canada, having an overall low level of energy productivity, displays a relatively low level of energy productivity in all four sectors. The overall picture, however, is that within most countries the energy-productivity performance can differ substantially among sectors. For example, Finland has a low energy-productivity level in Manufacturing, while the opposite is true for Services. Moreover, we find the USA to have an average level of energy productivity in Manufacturing while in Transport, Services and Agriculture the USA faces an energy-productivity disadvantage relative to most other OECD countries. Concerning labour productivity, Table 2 shows that the leading position of the USA holds for all four sectors, and although less pronounced than for energy productivity, there are also substantial cross-sectoral differences within most countries in terms of relative labour productivity performance.

The standard deviation of the log of relative energy- and labour-productivity performance in Table 2 confirms that the cross-country variation of energy-productivity levels is substantially larger than the cross-country variation of relative labour-productivity levels. In terms of energy productivity the largest cross-country differences are to be found in Services, while Agriculture exhibits the largest spread in cross-country labour-productivity levels. Finally, cross-country dispersion of both relative energy- and labour-productivity levels is decreasing over time, with two exceptions: Manufacturing shows a pattern of

[7] Although we have some reason to believe that this result might be due to poor data, the relatively good energy-productivity performance of Italy in Services is also found by Schipper and Meyers (1992: 185) who document for Italy in 1973 and 1988 an energy intensity level in Services that is substantially lower than in 8 other OECD countries.

increasing cross-country differences in energy-productivity levels while in Agriculture the relative cross-country differences in labour-productivity levels remain constant. In the next section we further explore cross-country productivity developments over time, by further analysing and decomposing macroeconomic growth rates.

3.3 Decomposing energy- and labour-productivity growth rates

Observed aggregate productivity trends are not directly attributable to technological change in individual sectors, but are also the result of changes in the distribution of production factors among sectors. The latter is due to the fact 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. In section 3.1 we have given a brief overview of such a degree of sectoral heterogeneity in our dataset. In order to identify to what extent aggregate productivity trends are to be explained from, respectively, shifts in the underlying sector structure and efficiency improvements in individual sectors, we decompose per country changes in overall productivity performance into a so-called ‘sectoral effect’ and an ‘efficiency effect’.

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 equation (1) and (2), we decompose for each of the 14 OECD countries the average annual macroeconomic energy- and labour-productivity growth rate into a structural and an efficiency effect, examining the role of the sectors Manufacturing, Services, Transport and Agriculture. 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 (Total Factor Productivity, 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 we refer to

Ang (1995a, 1995b, 1999) and Ang and Zhang (2000) concerning energy studies, and to Syrquin (1984) concerning macroeconomic studies focussing on aggregate (total factor) productivity.[8]

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 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, including a detailed examination of the role of Manufacturing, Services, Transport and Agriculture. 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 4 and 5 we present the results of the decomposition of the macroeconomic energy- and labour-productivity growth rates into a structural effect and an efficiency effect. Figures 4 and 5 plot for each country, respectively, the average annual macroeconomic

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[8] 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).

energy- and labour-productivity growth rate as the sum of an efficiency effect and a structural effect. 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 4 and 5 around here >

From Figure 4 it can be seen that, except for Belgium, Sweden, the United Kingdom and the United States, structural changes explain a substantial part of average annual macroeconomic energy-productivity growth rates. Structural effects even dominate efficiency effects in Australia, Denmark, Finland, Italy, the Netherlands and Norway. In most countries, the efficiency effect is positive, except for Finland, Italy and the Netherlands.

Figure 5 shows – on the contrary – that although in all countries the effect of structural changes on macroeconomic labour-productivity growth rates is positive, it is also relatively small, implying efficiency improvements to be the main source of macroeconomic labour-productivity growth. The latter result confirms what has been known from the macroeconomic empirical growth literature (e.g., van Ark 1996). Moreover, it can be concluded that considerable cross-country differences exist, in particular in terms of energy productivity. Finally, the figures reveal that on average macroeconomic labour-productivity growth is higher than macroeconomic energy-productivity growth, except for Canada, the United Kingdom and the USA. Using the data underlying Figures 4 and 5, we calculated the average annual growth rates of energy productivity and labour productivity for the 14 OECD countries combined, weighted by each country's share in total GDP. We found average annual growth rates of both energy- and labour productivity to be about 1.8% before correcting for structural changes, while they are, respectively, 1.7% and 1.6% after correcting for structural changes.

In order 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 4 and 5 respectively, into the percentage contribution of individual sub-sectors. The results are presented in Tables 3 and 4.

<Insert Table 3 around here >

In Table 3, for each country the first column denotes per individual sector its shift in energy share, expressed as a percentage contribution to the total effect of shifts in sectoral energy shares on macroeconomic productivity growth (i.e., the total structural effect). The second column denotes per individual sector its change in energy-productivity performance, expressed as a percentage contribution to the total change in energy-productivity performance at a constant sector structure (i.e. the total efficiency effect). The third column denotes per individual sector its total relative contribution to macroeconomic productivity change, being the sum of the structural and efficiency effects. From Table 3 it can be concluded that the largest effects of shifts in sectoral energy shares on macroeconomic energy-productivity growth are to be found in Manufacturing and Services, with the energy share declining in Manufacturing and increasing in Services (except for West Germany and Sweden). Moreover, it can be seen that the extraordinary positive effect of structural changes on macroeconomic energy-productivity growth in Finland, Italy and the Netherlands is to be explained from a strongly increasing energy share in Services.[9] Finally, the effect of shifts in the energy share of Transport and Agriculture on macroeconomic structural change is

[9] A closer look at the data reveals that this result is due to an exceptionally low initial level of energy consumption in Services in these countries, which then increases relatively fast over time to converge to an average level. Since we have no breakdown of energy data for the underlying sub-sectors we cannot explore this issue any further, but it might just be due to poor quality of the data. See also Ramirez et al. (2002), who found in a detailed analysis of the Dutch Service sector for the period 1984-1998, a minor increase of energy productivity, which has been hardly affected by structural changes.

relatively small, with small increasing energy shares in Transport and a mix of increasing and decreasing energy shares in Agriculture (decreasing in Denmark, Finland, France, West Germany, Sweden, United Kingdom and USA and increasing in other countries).

Concerning macroeconomic energy-efficiency improvements, Table 3 shows that they are mainly realised within Manufacturing. For Services, however, the picture is highly diverse with a mix of positive and negative percentage contributions to aggregate energy-efficiency improvements. Most notable is again the exceptional negative growth rate of energy productivity in Finland, Italy and the Netherlands, which drive the negative efficiency effects in these countries as plotted in Figure 4. The percentage contribution of Transport and Agriculture to macroeconomic energy-efficiency improvements is relatively small (except for Norway), with energy efficiency improving in Transport (except for Belgium, West Germany, Japan, Norway and the United Kingdom) while energy efficiency in Agriculture (slightly) improves in Australia, Denmark, France, West Germany, Sweden, United Kingdom and the USA and (slightly) decreases in the other countries.

< Insert Table 4 around here >

In Table 4 we present a similar breakdown of the total structural- and efficiency effects as in Table 3, but now for labour productivity. Table 4 shows that the relatively small impact of total structural change on macroeconomic labour-productivity growth does not imply that employment mixes have been constant over time. On the contrary, the employment mix changed considerably with a substantially decreasing employment share in Manufacturing and a substantially increasing employment share in Services. The fact that the net effect of this shift on macroeconomic labour-productivity growth is always positive confirms an employment shift from a relatively low- towards a relatively high value-added sector.

Moreover, Table 4 also shows that in terms of shifts in employment shares, the relative contribution of Transport and Agriculture to macroeconomic structural change is small, with decreasing employment shares in Agriculture and a mix of increasing and decreasing employment shares in Transport (decreasing in Australia, Canada, Netherlands, Norway, United Kingdom and USA, constant in Belgium and increasing in other countries). Concerning the efficiency effect, Manufacturing is not only an important source for energy-efficiency improvement, but also for labour-efficiency improvement (i.e., labour productivity corrected for structural changes). Furthermore, unlike energy efficiency, Services is also an important source for labour-efficiency improvement in most countries, except for the Netherlands. Similar to energy efficiency, the percentage contributions of Transport and Agriculture to macroeconomic labour-efficiency improvements are small, although positive in all countries.

3.4 Sectoral biases in productivity growth rates

The previous section offered a diverse picture on the role of Manufacturing, Services, Transport and Agriculture in driving, respectively, macroeconomic energy- and labour productivity growth. In this section, we continue by taking a closer look at each of these sectors. So far, we found macroeconomic growth rates of labour productivity in general to be substantially higher than macroeconomic growth rates of energy productivity. Does this pattern also holds for each of the 4 sectors under consideration? Is the growth of energy- and labour productivity positively or negatively correlated to one another among the different countries? In other words, do they complement each other, or are they substitutes? And is the observed relationship between energy- and labour-productivity growth changing over time?

In exploring these issues, 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 (e.g., Kennedy 1962; Binswanger 1974a, 1974b; 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 (e.g., 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. Here, we provide some empirical evidence on the existence and development of a potential bias towards either energy- or labour productivity, which might reflect sectoral biases of technological change.

For this aim, we calculate the average annual growth rates of energy- and labour productivity for each sector and country for the period 1970-1997.[10] They are presented in Figure 6 together with 2 regression lines through the origin, estimating the cross-sectional relationship between energy- and labour productivity growth rates for, respectively, the periods 1970-1982 and 1982-1997.

< Insert Figure 6 around here >

Figure 6 leads to the following conclusions. In Manufacturing all countries show a positive correlation between energy- and labour-productivity growth rates, suggesting manufacturing energy- and labour-productivity growth to be complements rather than substitutes. For most

[10] Note that the exact period differs per country due to data restrictions. We refer to Table A.2 in Appendix A for an overview of the periods used for each country as well as the sectoral growth rates per country (the same as in Figure 6 but then in table format).

countries, this conclusion holds also for Services and Transport. In Agriculture, however, 7 out of the 14 countries combine a positive labour-productivity growth with a negative energy-productivity growth, suggesting energy- and labour-productivity growth to be substitutes rather than complements in these countries. Of course, the figure shows again that labour-productivity growth is in general substantially higher than energy-productivity growth. Comparing the regression lines for the period 1982-1997 and the period 1970-1982 suggests that this bias towards labour productivity growth is increasing in aggregate Manufacturing, Transport and Agriculture, while it is decreasing in Services. Insofar as the observed sectoral productivity growth rates are driven by technological progress, the (increasing) bias towards labour productivity growth suggests the existence of a (increasing) bias towards labour-augmenting technological progress in aggregate Manufacturing, Transport and Agriculture.

4. Conclusions

In this paper we have presented an empirical analysis of several key issues concerning the interplay between economic growth, energy use and technological change, by exploring simultaneously trends in energy- and labour productivity for 14 OECD countries and 13 sectors over the period 1970-1997. Much emphasis has been put on tracing back macroeconomic productivity developments to developments at the level of individual sectors, notably Manufacturing, Services, Transport and Agriculture. We found a diverse picture for trends in macroeconomic energy productivity, including substantial cross-country differences. Italy and Japan show a high energy-productivity level while Canada, Finland, Norway and Sweden display a relatively low level of overall energy productivity. All other countries form a medium group. The USA tends to leave the lagging group over time to catch-up up with the medium group. For labour productivity we found the well-known leading position for the USA, with other OECD countries showing a clear tendency to catch-up at a macroeconomic level.

A decomposition analysis revealed that in most countries structural changes explain a substantial part of macroeconomic energy-productivity growth rates, while they explain only a small part of macroeconomic labour-productivity growth rates. At the macroeconomic level the dominating structural change consists of a shift in energy- and employment shares from Manufacturing towards Services. Macroeconomic energy-efficiency improvements are mainly realised within Manufacturing, while for Services the picture is highly diverse with a mix of positive and negative percentage contributions to macroeconomic energy efficiency improvements. In terms of labour-productivity improvements, the main macroeconomic efficiency improvements are not only realised within Manufacturing, but also within Services.

An exploration of the relationship between energy- and labour-productivity growth rates revealed this relationship in general to be positive, with some exceptions, particularly in Agriculture. This suggests that energy- and labour-productivity growth are in most OECD countries complements rather than substitutes. This may imply 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. 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, Transport and Agriculture and decreased in Services. Finally, we found cross-country differences in energy-productivity levels to be substantially larger than cross-country differences in labour-productivity levels.

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Appendix A

Table A.1 Percentage shares of total 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**
MAN	40	19	16	50	26	26	42	21	22	27	30	25	61	27	29	38	27	28	46	40	37
SRV	7	63	67	13	56	57	18	60	61	17	45	53	5	42	44	17	50	57	16	42	50
TAS	48	5	6	35	6	8	36	5	5	48	8	9	27	7	7	41	5	5	37	5	4
CST	2	7	7	--	9	7	1	8	9	2	10	8	1	12	12	1	10	7	--	9	7
AGR	3	6	4	2	3	2	3	5	3	7	8	6	6	12	8	3	8	4	2	4	2
	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----
TOT	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**
MAN	49	27	28	49	26	29	55	22	24	50	21	18	50	31	29	39	26	28	33	20	22
SRV	4	46	55	14	47	50	5	57	59	15	51	54	17	46	51	12	55	54	16	66	66
TAS	43	6	5	31	6	7	30	6	5	31	9	16	31	7	6	47	7	7	50	4	4
CST	--	9	8	2	11	11	1	9	7	2	10	7	--	10	10	1	9	9	--	7	5
AGR	4	12	4	4	10	3	9	6	5	2	9	5	2	6	4	1	3	2	1	3	2
	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----
TOT	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100

Table A.2 Average Annual Growth Rates of Energy Productivity (E) and Labour Productivity (L) in 5 sectors

		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	E	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
	L	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
		74-96	70-96	73-97	70-95	70-96	70-97	70-90	70-97	82-96	86-95	76-95	70-94	70-96	70-96	
TAS	E	1.18	-1.17	0.60	0.50	0.22	0.16	-0.33	0.16	-0.06	1.31	1.31	2.09	-0.15	1.02	0.39
	L	2.91	1.56	--	1.84	2.75	2.47	2.13	2.29	2.76	3.14	4.03	3.35	2.56†	1.11	2.03
SRV	E	-0.27	0.67	1.78	-1.05^	-2.82#	0.52º	2.43	-2.53	0.12	-2.56	0.76	2.18*	1.85	2.61	1.45
	L	0.64	0.96	0.49	1.63	2.87	1.54	2.16	0.97	2.12	0.18	0.48	1.63	0.22†	0.52	0.98
AGR	E	0.04	-2.58	-3.78	2.18	-1.16	0.36	1.50	-1.75	-3.42	-0.94	-4.07	0.58	2.19	2.68	0.18
	L	2.21	4.41	1.21	6.22	4.37	5.34	6.12	3.64	2.80	4.40	2.65	3.56	3.82	2.21	3.23

*1986-1994 † 1970-1990 ^1972-1995 #1970-1995 °1985-1997. The OECD average is weighted by each country's 1990 GDP share of total GDP per sector.

Table 1. Sector Classification

	Sector	Abbreviation	ISIC Rev. 2 code
1	Manufacturing	MAN	31, 32, 331[a,] 34, 351+352[b], 36, 371, 372, 381+ 382+383[c], 384
2	Services	SRV	61+62+63[d], 72, 81+82+83[e], 90[f]
3	Transport	TAS	71
4	Agriculture	AGR	10

[a] Wood sector excludes furniture, since the sector WOD in the IEA Energy Balances excludes furniture

[b] Part of Chemicals = Industrial Chemicals (351) + Other Chemical Products (352). Includes non-energetic energy consumption, i.e. using energy carriers as feedstock

[c] Part of Machinery = Metal Products (381) + Agricultural and Industrial Machinery (382) + Electrical Goods (383)

[d] Wholesale Trade (61), Retail Trade (62), Restaurants and Hotels (63)

[e] Communication (72),

[f] Financial Institutions (81), Insurance (82), Real Estate and Business Services (83)

[g] Community, social and personal services

Table 2. Energy- and Labour Productivity relative to USA (USA=100)

	MAN				SRV				TAS				AGR			
	Energy		Labour		Energy		Labour		Energy		Labour		Energy		Labour	
	1976	1990	1976	1990	1976	1990	1976	1990	1976	1990	1976	1990	1976	1990	1976	1990
USA	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100
AUS	105	71	57	54	413	244	70	72	183	175	57	74	165	91	83	58
BEL	84	93	59	84	149	130	86	91	481	372	94	124	114	81	79	88
CAN	67	51	74	69	61	52	81	77	115	125	--	74	146	50	89	63
DNK	188	185	54	49	183	94	66	77	333	316	63	76	34	63	41	64
FIN	57	55	43	64	321	141	50	69	319	268	52	67	145	64	57	61
FRA	214	172	76	85	74	123	91	106	256	242	65	87	176	135	52	74
WGR	209	175	78	73	106	104	77	98	252	209	55	73	142	103	39	49
ITA	150	166	55	74	1481	598	90	93	370	313	53	67	288	124	41	37
JPN	--	169	--	75	192	151	50	72	662	555	60	84	--	66	30	27
NLD	--	75	--	86	--	305	--	89	--	272	--	77	--	38	84	102
NOR	75	42	56	52	102	61	65	67	570	488	78	114	196	114	66	50
SWE	90	78	52	56	--	63	67	73	182	221	35	52	120	89	59	62
GBR	157	159	53	62	152	152	62	61	368	266	47	58	124	154	66	72
SD log	.44[a]	.52[a]	.22[a]	.21[a]	.84[b]	.61[b]	.21[c]	.17[c]	.55[c]	.47[c]	.28[d]	.25[d]	.49[a]	.32[a]	.35	.35

[a] excl. JPN and NLD, [b] excl. NLD and SWE, [c] excl. NLD, [d] excl. CAN and NLD.

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

	AUS 1974-96			BEL 1971-97			CAN 1980-97			DNK 1972-95			FIN 1971-95		
	STR	EFF	Total	STR	EFF	Total	STR	EFF	Total	STR	EFF	Total	STR	EFF	Total
MAN	-20.9	5.6	-15.3	-27.6	53.6	26.0	-1.1	18.9	17.9	-47.4	65.5	18.1	-19.6	89.9	70.3
TAS	4.1	8.4	12.4	13.1	-9.7	3.4	-1.2	4.6	3.4	4.9	10.0	14.9	5.9	1.8	7.7
AGR	0.7	0.2	0.9	9.0	-8.9	0.1	5.3	-5.0	0.4	-3.6	11.7	8.1	-9.9	-27.1	-37.0
SRV	126.3	-24.3	101.9	12.6	57.9	70.5	24.1	54.3	78.4	112.0	-53.0	58.9	259.0	-200.0	59.0
Total %	110.2	-10.2	**100.0**	7.1	92.9	**100.0**	27.1	72.9	**100.0**	65.9	34.1	**100.0**	235.5	-135.5	**100.0**
Total g	0.94	-0.09	**0.86**	0.08	1.01	**1.08**	0.42	1.14	**1.56**	0.90	0.47	**1.37**	1.53	-0.88	**0.65**

	FRA 1985-97			WGR 1970-90			ITA 1970-97			JPN 1982-96			NLD 1986-95		
	STR	EFF	Total	STR	EFF	Total	STR	EFF	Total	STR	EFF	Total	STR	EFF	Total
MAN	-103.8	61.4	-42.3	-24.3	38.7	14.4	-30.1	62.4	32.3	-38.7	67.0	28.3	-41.3	46.9	5.6
TAS	20.2	6.9	27.1	4.9	-0.6	4.2	6.5	0.5	7.0	9.8	-1.0	8.8	8.7	6.8	15.5
AGR	-27.9	10.9	-17.0	-0.9	1.9	1.0	3.9	-7.4	-3.5	3.3	-14.0	-10.8	14.4	-4.5	10.0
SRV	2.0	130.2	132.2	-13.7	94.1	80.3	178.9	-114.7	64.1	68.3	5.3	73.6	210.3	-141.4	69.0
Total %	-109.4	209.4	**100.0**	-34.1	134.1	**100.0**	159.2	-59.2	**100.0**	42.7	57.3	**100.0**	192.1	-92.1	**100.0**
Total g	-0.26	0.50	**0.24**	-0.58	2.27	**1.70**	2.36	-0.88	**1.48**	0.37	0.50	**0.87**	2.18	-1.05	**1.14**

	NOR 1976-97			SWE 1973-94			GBR 1970-90			USA 1970-94		
	STR	EFF	Total	STR	EFF	Total	STR	EFF	Total	STR	EFF	Total
MAN	-29.7	-4.7	-34.3	-1.9	25.4	23.5	-34.7	47.1	12.3	-12.1	29.6	17.5
TAS	22.0	38.4	60.4	2.6	9.7	12.3	9.6	-2.4	7.3	1.6	2.5	4.1
AGR	28.9	-29.8	-0.9	-11.3	10.6	-0.8	-2.0	4.4	2.4	-0.6	3.0	2.4
SRV	47.1	27.7	74.8	-8.6	73.6	65.0	2.6	75.4	78.0	7.5	68.5	76.0
Total %	68.4	31.6	**100.0**	-19.2	119.2	**100.0**	-24.5	124.5	**100.0**	-3.5	103.5	**100.0**
Total g	0.48	0.22	**0.70**	-0.30	1.84	**1.54**	-0.50	2.52	**2.03**	-0.10	2.81	**2.72**

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

	AUS 1974-96			BEL 1971-97			CAN 1980-97			DNK 1972-95			FIN 1971-95		
	STR	EFF	Total	STR	EFF	Total	STR	EFF	Total	STR	EFF	Total	STR	EFF	Total
MAN	-32.4	28.8	-3.6	-23.7	50.0	26.3	-50.9	4.9	-46.0	-3.7	25.6	21.9	-1.5	42.9	41.4
TAS	-3.0	13.2	10.2	0.0	6.2	6.2	-11.1	15.3	4.2	2.2	11.2	13.4	2.4	6.0	8.4
AGR	-4.6	6.6	2.0	-3.1	4.6	1.5	-11.6	10.1	-1.5	-7.6	14.8	7.3	-8.3	11.8	3.5
SRV	54.6	36.8	91.4	36.2	29.7	66.0	91.1	52.1	143.2	19.6	37.8	57.4	14.6	32.1	46.7
	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------
Total %	14.6	85.4	**100.0**	9.5	90.5	**100.0**	17.5	82.5	**100.0**	10.6	89.4	**100.0**	7.2	92.8	**100.0**
Total g	0.19	1.12	**1.31**	0.22	2.10	**2.32**	0.12	0.57	**0.70**	0.24	2.04	**2.29**	0.28	3.65	**3.94**

	FRA 1985-97			WGR 1970-90			ITA 1970-97			JPN 1982-96			NLD 1986-95		
	STR	EFF	Total	STR	EFF	Total	STR	EFF	Total	STR	EFF	Total	STR	EFF	Total
MAN	-24.2	45.0	20.8	-12.6	38.0	25.3	-11.6	42.3	30.8	-4.9	36.3	31.4	-49.6	55.0	5.3
TAS	2.1	5.7	7.8	0.6	3.8	4.3	1.5	5.0	6.5	0.8	7.5	8.3	-1.1	16.7	15.6
AGR	-9.3	11.5	2.2	-3.7	5.1	1.4	-6.6	7.4	0.8	-4.4	3.3	-1.1	-11.2	21.2	10.0
SRV	44.4	24.7	69.2	28.8	40.1	68.9	40.1	21.8	61.9	20.1	41.2	61.3	60.0	9.1	69.1
	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------
Total %	13.0	87.0	**100.0**	13.0	87.0	**100.0**	23.4	76.6	**100.0**	11.7	88.3	**100.0**	-1.9	101.9	**100.0**
Total g	0.26	1.74	**2.00**	0.35	2.32	**2.67**	0.64	2.10	**2.75**	0.33	2.53	**2.86**	-0.02	1.14	**1.12**

	NOR 1976-97			SWE 1973-94			GBR 1970-90			USA 1970-94		
	STR	EFF	Total	STR	EFF	Total	STR	EFF	Total	STR	EFF	Total
MAN	-19.0	19.2	0.1	-21.1	49.7	28.6	-57.4	64.2	6.7	-45.3	52.2	6.9
TAS	-6.9	41.5	34.5	2.5	6.6	9.1	-4.5	11.8	7.3	-1.8	5.3	3.5
AGR	-8.0	11.3	3.3	-2.6	4.2	1.6	-3.6	6.0	2.4	-4.0	6.0	2.0
SRV	42.9	19.1	62.0	26.8	33.8	60.7	83.7	-0.1	83.6	59.1	28.6	87.6
	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------
Total %	8.9	91.1	**100.0**	5.7	94.3	**100.0**	18.1	81.9	**100.0**	8.0	92.0	**100.0**
Total g	0.16	1.60	**1.76**	0.17	2.89	**3.06**	0.29	1.32	**1.61**	0.09	1.02	**1.10**

Figure 1. Percentage shares of non-residential final energy consumption, total employment and value added by sector in 1990. Sample of 14 OECD countries

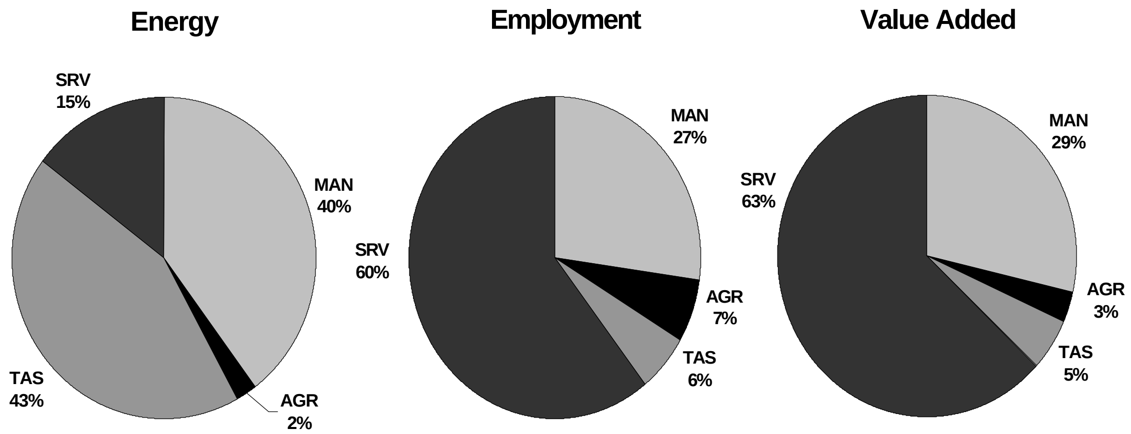

Figure 2. Trends in macroeconomic energy-productivity development

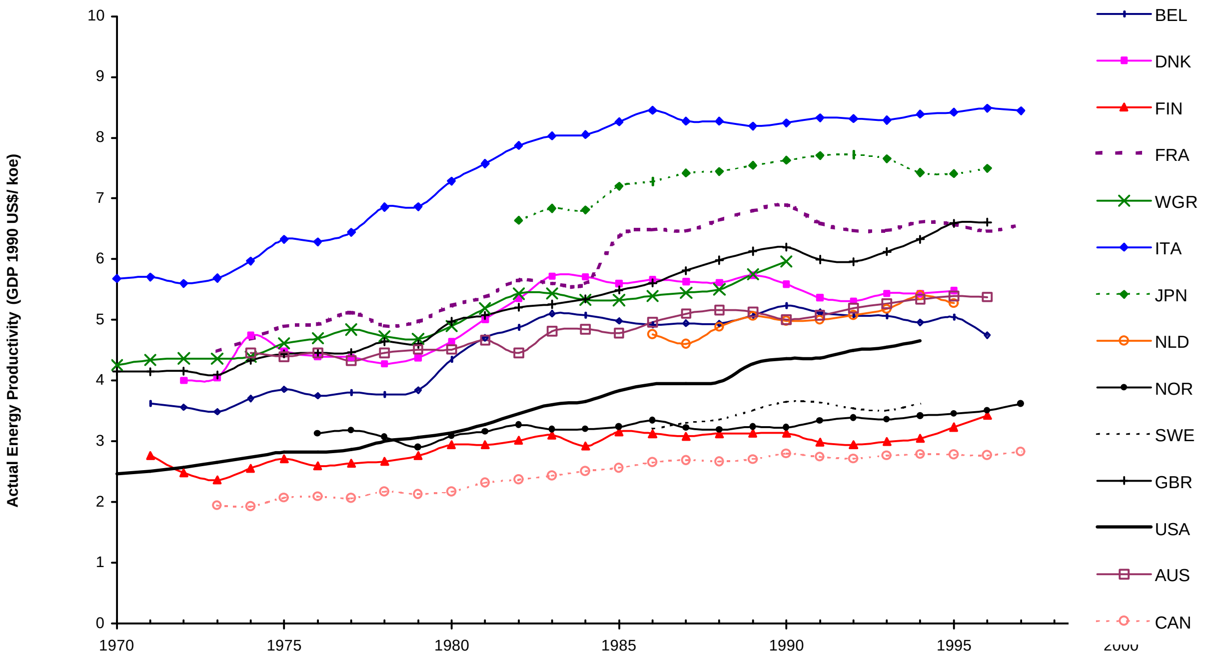

Figure 3. Trends in macroeconomic labour-productivity development

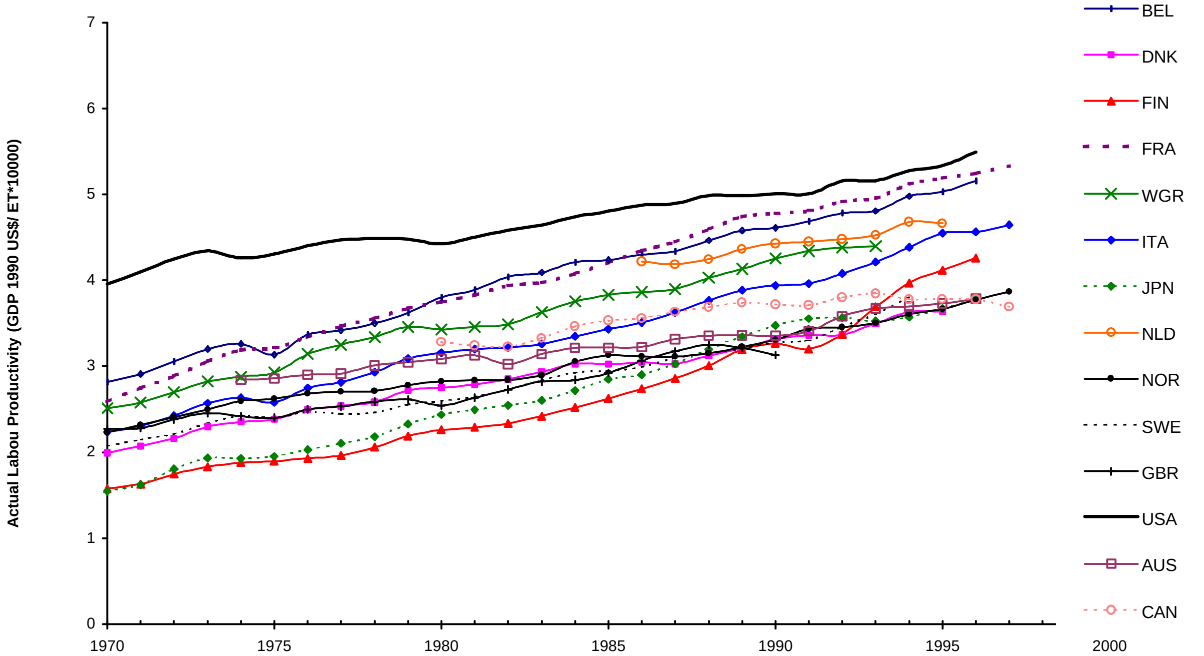

Figure 4. Decomposition of average annual growth rate of macroeconomic energy productivity

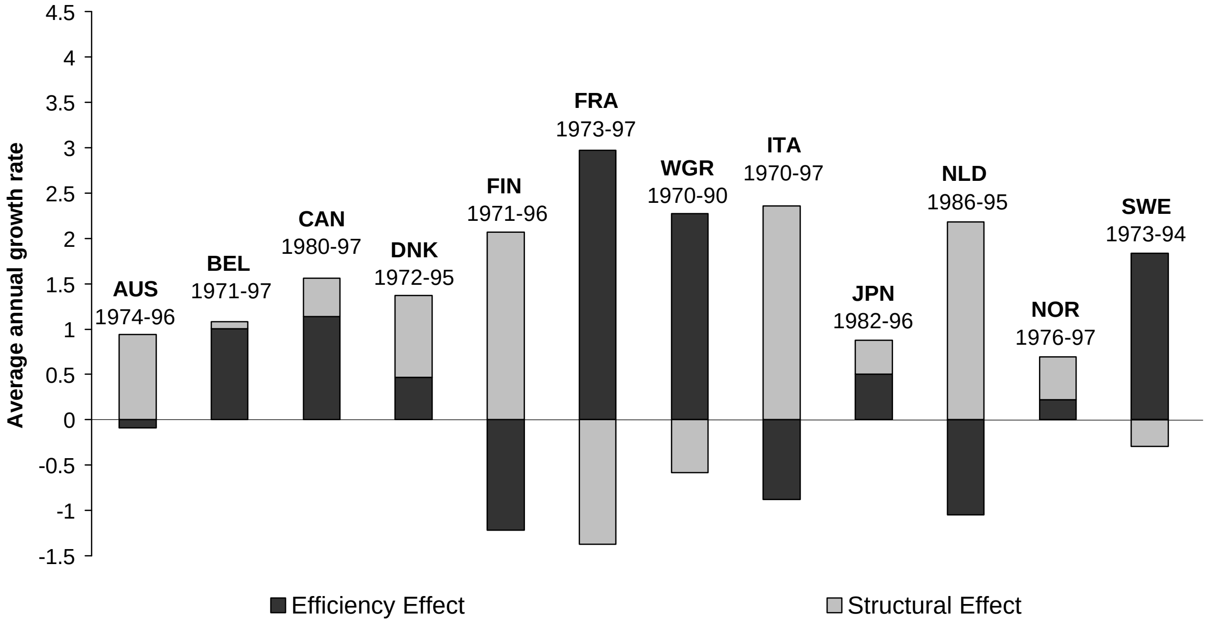

Figure 5. Decomposition of average annual growth rate of macroeconomic labour productivity

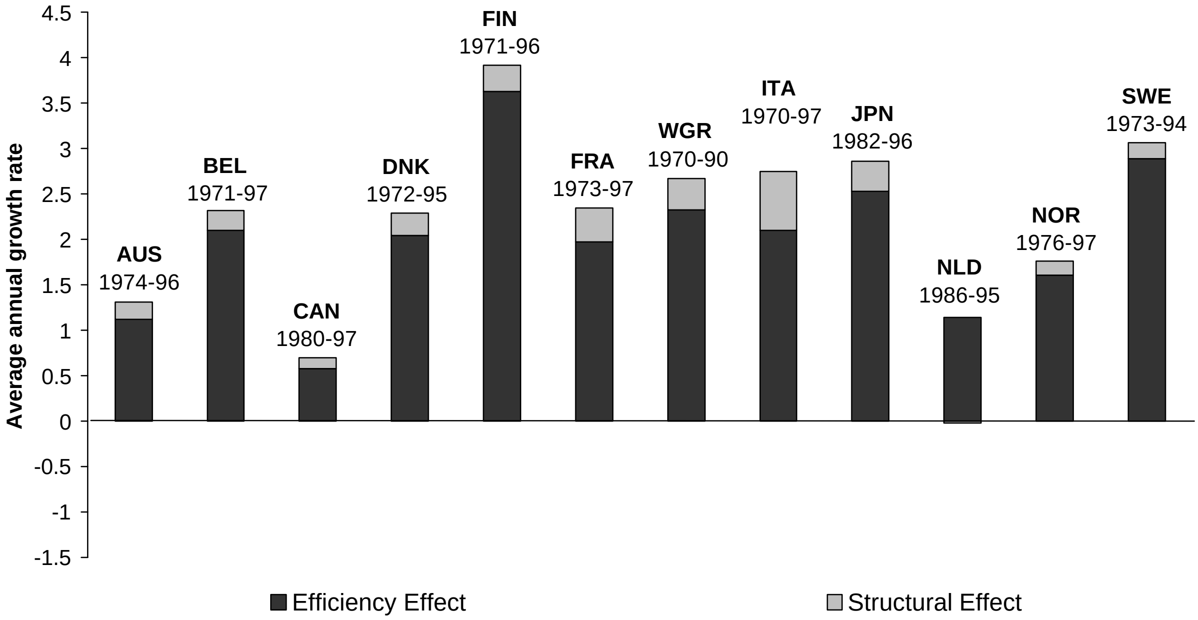

Figure 6. Energy- and labour productivity main sectors. Average annual growth rates