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INNOVATION ACTIVITIES AND INDUSTRIAL STRUCTURE:

INDUSTRY AND R&D IN A COMPARATIVE CONTEXT

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Summary

1. In the past, R&D has played a significant role in innovation policy. However the emphasis on R&D is now changing to a more complex mix of measures and instruments designed to reflect the fact that non-R&D aspects of both innovation and diffusion processes are increasingly important. Nevertheless, R&D remains a key input to innovation, and it is important to understand more about the nature of variation in R&D inputs.

2. In the past, analysts have focussed on the *effects* of differences in R&D intensity, rather than their *causes*. We seek to identify one particular causal factor in inter-country variation in R&D intensity, namely differences in industrial structure. We argue that this perspective may be of policy relevance, since it suggests that R&D, rather than being an independent causal factor in economic performance, may itself be shaped by a wide variety of non-R&D activities (including policy measures). In understanding innovative performance it is therefore important to be careful of the view that R&D plays some independent determining role.

3. How should we assess and interpret differences in R&D intensities (that is, R&D/Output ratios) between economies, particularly in the manufacturing sector? Variations in manufacturing R&D intensities are often substantial: small economies tend to have much lower manufacturing R&D intensities than large economies.

4. This paper shows that these differences predominantly reflect differences in industrial structure, rather than some underlying differences in the willingness or ability to perform R&D. The paper develops methods for quantifying the effects from R&D intensity which flow from absolute size and from the particular structure of industry in twelve economies within the Triad of North America, Japan and EC and EFTA Europe.

5. From a policy point of view, a clear lesson here is that we need to be very careful in making inter-country comparisons with science and technology data. In many economies, especially small economies, innovation policy-makers have the objective of raising the R&D intensity of manufacturing industry. Our analysis suggests that such objectives may need to be reconsidered, since R&D intensities strongly reflect the underlying activities of the economy. R&D performance seems to reflect what we call "R&D capability", which is a complex phenomenon based on all of the factors which shape the industrial structure. R&D should not be seen simply as an independent and separate factor in the technological performance of industries; rather, it is itself shaped by the multi-faceted non-R&D processes which shape industrial structures and industrial performance. If there is a policy conclusion to be drawn here, it may be that technological performance cannot be improved simply by raising R&D levels; it may be more important to focus on the wider processes which shape R&D performance. Finally, we suggest that these structural aspects of R&D have implications for policies which seek to improve convergence and cohesion in the EC.

Contents

1. Introduction

For many countries, a major problem in innovation policy lies in deciding the mix between R&D and non-R&D support measures. In the past, R&D has played a predominant role in such policy; however this is now changing to a more complex mix of measures and instruments designed to reflect the fact that non-R&D aspects of both innovation and diffusion processes are increasingly important. Nevertheless, R&D remains a key input to innovation, and it is important to understand more about the nature of variation in R&D inputs, and about the economic significance of such variation. This problem is in part a matter of understanding comparative R&D performance. This study argues that the usual measures of R&D performance - the R&D/Output ratio, sometimes referred to as the R&D intensity - can be misleading, and it explores a more nuanced approach to analysing R&D intensities in a transnational context.[1] One basic issue - of some importance for issues relating to cohesion in Europe - is the simple fact that larger economies tend to have higher R&D intensities, and different industry mixes, from small economies. Differences in the industrial mix are particularly important for analysing comparative innovation performance: different industries have different methods of creating technologies, with some industries relying heavily on R&D, while others access technology without significant research effort, for example by diffusing skills and technologies from other industries and sectors. This suggests that the industrial mix of a country will have significant effects on its overall R&D intensity, and this should be taken into account in making transnational comparisons.

Making such comparisons is an important challenge for innovation policy makers, in forming and implementing both national policy decisions and transnational decisions (for example at the level of the EC). Many policy decisions involve some assessment of relative strengths and weaknesses, of patterns of technological specialization, and of national and regional differences, and so on. This implies that we should take heed of relevant industrial differences when analysing performance differences using science and technology indicators. This can be a serious problem in comparative analyses at national level, because the aggregate statistics which are used to make international comparisons (such as national accounts statistics, or statistics at sector level)

[1] For related analyses of difficulties in using these measures in a policy context, see K. Hughes, "The interpretation and measurement of R&D intensity: a note", **Research Policy**, 17 (1988), 301-307, and K. Palda, "Technological intensity: concept and measurement", **Research Policy**, 15, 1986, pp. 187-198.

usually do not take account of even major variations in the underlying economic activity.

Improving the quality of transnational comparisons is partly a problem of producing new data (such as data on innovation outputs and non-R&D innovation costs), and partly of having a more sophisticated understanding of the data which we already have. By far the most important data on innovation inputs are official R&D statistics, which are available for most advanced countries, often over long time periods. Understanding R&D data is therefore of considerable importance for understanding innovation patterns across countries, especially since direct surveys of innovation usually show that R&D is closely correlated with innovation outputs at firm level. And in practice, policy-makers frequently use comparative R&D intensities (meaning R&D to output ratios for sectors) as a basis for discussing policy problems. For example, most small economies have lower R&D intensities than large economies, and it is very common to find policy-makers in small countries arguing that a core task for innovation policy is to raise R&D intensity.

However there are a number of complexities in making cross-country comparisons on the basis of R&D performance. This study takes up two basic problems, and shows how they can be taken into account in comparing R&D performance. These problems are, firstly, the absolute size of the economy, and secondly, its industrial structure. Both have important effects on R&D intensity, and should therefore be part of any transnational comparisons. In terms of size, there appears to be a clear positive link between the absolute size of an economy, and its R&D intensity, so simply comparing small and large economies without taking account of this size effect is potentially misleading. Secondly, R&D intensities, both for the manufacturing sector and for the economy as a whole, are strongly shaped by industrial structure. At the simplest level, an economy which specialises in industries which do not access their technologies through R&D will have a lower R&D intensity than an economy which has a large proportion of output coming from industries which rest in some sense on research. This industrial structure effect can be very important in analytical terms. But it is important in policy terms as well, because it is highly relevant for the balance between R&D policies and other forms of policy (such as diffusion or training policies) in the overall innovation policy mix.

In the study which follows, we focus on these two characteristics - size and industrial structure - and show how they interact, and how they affect our understanding of overall R&D performance in small and large economies of the Triad.

2. Sources and data

In this study we compare R&D intensities in the manufacturing sector across 12 different countries. We examine the relationship between these R&D intensities and the size of the economies concerned, as measured by GDP (gross domestic product), and then try to describe this relationship in further detail by taking the industrial structure of the countries concerned into account. Our main data source is a preliminary version of the *OECD STAN data base*, which involves a wide range of data including consistent R&D and output data from 1970 to 1987 for a number of countries; where necessary we have supplemented the STAN data with data drawn from the *Basic Science and Technology Statistics* publication from the OECD, and from national accounts statistics, also from the OECD.

By the *R&D intensity* in a given sector of the economy we understand the total R&D expenditures in this sector expressed as a proportion of total production in the sector (the sector in question may of course also be e.g. the whole economy). The R&D intensity within manufacturing industry we accordingly define as the *ratio between total R&D expenditures and total value added in the manufacturing sector*. The kind of R&D expenditures we consider are *all* expenditures on R&D, in our case in the manufacturing sector of the business enterprise sector, irrespective of source of financing. These are referred to as *BERD* (Business enterprise expenditure on R&D) in the OECD data sources. In addition to R&D expenditures financed by business enterprises themselves, they include government expenditure on R&D performed within the business enterprise sector, as well as 'funds from other national sources' and 'funds from abroad'.

In this study we look at comparative R&D performance in one particular year, namely 1985. The countries we compare are the USA, Japan, the Federal Republic of Germany (as it was in 1985), France, the UK, Italy, Canada, Australia, Denmark, Finland, Norway and Sweden; our selection is governed by data availability and consistency. However, the data are not altogether complete for these 12 countries. In the case of Finland, R&D expenditure figures are missing for several industries, and we have had to make a number of estimates using other sources. For the other countries, there are very few missing data.

3. Comparing R&D Intensities

Let us now look at the data. If we for each of the 12 countries we divide the total R&D expenditures in the manufacturing industry sector by total value added in the manufacturing industry sector, we get the R&D intensities in manufacturing industry in 1985 reported in Table 1, below.

Table 1: **R&D intensities in manufacturing, per cent, 1985.**

USA	9.7
Sweden	8.3
UK	6.5
Germany	5.8
Japan	5.7
France	5.6
Norway	3.4
Finland	3.4
Canada	3.2
Denmark	3.0
Italy	2.4
Australia	1.8

The mean of this distribution is 4.9, with standard deviation 2.3.

With the help of the average and the standard deviation we can express these R&D intensity figures in terms of so-called 'standard scores' or 'z scores', to get a clearer impression of each economy's relative position within the distribution. The meaning of these standard scores or 'z scores' is the following: in a univariate distribution, the standard scores express the values of each of the units on this variable in terms of the distance from the average of the distribution in question, where the unit of measurement is the standard deviation of the distribution. We get these standard scores, that is, by subtracting the average of the distribution from the original scores and then dividing by the standard deviation. In other words, we are measuring how many standard deviations each country is from the mean. These standard scores are shown in Table 2, below.

Table 2: **R&D intensities in manufacturing, z scores, 1985.**

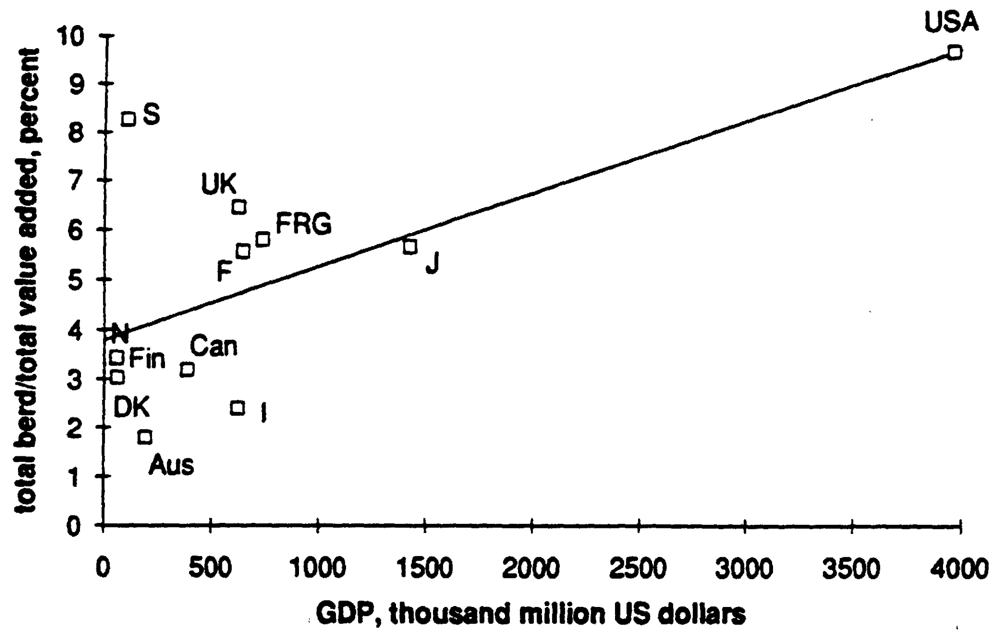
USA	2.06
Sweden	1.44
UK	0.67
Germany	0.39
Japan	0.33
France	0.29
Norway	- 0.63
Finland	- 0.63
Canada	- 0.73
Denmark	- 0.80
Italy	- 1.07
Australia	- 1.33

Table 1 shows that the USA has a R&D intensity in manufacturing of 9.7 %, while the mean is 4.9 % and the standard deviation is 2.3 %. This gives a z score for the USA on this variable of 2.06, registered in Table 2, which means that 9.7 % lies 2.06 standard deviations above the average of the distribution. Similarly, Australia's z score of - 1.33 means that this country's manufacturing R&D intensity of 1.8 % lies 1.33 standard deviations *below* the average of the distribution.

What seems to emerge from the above tables is that the large economies tend to have above-average manufacturing R&D intensities, while the small economies tend to have below-average intensities. If we define the USA, Japan, Germany, France, the UK and Italy as large economies, the remaining six as small ones, we find only two exceptions to this general tendency. These, however, are *gross* exceptions. Sweden is a small economy, but has a very high R&D intensity in the manufacturing industry, second only to the USA. On the other hand Italy is a large economy with a very low manufacturing R&D intensity.

In Figure 1, below, we show the relationship between size of economy and manufacturing R&D intensities by plotting these intensities against GDP. We have here used purchasing power parities (PPP) , rather than the exchange rates, to express the value of the GDPs of the different countries in US dollars.

Figure 1: **R&D intensity in manufacturing and size of economy, 1985.**



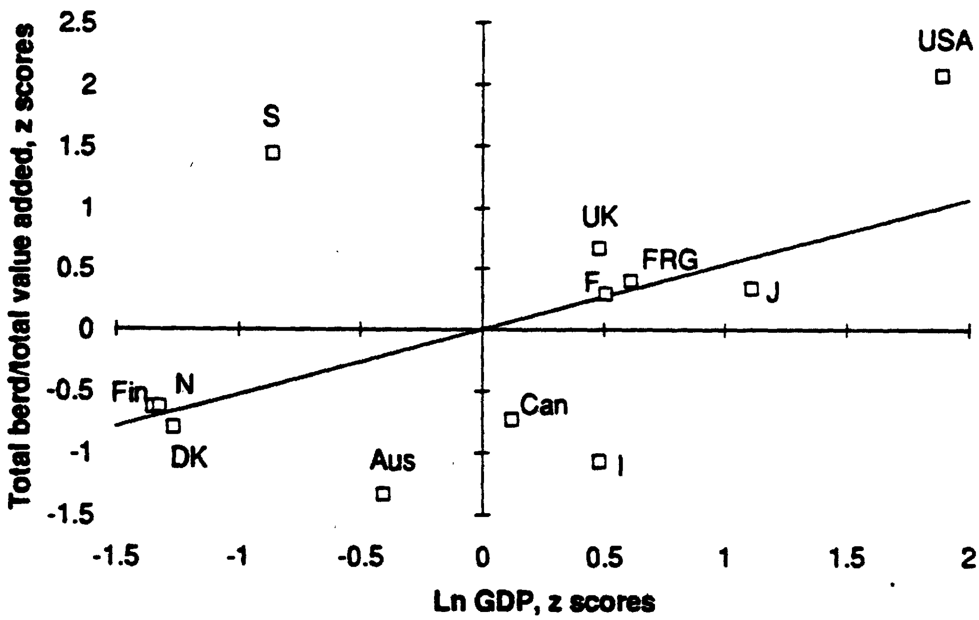
Notice that Norway and Finland are so close both in manufacturing R&D intensity and in GDP that they are not distinguishable in this diagram and are consequently represented by the same point.

There is a relatively high positive correlation between size of the economy as measured by the GDP and R&D intensity in the manufacturing sector. This relationship is illustrated by the linear regression line drawn through the diagram. The Pearson product-moment correlation coefficient, $r = 0.67$, $r^2 = 0.44$. Using a one-tailed test, this relationship is statistically significant (significantly larger than zero) at the .01 level of significance.

A word should be said about reporting statistical significance in this context, however. Firstly, regression coefficients and significance depend closely on the structure of the sample. On the one hand, taking out outlier economies such as Sweden and Italy, and perhaps also the USA (on the grounds of its size and technological leadership position) we might find an even tighter fit in the data. On the other hand, there is no question of generalizing from our sample to all the countries in the world, since our sample is a sample of very special economies: it consists of some of the most highly developed in the world economy, including its absolute leaders. With these reservations in mind, therefore, the larger the absolute size of the economy, the higher the R&D intensity of the manufacturing sector tends to be.

We now want to depict this relationship in a slightly different way, which makes the difference between large and small economies come out more clearly. This is done in Figure 2, below. This diagram differs from the one in Figure 1 in two ways. First, the scores on both variables have been transformed into 'standard scores' or 'z scores'. Second, when it comes to depicting size of economy (along the x-axis), we have not used the z scores of the GDP figures, but the z scores of *ln* to GDP. This has the effect of spreading the countries more evenly along this dimension.

Figure 2: **R&D intensities in manufacturing industry, z scores, and size of economy, z scores ln GDP, 1985.**



The differences among the large countries appear smaller than in Figure 1, which basically means that the score of the USA becomes less extreme compared to the other countries. At the other end of the scale, the differences among the small countries appear larger (notice that it is now possible to distinguish Norway and Finland), and they are to a lesser degree clustered together to the left in the diagram.

In Figure 2, then, we get the large economies to the right of the y-axis and the small economies to the left, apart from Canada, which comes slightly over to the right side. The figure clearly shows, then, that apart from the two gross exceptions, Italy and Sweden, the large economies have a manufacturing R&D intensity above average and the small economies a manufacturing R&D intensity below average.

Apart from the purely illustration purpose of using the *ln* to GDP instead of (or rather in addition to) the GDP, we also want to use the *ln* to GDP as an additional, separate measure of economy size. Even if we should have an hypothesis that there tends to be a positive relationship between economy size and R&D intensity, we might not have any idea as to the exact *shape* of this relationship, whether it is linear or non-linear, for instance, or whether there are critical threshold values involved, etc. Checking what happens with the relationship when we use a different measure of might then be of interest, especially if we should suspect that the correlation we found in the first place was heavily influenced by the one score of the USA. Computing the correlation coefficient between manufacturing R&D intensity and economy size when economy size is measured by ln to GDP, we get $r = 0.53$, $r^2 = 0.28$. With a one-tailed test, we find this relationship statistically significant at the 0.05 level.

We see that we get a somewhat smaller correlation than when we used GDP as a measure of economy size. The correlation is still a relatively high one, however. Again we have illustrated this relationship by drawing a linear regression line through the diagram (with z scores on both variables, r equals the slope of the regression line).

4. Interpreting Differences in R&D Intensity

How should one interpret these differences in manufacturing R&D intensities across countries? We will first suggest an interpretation which at first sight might seem plausible, but we will then suggest that this interpretation is superficial and one-sided, and that more complex relationships need to be examined before any conclusions can be drawn.

To simplify, then, the interpretation that might seem plausible at first sight, would be to see these differences in R&D intensities as reflecting differences in *performance* across countries. That is, the manufacturing sectors of some countries perform better when it comes to how much technological progress, structural change, productivity growth, etc., is going on inside each countries. The hypothesis would be that in some countries the manufacturing industry is advanced, dynamic, forward looking, and so on, and this is reflected in relatively high R&D intensities. On the other hand, in countries with a less advanced, less dynamic, less forward looking manufacturing sector, R&D intensities tend to be lower. This again one might think of as reflecting the different mentalities, attitudes, ideologies, etc., characteristic of the different cultures of the countries in question, or as reflecting differences in social and material resources to perform industrial R&D, or both. As we noted above, these views are frequently taken by policy-makers in low-R&D-intensity economies.

The above result, showing that there is a clear tendency for the large economies to have higher R&D intensities within the manufacturing sector than the small economies, might then be interpreted as reflecting that the large economies generally *perform* better than the small ones when it comes to dynamism, technological change, innovation, etc. One reason for this might be that inside the large economies the concentrations of resources required to perform and use R&D efficiently more easily occur than inside the small ones; this might be seen as a modified version of Schumpeter's arguments about firms size and innovative activity. Thus the concentration of financial resources, e.g. inside large corporations, and the concentration of human resources in large agglomerations, makes possible dense networks of R&D institutions and qualified personnel. In short, *scale* is crucial. One might perhaps also postulate that the large economies generally offer an environment which is conducive to dynamism on the part of economic actors, whereas the small economies on the contrary lack these positive environmental factors.

However, as we indicated above, this interpretation of differences in R&D intensities in terms of differences in performance, dynamism, advance, etc., is problematic. If not necessarily wrong, at the very least it is premature. There are, of course, several difficult problems involved here, among them the question of to what degree mere *expenditures* on R&D are a good indicator of technological and economic *performance*. This problem we will not discuss here, though it is a real one (especially when using aggregate data to make comparisons).

But even granted that R&D intensities constitute a reasonably good indicator of technological and economic performance, there is one crucial dimension which remains hidden in these overall manufacturing R&D intensity figures, namely the *industrial structures* of the economies in question. We turn now to this issue.

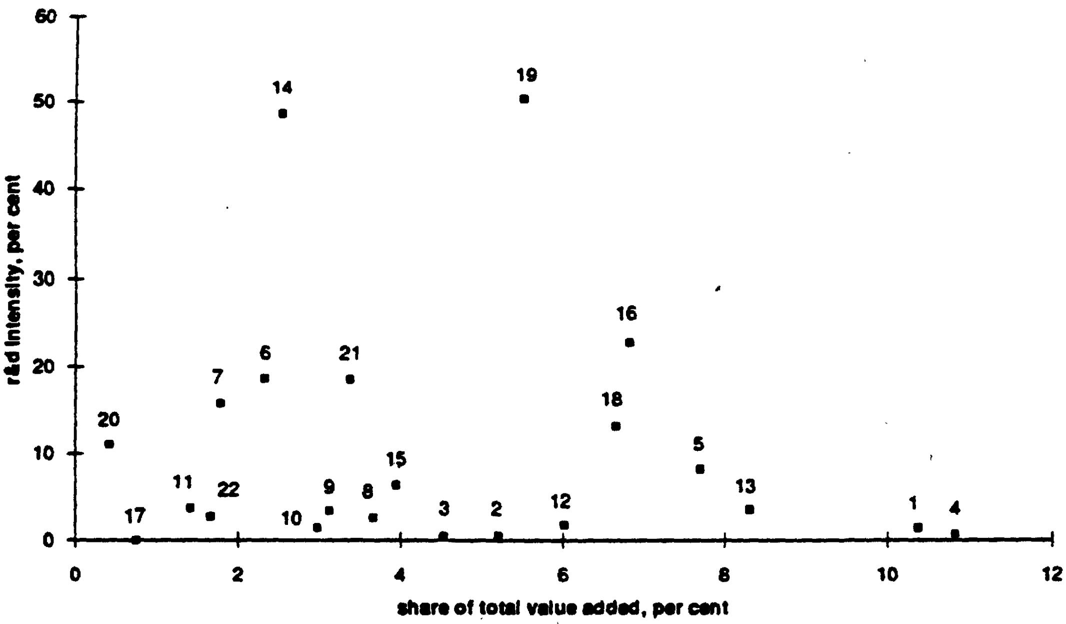
5. R&D Intensity and Industrial Structure

The manufacturing sector in any country is of course made up of a multitude of different industries, and the overall manufacturing industry R&D intensity of a given country is the sum of all R&D expenditures in all these industries divided by the sum of all the value added in all these industries. We can also calculate an R&D intensity for each of these industries. Now the main point here is that these industry-specific R&D intensities *vary enormously across industries*.

Let us explain this more precisely. In the OECD data sources total manufacturing production is divided into 22 different industries at 3-digit ISIC level. Both R&D expenditures (BERD) and value added are given for each of these industries, for each of the 12 countries in STAN. For each of the 12 countries we have taken each of these 22 industries and calculated its R&D intensity and its share of the country's total value added in the manufacturing sector. It is the pattern of the different industries' share of total manufacturing value added of each country that we here refer to as the *industrial structure* of the country concerned.

How much does R&D intensity vary across industries? Let us first take the case of the USA. Figure 3, below, depicts R&D intensity and share of total US manufacturing value added for each of the 22 industries that the manufacturing sector has been divided into in the OECD data sources.

Figure 3: **R&D intensity and share of total manufacturing value added of 22 industries, USA, 1985.**

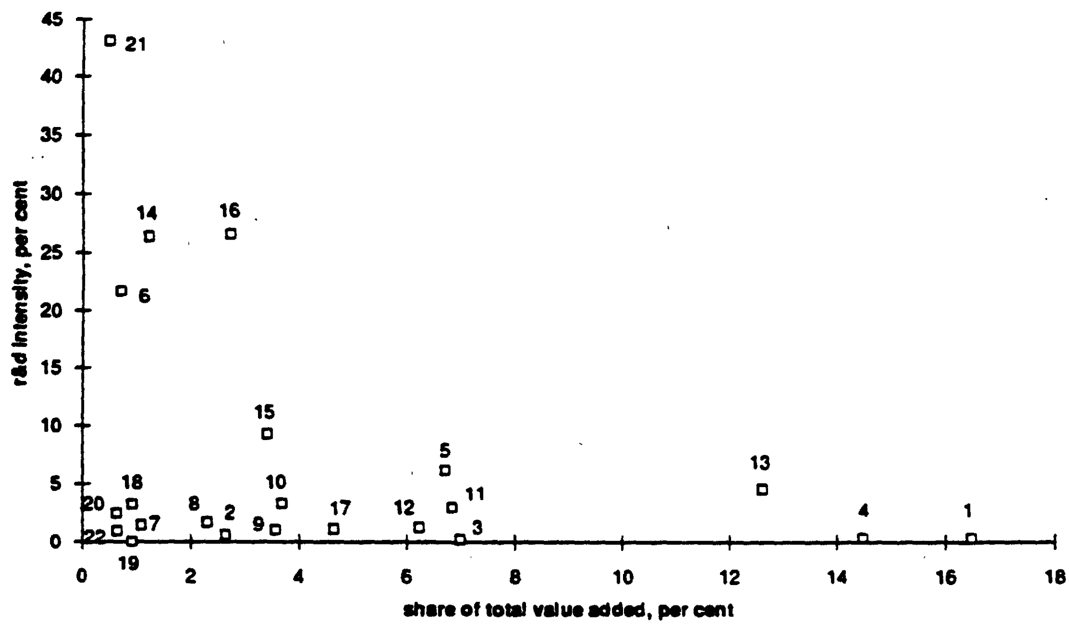


The industries are the following:

1	Food, drink and tobacco	12	Fabricated metal products
2	Textiles, footwear and leather	13	Non-electrical machinery
3	Wood, cork and furniture	14	Computers and office machinery
4	Paper, print and publishing	15	Electrical machinery
5	Industrial chemicals	16	Communication equipment and semiconductors
6	Pharmaceuticals	17	Shipbuilding
7	Petroleum refining	18	Motor vehicles
8	Rubber and plastic products	19	Aerospace
9	Stone, clay and glass	20	Other transport equipment
10	Ferrous metals	21	Instruments
11	Non-ferrous metals	22	Other manufacturing

In Figure 3 we have also identified each of the industries by numbers from 1 to 22, referring to the table above. It should be noted that for the USA there are no data for R&D expenditures in the shipbuilding industry (no. 17 in Figure 3). The figure shows clearly that the variation in R&D intensities across industries is very great, even inside one single country. This is not something which holds only for the USA. To take another example, we have made the same calculations of R&D intensities and share of total manufacturing value added of the different industries for an economy which is very different from the US economy, namely the Norwegian. The results are shown in Figure 4, below.

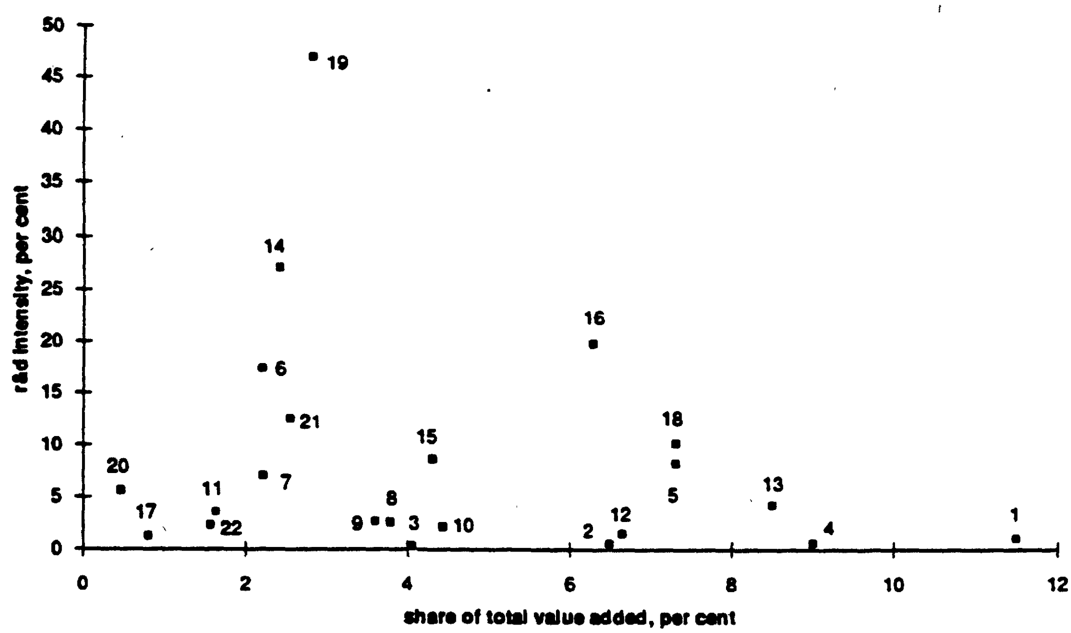
Figure 4: **R&D intensity and share of total manufacturing value added of 22 industries, Norway, 1985.**



The numbers identifying the different industries refer to the same table as in Figure 3. It should be noted that in the Norwegian case there are no data for R&D expenditures in the aerospace industry (no. 19 in the figure). We see that also the Norwegian manufacturing sector is characterized by very large inter-industry differences in R&D intensities. Comparing the two figures we see that, although R&D intensities in the same industry do vary between the two countries, substantially in some industries, insignificantly in others, there is a very clear tendency for the same industries to have high, respectively low, R&D intensities in both countries.

This quite generally applies among the 12 countries we examine. Irrespective of country, some industries tend to have high R&D intensities, some tend to have low R&D intensities. Although there is intra-industry variation in R&D intensities across countries, we may think of each industry as having a typical R&D intensity, which may be described for instance by giving some kind of average value. In Figure 5, below, we have depicted R&D intensity and share of total manufacturing value added for each industry for the 12 countries in our study *combined*. The R&D intensity of each industry we get when we take the total R&D expenditures and the total value added in each industry of the 12 countries combined might be thought of as one indicator of what the typical R&D intensity of each industry is.

Figure 5: **R&D intensity and share of total manufacturing value added of 22 industries, total for the 12 countries, 1985.**



The reference for the numbers identifying the industries is still the same as above. Quite generally we see that the industries having high, respectively low, R&D intensities to a very high degree tend to be the same as in the cases of the USA and of Norway (of course, given that the USA has almost 40 per cent of the manufacturing value added and 54 per cent of R&D expenditures in the manufacturing sector of these 12 countries together, both the R&D intensities and the industrial structure of these 12 countries taken together will by and large be highly influenced by the R&D intensities and the industrial structure of the US economy). By contrast, Norwegian R&D intensities and industrial structure hardly influences the totals at all, given that Norway accounts for no more than 0.4 per cent of the manufacturing value added and 0.2 per cent of the manufacturing sector R&D expenditures of the 12 countries).

These *typical* R&D intensities of each industry may be thought of as a characteristic of the industry as such, reflecting the fact that the R&D intensity of an industry to a large extent will be determined by the specific products of the industry, its typical production processes, demand conditions, the conditions of the competition in the industry, etc. Figure 5 shows that industries which typically have high R&D intensities are *aerospace* (no. 19), *computers and office machinery* (no. 14), *communication equipment and semiconductors* (no. 16), *pharmaceuticals* (no. 6), *instruments* (no. 21), *motor vehicles* (no. 18), and *electrical machinery* (no. 15). By contrast, important industries which typically have very low R&D intensities are *food, drink and tobacco* (no. 1), *paper, print and publishing* (no. 4), *textiles, footwear and leather* (no. 2), and *wood, cork and furniture* (no. 3).Basically the same picture emerges from Figure 3 and Figure 4. These differences are of course the basis for the OECD's well-known classification of industries into high, medium and low R&D-intensive industries.[2]

Now, given the enormous inter-industry variation in R&D intensities, the overall manufacturing R&D intensities of each country will be crucially dependent on its industrial structure. If a country has a disproportionately large share of its manufacturing production in the high intensity industries, this will, all other things equal, contribute to a high overall manufacturing R&D intensity. Since the inter-industry variation in R&D intensities is very large, this will be the case even if the country in question should have R&D intensities substantially below average in these high intensity industries. A disproportionately large share of manufacturing production in the low intensity industries will have the opposite effect on overall manufacturing R&D intensity. In this way it is quite possible for one country to have a higher R&D intensity than another country in each single industry, and nevertheless have a lower overall manufacturing R&D intensity, namely if the industrial structure of the first country to a larger extent is dominated by low R&D intensity industries than the second.

Going back to figures 3 and 4 again and comparing the US and Norwegian industrial structures, we do indeed find that the USA has a larger, and generally substantially larger, share of its manufacturing production in *all* the above-mentioned high R&D intensity industries. By contrast, Norway has a substantially larger share of manufacturing production than the USA in important very low R&D intensity industries like *food, drink and tobacco*, *paper, print and publishing*, and *wood, cork and furniture*. It seems reasonable to suppose, then, that a large part of the difference in overall manufacturing R&D intensity between the USA and Norway can be accounted for by the different industrial structures of the two countries.

However, when inspecting figures 3 and 4 more closely and comparing the R&D intensities of the two countries in each industry separately, the general impression is that the USA has a higher R&D intensity than Norway in about 2/3 of the 22 indus-

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[2] See OECD, **Science and Technology Indicators No 2: R&D, Innovation and Competitiveness** (OECD: Paris), 1986, pp. 58-70

tries, whereas the opposite is the case in the remaining 1/3. This suggests that the difference in overall manufacturing R&D intensities between the USA and Norway *also* to a certain extent is accounted for by the fact that the USA by and large has a higher R&D intensity than Norway in each of the industries taken separately.

In the following we will try to examine this issue in a more systematic way. Our point of departure is the overall manufacturing R&D intensities of the 12 countries in our sample. As we have seen, the overall manufacturing R&D intensity varies substantially across these countries. We want to be able say something about to what extent this variation expresses variation in industrial structure across these countries, and to what extent it expresses differences in R&D intensities among countries within the different industries.

Furthermore, a central theme of this paper is that there is a positive relationship between size of economy and manufacturing sector R&D intensity. Specifically, then, we want say something about to what extent this relationship between size of economy and R&D intensity in the manufacturing sector expresses differences in industrial structure between large and small economies and to what extent it expresses that large economies tend to have higher R&D intensities within the different industries than the small ones. Is the industrial structure the crucial factor, or is it rather the R&D intensities within the different industries, or are these two dimensions generally connected so that an 'advanced' industrial structure and high R&D intensities within the different industries tend to go together?

We consequently will try to construct some summary measures which permit us to decompose the overall manufacturing R&D intensities of the different countries into, on the one hand, what is due to the industrial structure of the country in question, and, on the other hand, what is due to the R&D intensities within the different industries. The latter of these measures involves the idea of somehow comparing the differences in overall manufacturing R&D intensity across countries *when the differences in industrial structure across the countries have been taken account of.*

6. Industrial structure and R&D Intensity: Decomposition

In this section we simply set out some of the above ideas in a more formal way; we then go on to quantify the effects of industrial structure. Our point of departure is the overall manufacturing R&D intensity of a given country (i.e. any of the countries which we examine), which we will denote by I_{tot} .This is defined by

$$I_{tot} = \frac{BERD_{tot}}{VA_{tot}} \quad ,$$

where $BERD_{tot}$ denotes total R&D expenditures in the manufacturing sector and VA_{tot} denotes total value added in the manufacturing sector of the country concerned. Now,

$$BERD_{tot} = BERD_1 + BERD_2 + \ldots\ldots\ldots + BERD_n \quad ,$$

where $BERD_1$, $BERD_2$, etc., denotes R&D expenditures in, respectively, industry no. 1, industry no. 2, etc., up to industry no. n (i.e. no. 22 in our case). Substituting in the above expression, we can express the overall manufacturing R&D intensities by:

$$I_{tot} = \frac{BERD_{tot}}{VA_{tot}} = \frac{BERD_1}{VA_{tot}} + \frac{BERD_2}{VA_{tot}} + \ldots\ldots\ldots \frac{BERD_n}{VA_n} \quad .$$

This expression we can transform by multiplying each of the components of the sum by $\frac{VA_i}{VA_i}$, i.e. by 1, where VA_i is value added in industry no. i:

$$I_{tot} = \left(\frac{BERD_1}{VA_1} \cdot \frac{VA_1}{VA_{tot}}\right) + \left(\frac{BERD_2}{VA_2} \cdot \frac{VA_2}{VA_{tot}}\right) + \ldots\ldots\ldots + \left(\frac{BERD_n}{VA_n} \cdot \frac{VA_n}{VA_{tot}}\right) \quad ,$$

or

$$I_{tot} = \sum_{i=1}^{n} \frac{BERD_i}{VA_i} \cdot \frac{VA_i}{VA_{tot}} \quad .$$

Now, the first expression, $\frac{BERD_i}{VA_i}$, of course gives the R&D intensity in industry no. i, which we will denote by I_i. The second expression, $\frac{VA_i}{VA_{tot}}$, is industry i's share of total value added, which we will denote by w_i (w for weight). We then get:

$$I_{tot} = \sum_{i=1}^{n} I_i \cdot w_i \quad .$$

That is to say, the overall R&D intensity in the manufacturing industry sector is the weighted sum of the R&D intensities of all manufacturing industries, when the weights are each industry's share of total manufacturing value added.

We now want to define a typical R&D intensity for each industry. As this typical value we choose the average R&D intensity across the 12 countries in the industry concerned, denoted by $\bar{I}_i$. Notice that these R&D intensities are not the same as those depicted in Figure 5. There we used the R&D intensities in each industry when all the 12 countries together were considered as one large economy. The averages we operate with here are obtained in the following way: In any given industry, each of the 12 countries has a given R&D intensity. The average in question here is just an average of these 12 values, which is to say that it is an unweighted average.

Now, the expression

$$I_{tot} = \sum_{i=1}^{n} I_i \cdot w_i$$

we can transform by adding and subtracting $\bar{I}_i$, that is to say by adding 0, in each of its components:

$$I_{tot} = \sum_{i=1}^{n} \left(I_i + \bar{I}_i - \bar{I}_i \right) \cdot w_i \quad ,$$

which gives

$$I_{wt} = \sum_{i=1}^{n}\left[\left(\bar{I}_i \cdot w_i\right) + \left(I_i - \bar{I}_i\right) \cdot w_i\right]$$

and

$$I_{wt} = \sum_{i=1}^{n} \bar{I}_i \cdot w_i + \sum_{i=1}^{n}\left(I_i - \bar{I}_i\right) \cdot w_i \ .$$

We have here expressed the overall manufacturing R&D intensity of a country as a sum of two different components. The first of these components, $\sum_{i=1}^{n} \bar{I}_i \cdot w_i$, is a measure of the effect of the industrial structure on the overall manufacturing R&D intensity. This is the sum of the average R&D intensities across the 12 countries multiplied by the actual share of total manufacturing value added for each industry of the country in question. It answers the question: Given the industrial structure of the country in question, what would the country's overall manufacturing R&D intensity have been if it in each single industry had had the average R&D intensity of the industry in question? Comparing across the 12 country's, we see that this component tells us what the differences in overall manufacturing intensities among the countries had been if they had had the same R&D intensity in each single industry. Holding R&D intensity constant in this way (here, of course, it is crucial that these same R&D intensities can be said to be typical of the industry in question), this expression may reasonably be thought of as a measure of the effect of industrial structure on overall manufacturing R&D intensities.

The other component of the sum, $\sum_{i=1}^{n}\left(I_i - \bar{I}_i\right) \cdot w_i$, may, then, be thought of as a measure of the pure effect of R&D intensities on overall manufacturing R&D intensities, when differences in industrial structure have been taken account of. For each country, it gives the weighted sum over all industries of the difference between the R&D intensity of the country concerned and the average R&D intensity in each industry, when the weights that are attached to each industry are defined by the industry's share of total manufacturing value added of the country concerned. We will discuss this measure of the 'pure' effect of R&D intensities on overall manufacturing R&D intensities later in the paper.

Now, in the expression $I_{tot} = \sum_{i=1}^{n} \bar{I}_i \cdot w_i + \sum_{i=1}^{n} (I_i - \bar{I}_i) \cdot w_i$, the two components of the sum are not, so to speak, 'symmetrical'. The first component says what the overall R&D intensity would have been if the country in question had had the average industry-specific R&D intensity in each single industry, it gives a hypothetical overall R&D intensity value. The second component, by contrast, is defined as a weighted difference from an average. We now want construct the formula in a more 'symmetric' way, by letting both components be expressed differences from an average.

To do this, we first define the average overall manufacturing R&D intensity among the 12 countries, denoted by $\bar{I}_{tot}$. This is the average of the numbers presented in Table 1, and is an unweighted average. As reported just below Table 1, this average is 4.9 per cent. This average must be distinguished from the overall manufacturing R&D intensity of all the 12 countries combined, which is considerably higher (6.9 per cent), reflecting, of course, that the large economies tend to have higher overall manufacturing R&D intensities than the small ones.

This average value we now subtract from both sides of the equation

$I_{tot} = \sum_{i=1}^{n} \bar{I}_i \cdot w_i + \sum_{i=1}^{n} (I_i - \bar{I}_i) \cdot w_i$ to get

$$I_{tot} - \bar{I}_{tot} = \sum_{i=1}^{n} \bar{I}_i \cdot w_i + \left[\sum_{i=1}^{n} (I_i - \bar{I}_i) \cdot w_i \right] - \bar{I}_{tot} \quad .$$

Rearranging, we get

$$I_{tot} - \bar{I}_{tot} = \left[\left(\sum_{i=1}^{n} \bar{I}_i \cdot w_i \right) - \bar{I}_{tot} \right] + \left[\sum_{i=1}^{n} (I_i - \bar{I}_i) \cdot w_i \right] \quad .$$

This expression takes the difference of the overall manufacturing R&D intensity of the country in question from the average overall manufacturing R&D intensity as the point of departure, and it expresses this difference as a sum of, on the one hand, how much of this difference can be attributed to the industrial structure of the country (the expression in the first brackets), and, on the other hand, how much of this difference can be attributed to the R&D intensities 'as such', i.e. within the different industries (the expression in the second brackets).

7. R&D Intensities: quantitative decomposition

Let us now see what results we get when we for each of the countries in our study decompose the difference between the overall manufacturing R&D intensity of the country and the average overall manufacturing R&D intensity into an effect of *industrial structure* and an effect of *'pure' R&D intensities*, in the way described above.

We start out from the overall manufacturing R&D intensities reported in Table 1 above. Subtracting the average value (4.9 per cent) from the value of each of the countries, we get the differences from the average reported in Table 3, below:

Table 3: **R&D intensities in manufacturing, differences from average, per cent, 1985.**

USA	4.82
Sweden	3.36
UK	1.57
Germany	0.92
Japan	0.78
France	0.68
Norway	- 1.47
Finland	- 1.47
Canada	- 1.71
Denmark	- 1.87
Italy	- 2.50
Australia	- 3.11

It is these overall manufacturing R&D intensities expressed as differences from the average value that we now intend to decompose as a sum of, on the one hand, an effect of R&D intensities within the different industries, and, on the other hand, an effect of industrial structure. The results of this decomposition are given in Table 4, below.

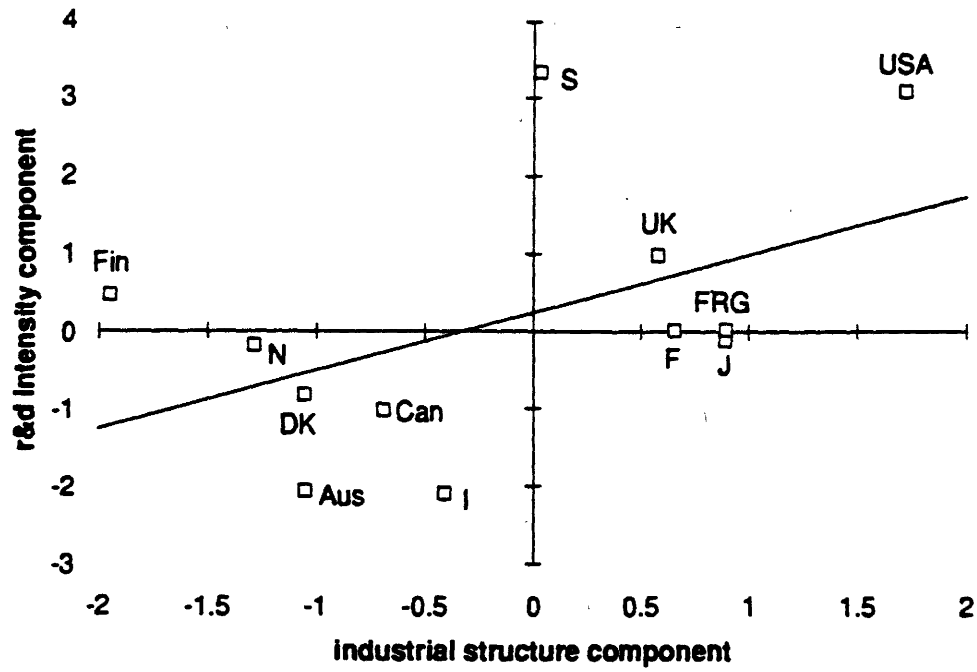
Table 4: **R&D intensities in the manufacturing sector differences from average: Decomposition in effect of R&D intensities within the different industries and industrial structure. 1985.**

	(1) effect of R&D intensities	(2) effect of industrial structure	(3) overall R&D intensities
USA	3.10	1.72	4.82
Sweden	3.33	0.03	3.36
UK	0.99	0.58	1.57
Germany	0.03	0.90	0.92
Japan	- 0.11	0.89	0.78
France	0.02	0.66	0.68
Norway	- 0.18	- 1.28	- 1.47
Finland	0.48	- 1.95	- 1.47
Canada	- 1.02	- 0.69	- 1.71
Denmark	- 0.82	- 1.05	- 1.87
Italy	- 2.09	- 0.41	- 2.50
Australia	- 2.06	- 1.05	- 3.11

Here (1) + (2) = (3).

These results are depicted graphically in Figure 6, below, which shows how the 12 countries are distributed according to their values on the variable expressing the effect on total manufacturing R&D intensity of the R&D intensities within the different industries, along the y-axis, and on the variable expressing the effect on total manufacturing R&D intensity of the industrial structure, along the x-axis.

Figure 6: Decomposition of manufacturing R&D intensities, differences from average, into effect of R&D intensities in the different industries (y-axis), and effect of industrial structure (x-axis), 1985.



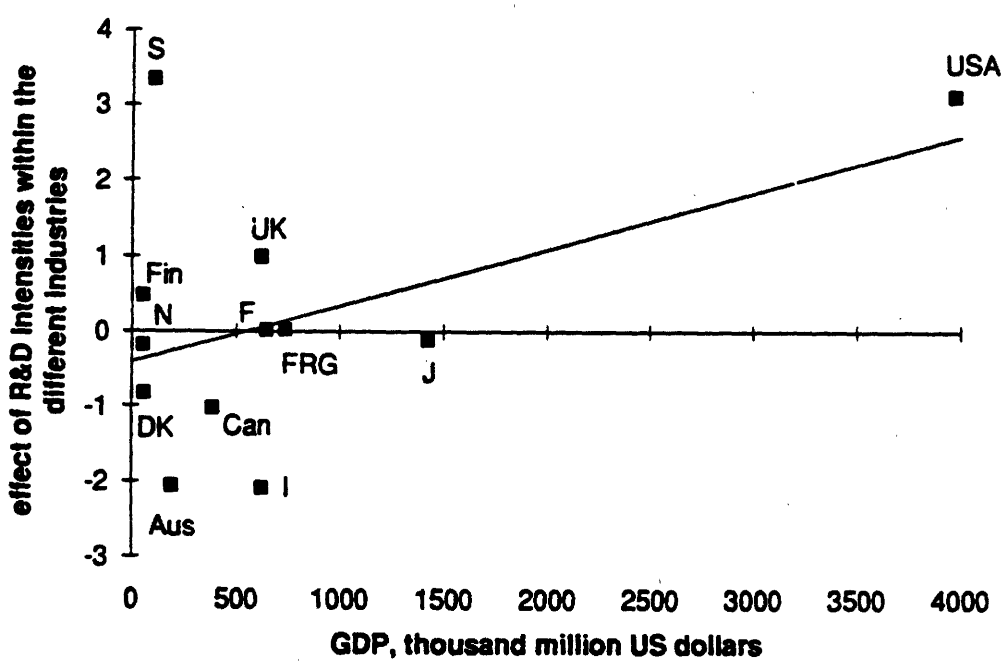
We see that there is a clear tendency for these two dimensions to be connected. Countries with a high value on the industrial structure variable also tend to have a high value on the R&D intensity in the different industries variable, and, especially, countries with a *low* value on the industrial structure variable also tend to have a low value on the R&D intensity in the different industries variable. The correlation is a moderately high one, $r = 0.49$, $r^2 = 0.24$. Using a one-tailed test, we find that this relationship is statistically significant at the .10 level.

We may note some exceptions to this general tendency. The most conspicuous is perhaps Finland, which has by far the lowest value on the industrial structure variable, but nevertheless lies well above zero on the R&D intensity variable. Also Sweden may be counted as a clear exception, with the highest value of all the countries on the R&D intensity variable, but only slightly above zero on the industrial structure variable. The USA, by contrast, has a very high value on both variables.

Returning now to the question of the relationship between overall manufacturing R&D intensities and size of the economy, we will now examine the relationship between size of economy and each of these two components of the overall manufacturing intensities, considered separately.

We start with the relationship between size of economy and the variable measuring R&D intensities within the different industries. Figure 7 below shows the distribution of the 12 countries on these two variables, when size of economy is measured by GDP.

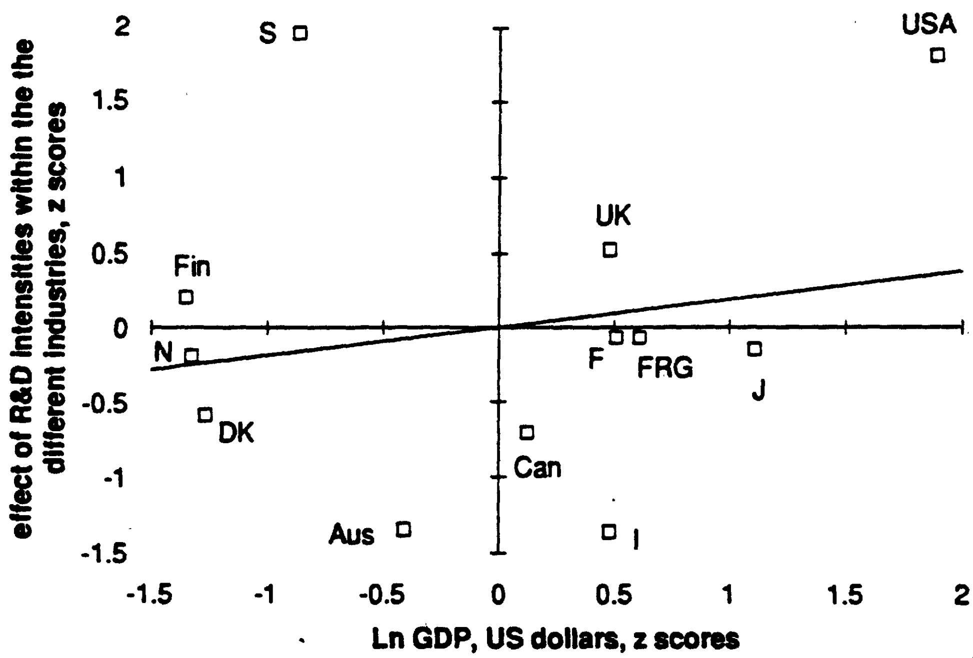
Figure 7: Relationship between GDP (x-axis) and index measuring R&D intensities within the different industries (y-axis), 1985.



Recall that for the correlation between GDP and *overall manufacturing R&D intensity* we had r = 0.67, with $r^2 = 0.44$. The correlation between GDP and the R&D intensity component of the overall manufacturing R&D intensity is lower, with r = 0.48 and $r^2 = 0.23$. (Using a one-tailed test, this relationship is statistically significant at the .10 level). However, a quick glance at this figure suggests that this relationship is heavily dependent on the values of the USA on these two variables. This is indeed the case. If we do not include the USA in the calculation, the correlation becomes quite negligible (r = 0.10, $r^2 = 0.01$).

This is reflected in the fact that when we measure size of economy by *ln to GDP* instead of by GDP, we get a lower correlation between size of economy and the R&D intensity component of the overall manufacturing R&D intensity. In Figure 8, below, we have depicted this relationship. Also, in Figure 8 we use the z scores instead of the 'raw scores'.

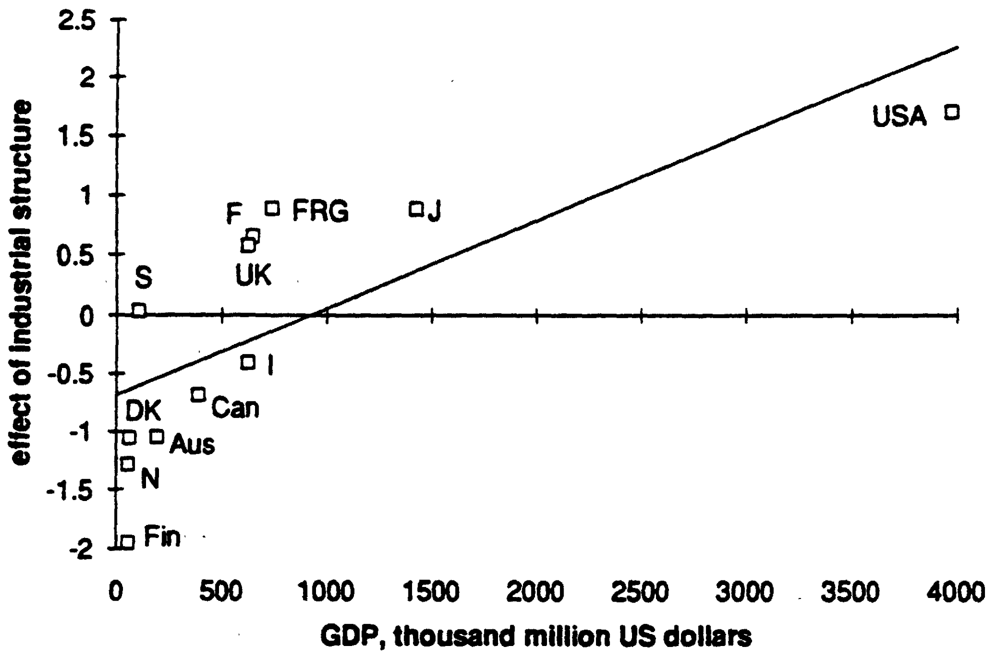
Figure 8: Relationship between ln GDP (x-axis) and index measuring R&D intensities within the different industries (y-axis), 1985. Z scores.



With *ln GDP* as a measure of economy size, we found a correlation between size of economy and overall manufacturing R&D intensity of $r = 0.53$, $r^2 = 0.28$. With this measure the correlation between economy size and the R&D intensity component of the overall manufacturing R&D intensity becomes very much lower, with $r = 0.19$ and $r^2 = 0.04$. This relationship is *not* statistically significant at the .10 level.

We now turn to the relationship between economy size and the *industrial structure component* of the overall manufacturing R&D intensity. First we use GDP as a measure of economy size. This relationship is depicted in Figure 9, below.

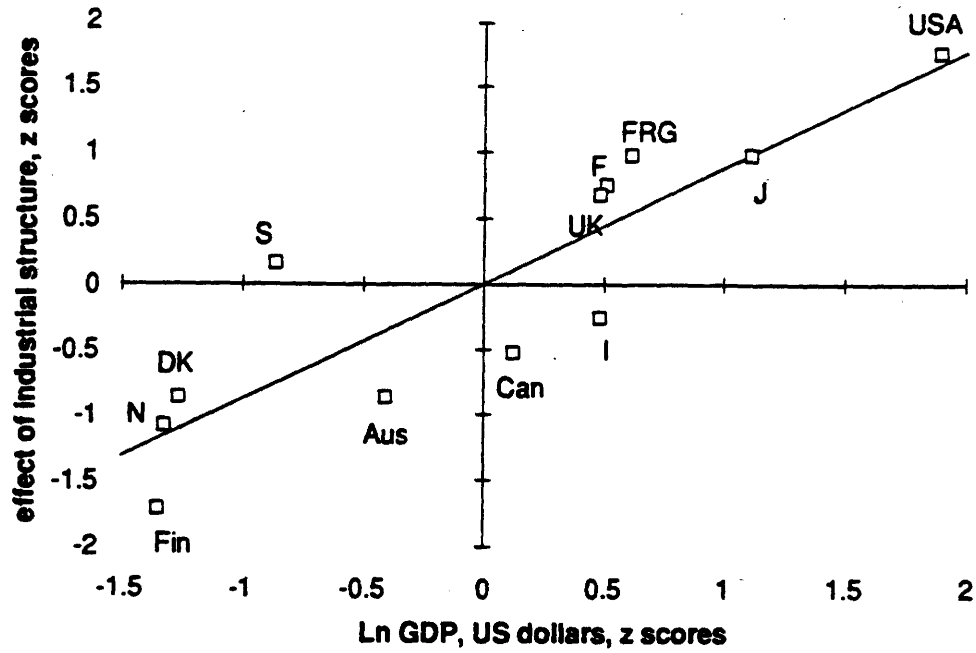
Figure 9: **Relationship between GDP (x-axis) and index measuring the effect of industrial structure on overall manufacturing R&D intensities (y-axis), 1985.**



Here the positive relationship seems evident from the figure. The correlation is high, with $r = 0.74$, $r^2 = 0.55$. This relationship is statistically significant at the .01 level. The correlation is higher than the one between GDP and overall manufacturing R&D intensity, where we had $r = 0.67$. Consequently, it is substantially higher than the correlation between GDP and the R&D intensity component of the overall manufacturing R&D intensity, where we had $r = 0.48$. Besides, this time excluding the USA from the calculations does *not* give a lower correlation. On the contrary, the correlation is even higher excluding the USA ($r = 0.79$, $r^2 = 0.62$).

The relationship between size of economy and the industrial structure component of the manufacturing R&D intensity is even more evident when we measure size of economy by *ln GDP* than by GDP (which is to be expected given that the correlation between GDP and the industrial structure component gets higher when we exclude the USA from the calculations). This relationship is shown graphically in Figure 10, below, where z scores is used on both variables.

Figure 10: Relationship between ln GDP (x-axis) and index measuring the effect of industrial structure on overall manufacturing R&D intensities (y-axis), 1985. Z scores.



The correlation here is a very high one, with r = 0.88 and $r^2 = 0.78$. This relationship is statistically significant at the .01 level. This contrasts with an r of 0.53 for the correlation between ln GDP and overall manufacturing R&D intensity and of only 0.19 for the correlation between ln GDP and the R&D intensity component of the overall manufacturing R&D intensity.

Let us now sum up the argument so far. Our point of departure was the positive relationship between size of economy and R&D intensity in the manufacturing industry sector. This relationship we found both when measuring size of economy by GDP and by ln GDP. Since our data allowed us to break down the manufacturing industry sector into 22 different industries, where for each industry we had data both for R&D expenditures and value added, we were able to decompose R&D intensity in the manufacturing sector into two different components: one component expressing the effect of the R&D intensities within the different industries on total manufacturing R&D intensity, controlling, so to speak, for industrial structure, and one component expressing the effect of the industrial structure on total manufacturing R&D intensity. This should enable us to examine more closely what bearing *industrial structure* has on the relationship between size of economy and R&D intensity in the manufacturing sector. Does the tendency for manufacturing R&D intensity to rise with size of economy primarily mean that the large economies generally tend to have higher R&D intensities in each single industry than the small ones, or does this tendency rather express a difference in industrial structure between large and small economies? Or is it rather the case that these two aspects tend to go together, so that the larger economies both tend to have higher R&D intensities within each single industry *and* a larger proportion of their manufacturing production in industries characterized by high R&D intensity than the smaller economies? By calculating the correlation coefficients between the variables measuring size of economy and the variables measuring the two components of overall manufacturing R&D intensity, we should get an indication of what the answers to these question are.

The results of these exercises are summarized in Table 5, below, where we have given the Pearson product-moment correlation coefficient, r, for the relationship between size of economy and manufacturing R&D intensity, and between size of economy and each of the two components we have decomposed the manufacturing R&D intensity into. Furthermore, we have done this both with GDP and ln GDP as a measure of size of the economy.

Table 5: **Product-moment correlation coefficients (r) between size of economy and manufacturing R&D intensity, and between size of economy and the two components of manufacturing R&D intensity. 1985.**

Measure of size of economy	Overall manufacturing R&D intensity	R&D intensities within different industries component	Industrial structure component
GDP	0.67	0.48	0.74
ln GDP	0.53	0.19	0.88

What this table shows, is that size of economy is much more highly correlated with the industrial structure component of the overall manufacturing R&D intensity than with the R&D intensities within the different industries component. This is especially marked when we use ln GDP as a measure of size of economy, but it also is evident when we measure size of economy simply by GDP. There is a clear tendency, then, for industrial structure to vary with size of economy in such a way that the larger the economy, the higher the proportion of manufacturing production accounted for by industries characterized by high R&D intensity tends to be. This means that all other things being equal, that is, even supposing that R&D intensities in the same industries were the same in large and small economies, the differences in industrial structure between large and small economies would have the effect that the large economies would still have higher overall manufacturing R&D intensities than the small ones.

To have the same overall manufacturing R&D intensity as the large economies, the small economies would generally have had to have *higher* R&D intensities than the large economies within the different industries. But actually, there is also a tendency for the R&D intensities within the different industries to rise with size of economy, although this tendency is far less strong than the tendency for the R&D intensity effect of industrial structure to vary with size of economy.

This would seem to indicate that differences in overall manufacturing R&D intensities between large and small economies to a large extent reflect differences in industrial structure. However, even given the extremely narrow focus of this paper, this is not as straightforward as it might seem. We will now look further into some of the complexities involved.

8. R&D Efforts, Industrial Structure and Size; some causal possibilities

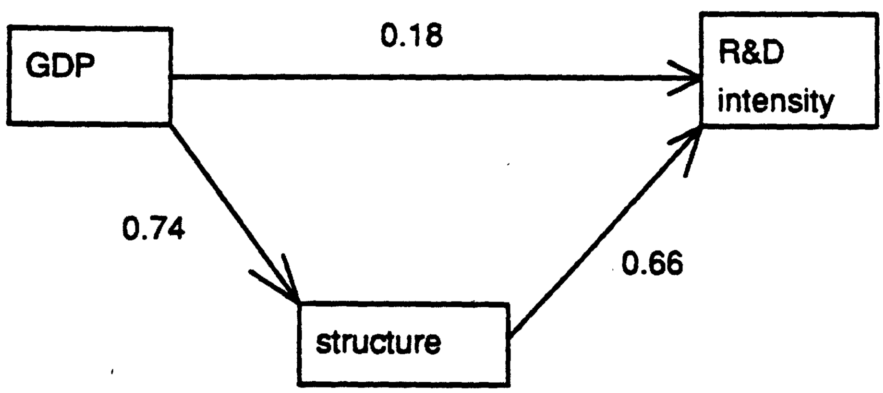
Let us start with a very simple way of depicting the relationship between size of economy, industrial structure and manufacturing R&D intensity. We will think of industrial structure as an 'intermediate variable' which mediates the relationship between size of economy and manufacturing R&D intensity. 'Industrial structure' we will suppose is measured by the industrial structure component variable we constructed above.

Our point of departure is the relationship between size of economy and manufacturing R&D intensity. This relationship we will think of as expressing two different relationships. First, size of economy affects industrial structure, which in turn affects manufacturing R&D intensity. The larger the economy, the more likely it is that the country in question has an industrial structure which is conducive to a high manufacturing R&D intensity, and the more conducive the industrial structure is to a high manufacturing R&D intensity, the more likely it is that the country in question has actually realized a high manufacturing R&D intensity. There is an *indirect effect*, that is, of size of economy on manufacturing R&D intensity *through* the effect of size of economy on industrial structure.

But second, size of economy affects manufacturing R&D intensity *directly*, that is to say, the effect which goes through industrial structure will not account for all of the effect of economy size on manufacturing R&D intensity. This *direct effect* is expressed in the tendency for the large economies to have higher R&D intensities than the small ones even within the different industries.

We these assumptions about the relationships involved by means of a simple 'causal model'. In Figure 11, below, we have done this using GDP as a measure of size of economy.

Figure 11: **'Causal model' of relationship between size of economy, measured by GDP, and manufacturing R&D intensity, with industrial structure as an intermediate variable.**



We have here shown the assumptions of the causal relationships involved by means of arrows: GDP, the 'independent variable', has an effect both on industrial structure, the 'intermediate variable' (denoted by 'structure' in the figure) and manufacturing R&D intensity, the 'dependent variable' (denoted by 'R&D intensity' in the figure). Industrial structure has an effect only on manufacturing R&D intensity, and manufacturing R&D intensity is simply considered to be a dependent variable.

We will now decompose the effect of size of economy, as measured by GDP, on manufacturing R&D intensity as a sum of, on the one hand, a direct effect, and, on the other hand, an indirect effect through industrial structure.

The point of departure is the bivariate correlation between the independent and the dependent variable, as measured by the product moment correlation, r. In this case we have $r = 0.67$. This measure we will now think of as a measure of the strength of the causal relationship between the independent and the dependent variable, i.e. as expressing a 'force'. It is this effect or force we will now decompose as a sum of a direct and an indirect effect.

Attached to each of the arrows in the figure is a measure of the direct effect between each of the variables. The direct effect between the independent and the dependent variable is simply the indicated direct effect between GDP and manufacturing R&D intensity. To compute the indirect effect of GDP on manufacturing R&D intensity through industrial structure, we *multiply* the two direct effects which lie along this path by each other, i.e. we multiply the direct effect of GDP on industrial structure with the direct effect of industrial structure on manufacturing R&D intensity.

The direct effect between each of the variables is computed in the following way. Where the relationship between two variables in the model is not supposed to be dependent on a third variable, the direct effect the two variables is simply represented by the bivariate correlation between them, as measured by r. Thus, in Figure 11 the effect of GDP on industrial structure is represented by the bivariate correlation between them ($r = 0.74$), because the way this model is constructed, neither GDP nor industrial structure is dependent on any third variable (i.e. neither of them are dependent on manufacturing R&D intensity).

By contrast, both the relationship between GDP and manufacturing R&D intensity and between industrial structure and manufacturing R&D intensity is dependent on a third variable. The relationship between GDP and manufacturing R&D intensity is dependent on industrial structure, because GDP has an effect on industrial structure, and industrial structure has an effect on manufacturing R&D intensity. The relationship between industrial structure and manufacturing R&D intensity is dependent on GDP, because GDP has an effect on both industrial structure and manufacturing R&D intensity. Consequently, if we want to find an expression for the direct effect of GDP on manufacturing R&D intensity and of industrial structure on manufacturing R&D intensity, we must control for the effect of the third variable (industrial structure and GDP, respectively). To get a correct decomposition of a bivariate relationship as a sum of direct and indirect effects, we must use the *beta coefficients of a linear multiple regression equation* as the expression of the direct effect of one variable on another when the effect of a third variable has been controlled for. (The beta coefficients are the regression coefficients for a regression equation in standard score form.) This means that the measures of the direct effect of GDP on manufacturing R&D intensity and of industrial structure on manufacturing R&D intensity are the regression coefficients of the multiple regression equation with GDP and industrial structure as independent variables and manufacturing R&D intensity as independent variable, when all three variables are in standard or z score form.

Of course, even if we have a positive relationship between two variables, either the direct effect or the indirect effect may be negative. This simply means that the relationship is to be understood as a result of opposite forces, where the positive is stronger than the negative. (If we have more than three variables, we will get more than one indirect effect. We then get a sum of these indirect effects plus the direct effect. Some of these may be positive, some may be negative. To get a positive total effect, all that is required is that the sum of these effects is positive.)

Referring to Figure 11, above, let us now see how the bivariate relationship between GDP and manufacturing R&D intensity, considered as an effect of GDP (economy size) on manufacturing R&D intensity, decomposes into a sum of a direct effect and an indirect effect through industrial structure. For the bivariate relationship we have $r = 0.67$, consequently the total effect of GDP on manufacturing R&D intensity is 0.67. The decomposition is performed in Table 6, below.

Table 6: **Decomposition of effect of GDP (size of economy) on manufacturing R&D intensity into direct and indirect effect, with industrial structure as intermediate variable.**

direct effect: 0.18	0.18
+ indirect effect through industrial structure: $0.74 \cdot 0.66 =$	0.49
= total effect	0.67

We see that this model seems to confirm the impression that we got when examining the correlation between GDP and each of the components of the manufacturing R&D intensity above, namely that differences in overall manufacturing R&D intensities between large and small economies to a large extent reflect differences in industrial structure. In this model 0.49 of the total effect of GDP on manufacturing R&D intensity of 0.67, or more than 70 per cent of this effect, is an indirect effect through industrial structure, while only 0.18, or less than 30 per cent, is a direct effect. As we said above, this direct effect should reflect that there is a tendency for R&D intensities *within* the different industries to rise with size of economy. Given that we have already found that GDP is more highly correlated with the industrial structure component of the overall manufacturing R&D intensity than with the R&D intensity within the different industries component, the result of the above decomposition that the main part of the total effect of GDP on manufacturing R&D intensity is an indirect effect through industrial structure, seems reasonable.

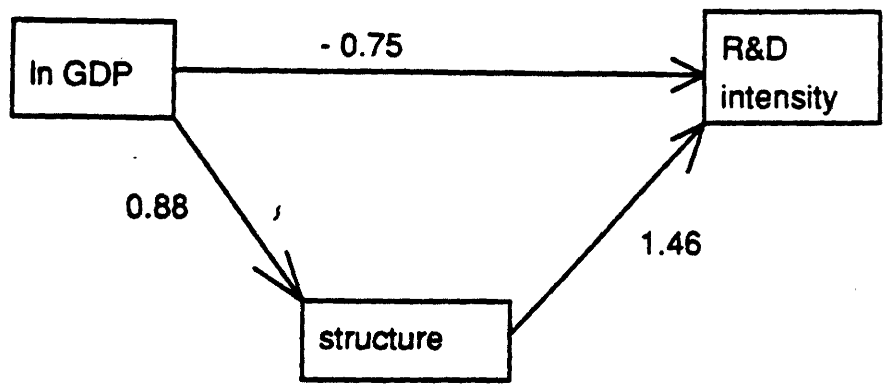
However, this would be a premature conclusion, because things are a bit more complicated than the above analysis suggests. If we make the same kind of decomposition of effect of size of economy on manufacturing R&D intensity into a direct effect and an indirect effect through industrial structure when measuring size of economy by *ln GDP* instead of by GDP, we will see that we get results which at first sight seem more difficult to interpret by referring to the correlation between ln GDP and the industrial structure component of the overall manufacturing R&D intensity and between ln GDP and the R&D intensity within the different industries component.

Remember that for the bivariate correlation between ln GDP and manufacturing R&D intensity, we had r = 0.53, which is the expression of the total effect of economy size on manufacturing R&D intensity when economy size is measured by ln GDP. Moreover, the correlation between economy size and the industrial structure component of the overall manufacturing R&D intensity was even higher when economy size was measured by ln GDP than when economy size was measured by GDP, whereas the opposite was true with the correlation between economy size and the R&D intensity within the different industries component of the overall manufacturing R&D intensity: with ln GDP instead of GDP as a measure of economy size, this correlation was considerably lower.

We would then expect that when we decompose the total effect of economy size on manufacturing R&D intensity when using ln GDP as a measure of economy size, the indirect effect through industrial structure should account for a larger share of the total effect and the direct effect a smaller share than was the case when we measured economy size simply by GDP.

The relationship that we have here assumed between the variables, with size of economy having an effect on manufacturing R&D intensity both directly and indirectly through industrial structure, and with ln GDP as a measure of size of economy, is depicted by means of the 'causal model' in Figure 12, below. Here we also show the direct effects between each of the variables.

Figure 12: 'Causal model' of relationship between size of economy, measured by ln GDP, and manufacturing R&D intensity, with industrial structure as an intermediate variable.



Using these direct effects, we get the following decomposition of the total effect of ln GDP (size of economy) on manufacturing R&D intensity (Table 7):

Table 7: Decomposition of effect of ln GDP (size of economy) on manufacturing R&D intensity into direct and indirect effect, with industrial structure as intermediate variable.

direct effect: - 0.75	- 0.75
+ indirect effect through industrial structure: 0.88 · 1.46 =	1.28
= total effect	0.53

In a way, what we expected turned out to be the case: not only is the indirect effect through industrial structure much larger than the direct effect, but the *difference between* these two effects is much larger than in the case where economy size was measured by GDP. However, the contrast between the direct and the indirect effect here seems to be *too* great, to be exaggerated, in relation to what we would have expected. Here the direct effect actually is *negative*, even very much negative. This negative direct effect is then by far outweighed by an even larger positive indirect effect through industrial structure.

The problem here is that it is difficult to see why the direct effect should be *negative*. As we have said, the direct effect should express the relationship between economy size and manufacturing R&D intensity when we have controlled for the effect of industrial structure on this relationship. This direct effect we would expect to express the relationship between economy size and the R&D intensities within the different industries. However, we have seen that even when we measure economy size by ln

GDP, there is a *positive* correlation between economy size and the variable we constructed to summarize the R&D intensities within the different industries, even if this correlation is a rather low one. We would consequently expect the direct effect to be *small*, even perhaps quite negligible, and anyway smaller than in the case where economy size was measured by GDP. But it is not easy to see how it can be *negative*.

However, here we refer to a variable which is not specified in this very simple model (namely to the R&D intensities within the different industries component variable which we constructed earlier in the paper). Further below we will see how it comes about that the direct effect in the above model is negative. But to see this, and generally to get a better view of what is happening, we have to construct models which are slightly more complex and which explicitly includes the variable not included in the simple model above.

Before we go on, we also have to mention another problem which we run into in the model set out in Figure 12 and Table 7 above where both ln GDP and the industrial structure variable are independent variables. This is the problem of high multicollinearity, which means that the independent variables in the model are highly correlated. Clearly, this is the case here, the correlation coefficient between ln GDP and the industrial structure variable being 0.88 ($r^2 = 0.78$). When there is high multicollinearity, the slope estimates in a regression equation become unreliable, which of course makes it highly problematic to compare the beta coefficients.[3] This may be one reason for the rather extreme coefficients we get in Figure 12 and Table 7 above. We will nevertheless examine also this example more closely, because considering how the direct effect of ln GDP on R&D intensity becomes negative may give a more precise understanding of how this decomposition works. But we should stress that especially in this case (i.e. in the case where we have a model where *both* ln GDP *and* the industrial structure variable are *independent* variables) it is highly problematic to interpret the estimates of the different effects in a substantive manner, and that the rationale of the exercise is to explain and illustrate methodological points.

Having made these important qualifications, let us, then, resume our argument. Before we go on explicitly including the variable not included in the simple model above, we have to discuss briefly these relationships in more substantial terms, rather than just in terms of correlation. In the simple 'causal model' above (in both the GDP and the ln GDP version), we have assumed that size of economy is an independent

[3] For an exposition of the multicollinearity problem, cf. Michael S. Lewis-Beck: *Applied Regression - An Introduction*, Sage University Paper series on Quantitative Applications in the Social Sciences, series no. 07-022, Newbury Park 1980, pp. 58-63.

variable, industrial structure an intermediate variable and manufacturing R&D intensity a dependent variable. This, of course, is a very gross simplification, and in actual fact the influences will not just go one way, but will be more complex and reciprocal.

In the first case, size of economy will not be something which is independent of R&D efforts. Given that the R&D expenditures have any effect on production at all, there will be a reciprocal relationship between size of economy and manufacturing R&D intensity: the more is spent on R&D (within reasonable limits, of course), the higher GDP will be. We will not go further into this problem here, though, but will continue to treat size of economy as an independent variable. This is probably also to a large extent reasonable. R&D expenses will influence production per person, R&D intensity will therefore influence GDP primarily in the sense of *GDP per capita*. However, among the 12 countries which we study in this paper, variation in GDP per capita is far less important than variation in the size of *population*. Consequently, size of economy measured by GDP primarily reflects size of *population* as far as these 12 economies are concerned. This indicates that the effect of manufacturing R&D intensity on GDP will not be very important in this case.

We *will*, however, look further into the relationship between industrial structure and manufacturing R&D intensity. In the simple model above, there is an effect of industrial structure on manufacturing R&D intensity, but no effect in the opposite direction. But in actual fact, there probably *will* be an effect in the opposite direction. Let us think of each country, and particularly the manufacturing sector of each country, as having a certain general capability to perform industrial R&D, reflecting its possession of resources of different kinds (human, cultural, organizational, material, etc.). Some countries will have a high 'R&D capability', others will have lower 'R&D capability'. This general 'R&D capability' of each country will be reflected in the manufacturing R&D intensity of the country.

Now, the industrial structure of a country will not be independent of its 'R&D capability'. A country with a high R&D capability will, all other things equal, more easily engage in production in high R&D intensity industries than a country with a low R&D capability. Of course, there is a host of factors, both economic, social, geographical, cultural, historical, etc., which go together to determine a country's industrial structure. All in all, the industrial structure of a country is determined through complex economic and social processes and changes only slowly. To a large extent, therefore, it can be considered as determined independently of the R&D capability of the country. Nevertheless, there will also be a certain effect of 'R&D capability' on industrial structure. More precisely, the R&D capability of a country will be one of the elements in the complex process which creates, reproduces and transforms the industrial structure. Since the manufacturing R&D intensity of a country partly will reflect this R&D capability, there will be an effect of manufacturing R&D intensity on industrial structure.

However, there will also be an effect in the opposite direction, that is, between industrial structure and 'R&D capability'. If a country has an industrial structure characterized by a comparatively large part of industrial production in high R&D intensity industries, this industrial structure will make it necessary to devote substantial resources to R&D. But the more a country is 'forced' to engage in R&D, the more competent it will be, through a process of learning and experience, to perform R&D. There thus will be an effect of industrial structure not only on the amount of R&D performed, but, through the learning mechanism, on the competence with which the R&D is performed, that is, on the 'R&D capability' of the country.

There will, then, be a mutual relationship between 'R&D capability' and industrial structure. If a country has a high R&D capability, it will also more easily engage in production in high R&D intensity industries. And if it has an industrial structure characterized by in high R&D intensity industries, it will be led to perform much R&D, and the very act of performing R&D will eventually enhance its competence and capability for performing R&D.

Now, what we here try to grasp by the notion of 'R&D capability' is a complex phenomenon, which will not be easy to measure. As we have said, it will to a certain extent be reflected in manufacturing R&D intensity. However, this is the dependent variable in our models, it is precisely what we try to describe more accurately by decomposing it into different components, and our models will break down if we should also use manufacturing R&D intensity as a measure of R&D capability.

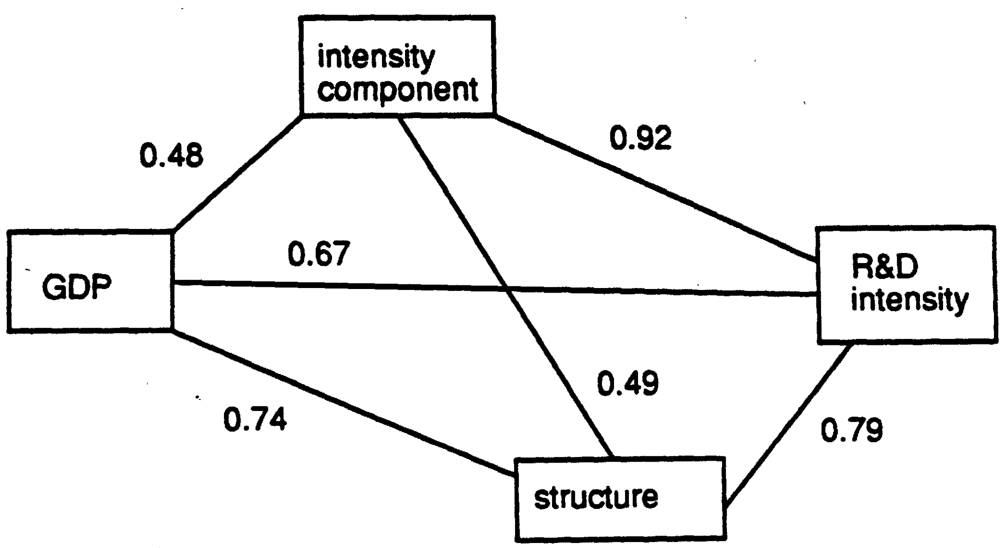
This paper has an extremely narrow focus, and we have used an extremely narrow set of data in our work. Only data for R&D expenditures and for value added in a number of industries have been used. Now, to get a measure or an indicator of 'R&D capability' without introducing other data while still having manufacturing R&D intensity as the dependent variable, let us assume that what we here have termed 'R&D capability' to a reasonable extent can be measured by the *R&D intensity within the different industries* variable that we constructed above. This would mean assuming that the general 'R&D capability' of a country as a general tendency will be reflected in the R&D intensity of each of the different industries of the country. As a very rough approximation, and serving mainly to illustrate, this may perhaps be not a too dubious assumption.

We are now in a position to construct simple 'causal models' which are slightly more complex than the one (in two versions) we constructed above. Size of economy is still the independent variable. This variable influences both the R&D intensities within the different industries, what we now also regard as an indicator of 'R&D capability', and industrial structure. These two variables then both influence manufacturing R&D intensity. Besides, these two intermediate variables influence each other.

We will construct two sets of models, one where GDP is used as a measure of size of economy, the other where ln GDP is used as a measure of size of economy. We will start by measuring size of economy by GDP.

Let us first indicate the bivariate correlation coefficients (r) between each of the variables involved. These are shown in Figure 13, below.

Figure 13: **Bivariate correlation, measured by r, between each of the variables GDP (size of economy), R&D intensity within the different industries, industrial structure and manufacturing R&D intensity.**



In this figure we have denoted the variable measuring R&D intensity within the different industries 'intensity component'. Otherwise, the variables are denoted in the same way as in Figure 11.

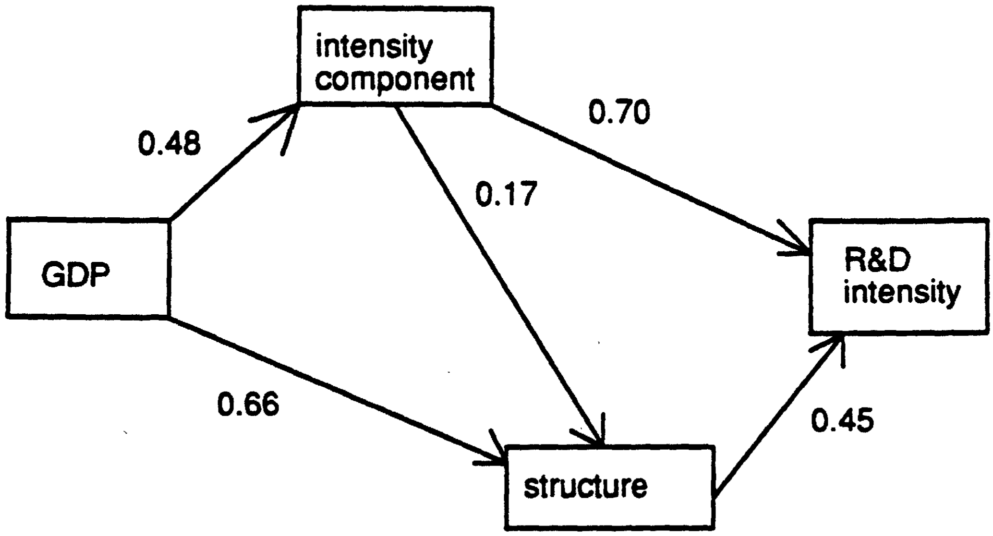
We may note that although the correlation between GDP and the industrial structure variable (0.74) is higher than the correlation between GDP and the intensity component variable (0.48), the bivariate correlation between the industrial structure variable and manufacturing R&D intensity (0.79) is *lower* than the one between the intensity component variable and manufacturing R&D intensity (0.92).

Now, the correlation between GDP and manufacturing R&D intensity, given by $r = 0.67$, we now want to interpret as an effect of GDP (size of economy) on manufacturing R&D intensity, 0.67 being a measure of the strength of the effect. We want to decompose this total effect into a direct effect and different indirect effects.

This we do in two different models, representing two opposite limiting cases. What distinguishes them is the direction we assume of the causal relationship between the two intermediate variables. In the first model, we see what happens when we assume that the intensity component or 'R&D capability' variable influences the industrial structure variable, but not the other way round. In the second model, on the other hand, we see what happens if we assume the opposite causal relationship, namely that industrial structure influences the R&D intensity within the different industries.

In the first model, then, depicted in Figure 14, size of economy (GDP) influences both the intensity within the different industries (intensity component), industrial structure and manufacturing R&D intensity. The intensity component variable influences both industrial structure and manufacturing R&D intensity. Industrial structure has an effect only on manufacturing R&D intensity, the dependent variable.

Figure 14: 'Causal model' of effect of size of economy, measured by GDP, on manufacturing R&D intensity, with R&D intensity within the different industries and industrial structure as intermediate variables, and with R&D intensity within the different industries influencing industrial structure.



Here the direct effect of GDP on the intensity component is the bivariate correlation between these two variables, measured by r. The direct effects of GDP on structure and of the intensity component on structure, are the beta coefficients of the multiple linear regression equation with structure as dependent variable and GDP and intensity component as independent variables. The direct effects of GDP on manufacturing R&D intensity, of the intensity component on manufacturing R&D intensity and of structure on manufacturing R&D intensity, are the beta coefficients of the multiple linear regression equation with manufacturing R&D intensity as dependent variable and GDP, intensity component and structure as independent variables.

Now, *since manufacturing R&D intensity is completely decomposed into the R&D intensity within the different industries component and the industrial structure component, there is no direct effect of GDP on manufacturing R&D intensity* (this direct effect is 0). *All* the effect of GDP on manufacturing R&D intensity goes through these two intermediate variables.

By using the direct effects indicated in Figure 14, we can decompose the total effect of size of economy, measured by GDP, on manufacturing R&D intensity into a sum of various indirect effects. This we have done in Table 8, below.

Table 8: **Decomposition of effect of GDP (size of economy) on manufacturing R&D intensity into indirect effects through R&D intensity within the different industries and industrial structure. First case: R&D intensity within the different industries influences industrial structure.**

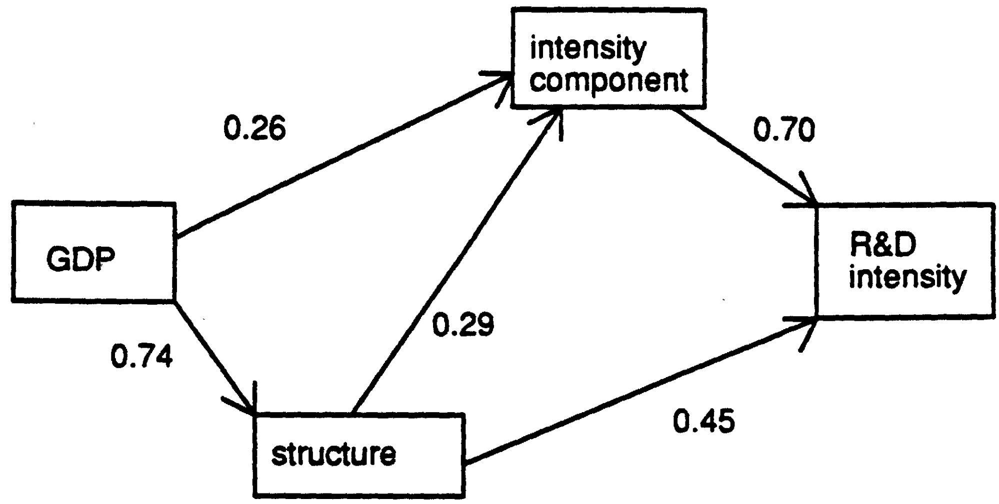
direct effect: 0	0
+ indirect effect through intensity component: $0.48 \cdot 0.70 =$	0.33
+ indirect effect through industrial structure: $0.66 \cdot 0.45 =$	0.30
+ indirect effect through intensity component *and* industrial structure: $0.48 \cdot 0.17 \cdot 0.45 =$	0.04
= total effect	0.67

We see that with these assumptions, 0.30 of the total effect of size of economy on manufacturing R&D intensity of 0.67 (or about 45 per cent of this total effect) goes through industrial structure only. 0.33 goes through the intensity component only, while 0.04 goes through *both* the intensity component and industrial structure.

Now, remember that earlier in this paper we posed the question of to what extent the relationship between size of economy and R&D intensity in the manufacturing sector expresses differences in industrial structure between large and small economies and to what extent it expresses that large economies tend to have higher R&D intensities within the different industries than the small ones. Here, then, is one answer to this question, based on one set of assumptions. With 0.67 as the total effect of economy size on R&D intensity in the manufacturing sector as the point of departure, 0.30 expresses differences in industrial structure between large and small economies, independently of any effect of 'R&D capability' on industrial structure. 0.33 expresses the tendency for R&D intensities within the different industries to rise with size of economy. In addition, 0.04 expresses this same tendency, but this time *through* the effect of R&D capability on industrial structure.

Let us now see what results we get when we change one of the assumptions, namely when we assume the reverse direction of the causal relationship between the intermediate variables. This time industrial structure has an effect on 'R&D capability', the intensity component. Size of economy is still measured by GDP.

Figure 15: 'Causal model' of effect of size of economy, measured by GDP, on manufacturing R&D intensity, with R&D intensity within the different industries and industrial structure as intermediate variables, and with industrial structure influencing R&D intensity within the different industries.



Here the direct effect of GDP on industrial structure is the bivariate correlation between these two variables, measured by r. All the other direct effects are the beta coefficients of the respective multiple linear regression equations. These direct effects give us the decomposition of the total effect of size of economy, measured by GDP, on manufacturing R&D intensity presented in Table 9, below.

Table 9: **Decomposition of effect of GDP (size of economy) on manufacturing R&D intensity into indirect effects through R&D intensity within the different industries and industrial structure. Second case: industrial structure influences R&D intensity within the different industries.**

direct effect: 0	0
+ indirect effect through intensity component: $0.26 \cdot 0.70 =$	0.18
+ indirect effect through industrial structure: $0.74 \cdot 0.45 =$	0.33
+ indirect effect through industrial structure *and* intensity component:	
$0.74 \cdot 0.29 \cdot 0.70 =$	0.15
= total effect	0.67

(The deviation of the sum of the indirect effects as reported here from the total effect is due to rounding errors.)

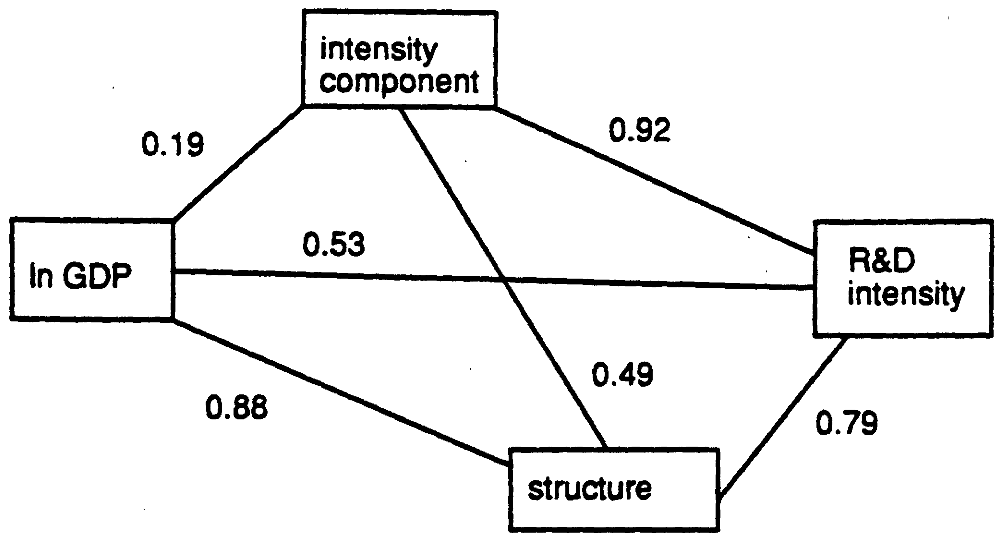
With these assumptions, 0.33 of a total effect of 0.67 of economy size on R&D intensity in the manufacturing sector expresses differences in industrial structure between large and small economies. In addition, there is an effect of 0.15 which goes through the effect of industrial structure on the R&D intensity within the different industries. Only 0.18 expresses the tendency for R&D intensities within the different industries to rise with size of economy, independently of any effect of industrial structure on R&D intensities within the different industries.

We can compare this decomposition with the simpler model presented in Figure 11 and Table 6 above. There we only had one intermediate variable, namely industrial structure. The strength of the indirect effect there was 0.49. As we can see from the slightly more complex model we have just presented, this includes everything which includes industrial structure, both the effect which goes through industrial structure only (0.33) and the effect which goes through the effect of industrial structure on R&D intensities within the different industries (0.15). The direct effect in the simpler model (0.18), which, as we argued, should reflect the tendency for R&D intensities within the different industries to rise with size of economy, is equal to the indirect effect of the slightly more complex model which goes through the intensity component only, given the assumption that industrial structure as an effect on the intensity component, but not the other way round.

Let us now perform the same exercises with *ln GDP* instead of GDP as a measure of size of economy. We must then again stress that we in this case have a multicollinearity problem, which makes substantive interpretations of the results particularly problematic in this case. Our concern here is almost exclusively to explain how these decomposition exercises work.

First we recapitulate the bivariate correlation between each of the variables involved. The correlation coefficients are shown in Figure 16, below.

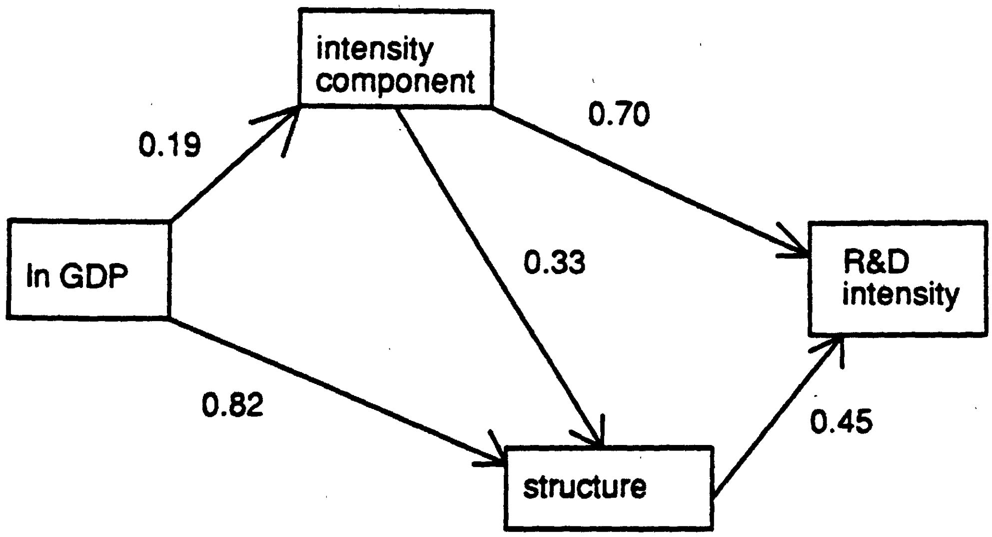
Figure 16: Bivariate correlation, measured by r, between each of the variables ln GDP (size of economy), R&D intensity within the different industries, industrial structure and manufacturing R&D intensity.



Here our point of departure, the bivariate correlation between economy size and manufacturing R&D intensity is given by $r = 0.53$, which we also consider as a measure of the effect of economy size on manufacturing R&D intensity. This is lower than in the case where GDP was a measure of economy size. The bivariate correlation between economy size and the intensity components is also lower than in the case where economy size was measured by GDP (0.19 as against 0.48), whereas the bivariate correlation between economy size and industrial structure is higher than in this former case (0.88 as against 0.74). The other three bivariate correlation coefficients are not altered, of course.

As in the case where we used GDP as a measure of economy size, in the first causal model we assume that the R&D intensity within the different industries, understood as a measure of 'R&D capability', has an effect on industrial structure, but not the other way round. This model is presented in Figure 17, below.

Figure 17: **'Causal model' of effect of size of economy, measured by ln GDP, on manufacturing R&D intensity, with R&D intensity within the different industries and industrial structure as intermediate variables, and with R&D intensity within the different industries influencing industrial structure.**



This model is constructed in exactly the same way as the model presented in Figure 14, the only difference being that ln GDP has been substituted for GDP. To document the multicollinearity problem here, when we regress each of the independent variables on the two other independent variables, we get R^2 of 0.88, 0.85 and 0.49, respectively, i.e. there is indeed high multicollinearity.

The decomposition of total effect of economy size on manufacturing R&D intensity in this case is presented in Table 10, below.

Table 10: **Decomposition of effect of ln GDP (size of economy) on manufacturing R&D intensity into indirect effects through R&D intensity within the different industries and industrial structure. First case: R&D intensity within the different industries influences industrial structure.**

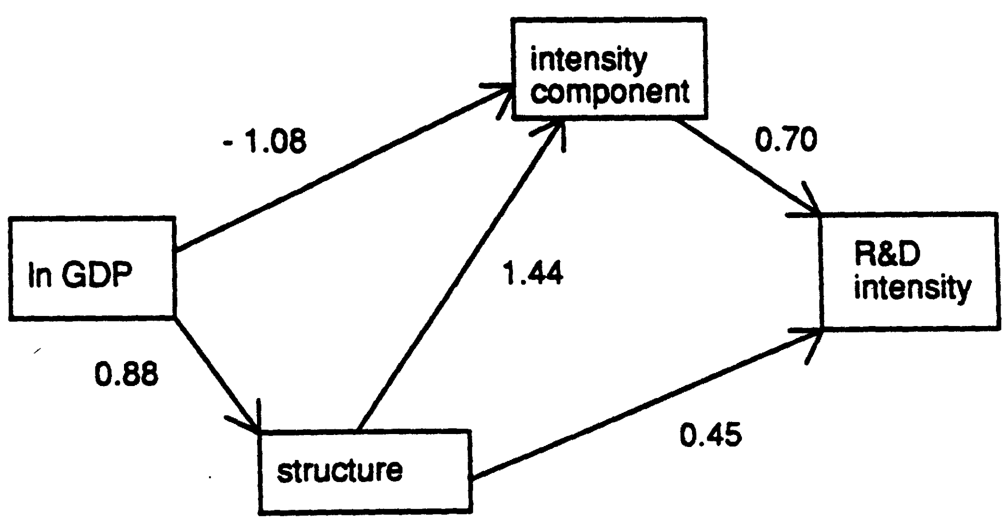
direct effect: 0	0
+ indirect effect through intensity component: $0.19 \cdot 0.70 =$	0.13
+ indirect effect through industrial structure: $0.82 \cdot 0.45 =$	0.37
+ indirect effect through intensity component *and* industrial structure: $0.19 \cdot 0.33 \cdot 0.45 =$	0.03
= total effect	0.53

We see that compared to the decomposition presented in Table 8, performed on the basis of the same assumptions but with GDP as a measure of economy size, although the total effect of economy size on manufacturing R&D intensity is smaller (0.53 as against 0.67), the effect which goes through industrial structure only is larger (0.37 as against 0.30). The effect which goes through the intensity component only, on the other hand, is smaller (0.13 as against 0.33). In addition, there is an effect of 0.03 (as against 0.04 in the case where we measured economy size by GDP) which goes through *both* the intensity component and industrial structure, reflecting the assumption that 'R&D capability' has an effect on industrial structure.

When measuring economy size by ln GDP, then, even with the assumption that 'R&D capability' influences industrial structure but not the other way round, then, the tendency of manufacturing R&D intensity to rise with size of economy predominantly expresses a tendency of industrial structure to vary with size of economy, and to a much lesser extent a tendency of the R&D intensity within the different industries to vary with size of economy.

We now assume the reverse direction of the causal relationship between the two intermediate variables, letting industrial structure have an effect on 'R&D capability', the intensity component. This gives us the model presented in Figure 18, below.

Figure 18: 'Causal model' of effect of size of economy, measured by ln GDP, on manufacturing R&D intensity, with R&D intensity within the different industries and industrial structure as intermediate variables, and with industrial structure influencing R&D intensity within the different industries.



Exactly the same remarks about high multicollinearity as we made in relation to Figure 17 apply here as well, of course.

This gives us the decomposition of the total effect of economy size on manufacturing R&D intensities presented in Table 11, below.

Table 11: **Decomposition of effect of ln GDP (size of economy) on manufacturing R&D intensity into indirect effects through R&D intensity within the different industries and industrial structure. Second case: industrial structure influences R&D intensity within the different industries.**

direct effect: 0	0
+ indirect effect through intensity component: $-1.08 \cdot 0.70 =$	- 0.75
+ indirect effect through industrial structure: $0.88 \cdot 0.45 =$	0.40
+ indirect effect through indusrial structure *and* intensity component: $0.88 \cdot 1.44 \cdot 0.70 =$	0.89
= total effect	0.53

(The deviation of the sum of the indirect effects as reported here from the total effect is due to rounding errors.)

When we made the corresponding analysis with GDP as a measure of economy size in Figure 15 and Table 9, we noted that what we then got was a more detailed version of the simpler model presented in Figure 11 and Table 6. We saw that the indirect effect through industrial structure in the simpler model, the model which excludes the intensity component variable, includes *all* the effect which goes through industrial structure in the more complex model, both the effect which goes through industrial structure only and the effect which goes through both industrial structure and the intensity component. The direct effect in the simpler model includes only the effect which goes through the intensity component only in the more complex model.

Exactly the same relationship holds between the model in Figure 18 and Table 11 above and the simpler model presented in Figure 12 and Table 7. Investigating the more complex model above, we now see how the direct effect in the simpler model comes to be negative. The direct effect in the simpler model includes only the effect which goes through the intensity component only in the more complex model. And although there is a positive *bivariate* relationship between ln GDP and the intensity component, this comes about through a positive relationship between ln GDP and industrial structure and a positive relationship between industrial structure and the intensity component. Controlling for industrial structure, we find a *negative* relationship between ln GDP and the intensity component.

From Table 11, then, we see that with ln GDP as a measure of economy size, and with the assumption of a one way effect of industrial structure on the intensity component, of a total effect of 0.53 of economy size on manufacturing R&D intensity, 0.40 or 75 per cent goes through industrial structure only. The rest, 0.14, goes through the intensity component. However, this latter effect is composed of two opposite effects or forces, and it is positive because industrial structure in this model has a very large effect on the intensity component. The effect which goes through both industrial structure and the intensity component is a very large positive effect, that is. By contrast, the effect which goes through the intensity component only is an almost equally large negative effect.

Let us now try to summarize the argument of this paper. Using data for 1985 only, for 12 advanced OECD economies, we found a positive relationship between size of economy, as measured by GDP, and R&D intensity in the manufacturing sector. The larger the economy, that is, the higher the R&D intensity in the manufacturing sector tends to be. We wanted to be able to give an indication of to what extent this positive relationship expresses a tendency for the larger economies to have higher R&D intensities within each single industry than the smaller, and to what extent it expresses a tendency for the larger economies to have different industrial structures from the smaller ones. Or specifically, we wanted an indication of the role of industrial structure in the relationship between economy size and manufacturing R&D intensity.

To accomplish this, we decomposed the manufacturing R&D intensity of each of the countries, or rather each country's deviation from the average manufacturing R&D intensity among these countries, into a sum of a component expressing the R&D intensities within each of the different industries of the country and a component expressing the industrial structure of the country.

We then measured the correlation between size of economy and each of these two component variables. We found a substantially higher correlation between economy size and the industrial structure component variable than between economy size and the variable expressing the R&D intensities within the different industries. This latter correlation was also positive, however, although only slightly when economy size was measured by ln GDP rather than by GDP. That the former correlation was found to be higher should indicate that the positive relationship between economy size and manufacturing R&D intensities *predominantly* expresses a tendency for industrial structure to vary with size of economy, and that it to a lesser extent expresses a tendency for the R&D intensities within the different industries to rise with size of economy.

However, strictly speaking we cannot draw this conclusion by looking at the relationship between size of economy and each of these components only. We have to track the relationships all the way from economy size via the two components through to the actually realized manufacturing R&D intensities. This involves taking account also of the correlation between each of the two component variables and the actual manufacturing R&D intensities.

Besides, there is the complication of the influence of R&D intensities on industrial structure. When we say we want to know the effect industrial structure has on manufacturing R&D intensity, we are likely - implicitly or explicitly - to treat industrial structure as something given independently of and so to speak prior to R&D intensities. The same is likely to be the case when we regard R&D intensities as a measure of R&D *performance*, and say that to get an accurate measure of the R&D performance of a country, we must take account of the industrial structure. We may, for instance, find that a country performs rather poorly when we just look at overall manufacturing R&D intensity, but when we take account of the industrial structure, characterized, let us suppose, by a very high proportion of total value added in low R&D intensity industries, we find that it *really* performs much better.

However, these manufacturing R&D intensities will also reflect what we have called 'R&D capability', the ability and competence of the country to perform industrial R&D. And this 'R&D capability' of a country will influence the industrial structure of the country, a country with a high R&D capability having a stronger tendency to engage in production in high R&D intensity industries than a country with a low 'R&D intensity'. In other words, we cannot treat industrial structure entirely as given when we wish to evaluate R&D performance, because to a certain extent the industrial structure of a country will be an effect of its R&D performance. As we argued above, there will also be an effect in the opposite direction, however.

Now, to be able to give some indication of the effect of what we have called 'R&D capability' on industrial structure, given the data that we have at our disposal in this paper, we made the assumption that 'R&D capability' in a reasonably adequate way can be measured by the variable expressing the R&D intensities within the different industries component of manufacturing R&D intensity. It is clear that this is problematic, but our aim here is only to give an impression of what kind of results taking this effect into account might give.

Given this assumption, we were able to construct a model, or rather a set of similar models differing from one another in one or two assumptions only, where we decomposed the total effect of economy size on manufacturing R&D intensity, measured by the product moment correlation (r), into a sum of effects going through the R&D intensities within the different industries component variable, through the industrial structure component variable, and through both of these variables.

Of these models, we here want to concentrate on the two were we assume a one-way effect between 'R&D capability' and industrial structure, that is an effect of 'R&D capability' on industrial structure, but no effect in the opposite direction. Since there in fact will be a two-way causal relationship here, it is clear that this assumption represents a *limiting case*, giving a *minimum* estimate of the impact of industrial structure on the relationship between economy size and manufacturing R&D intensity.

Let us take the case were we measured economy size by GDP first, presented in Figure 14 and Table 8. We here found that out of a total effect of economy size on manufacturing R&D intensity of 0.67, the effect which went through industrial structure only, that is independently of any effect of 'R&D capability' on industrial structure, was 0.30. The effect which went through both intermediate variables, that is through industrial structure mediated by the effect that 'R&D capability' has on industrial structure, we found to be 0.04. Finally, the effect which went through the R&D intensities within the different industries component variable only was 0.33. In this model then, the positive relationship between economy size and manufacturing R&D intensity expresses both a tendency for the R&D intensities within the different industries to rise with economy size and a tendency for industrial structure to vary with economy size, to a more or less equal degree. But remember, this represents a *minimum* estimate of the impact of industrial structure, given the assumptions that these models rest upon.

When we use ln GDP instead of GDP as a measure of economy size, the impact of industrial structure becomes more important, especially in relative terms. This is the model of Figure 17 and Table 10. With a total effect of economy size on manufacturing R&D intensity of 0.53, we find that the effect which goes through industrial structure only, that is independently of any effect of 'R&D capability' on industrial structure, is 0.37. The effect which goes through both the intermediate variables, that is through industrial structure mediated by the effect that 'R&D capability' has on industrial structure, is 0.03. The effect which goes through the R&D intensities within the different industries component variable only is in the model no higher than 0.13.

To put these figures in perspective, we also constructed the same models with the assumption of the direction of the causal relationship between the intermediate variables reversed (in Figure 15 and Table 9 for the case of GDP as a measure of economy size and in Figure 18 and Table 11 for the case of ln GDP as a measure of economy size), thereby getting the *maximum* estimate of the impact of industrial structure, given the basic assumptions underlying all these models.

Here we again want to stress that when we use ln GDP as a measure of economy size in these models, we get a problem of high multicollinearity, i.e. this happens when *both* ln GDP *and* the industrial structure variable are *independent* variables. Therefore, the models with ln GDP as a measure of economy size are only included to explain methodological points. To the extent that we want to give substantive interpretations of the results of these models, we should only use the models with *GDP* as a measure of economy size.

But perhaps at least as interesting as these complete 'causal' relationships from economy size via the two components of manufacturing R&D intensity through to the actually realized manufacturing R&D intensity, is the more simple correlation between economy size and industrial structure (the industrial structure component). This correlation we found to be a high positive one, even a very high one in the case where we measured economy size by ln GDP rather than by GDP. (And *here*, of course, there is no multicollinearity problem connected with using ln GDP as a measure of economy size.) This means that when it comes to having high manufacturing R&D intensity, the small economies have a 'structural disadvantage' compared to the large economies, that is, if the small economies were to have manufacturing R&D intensities which were as high as those of the large economies, they would actually as a general rule have to have *higher* R&D intensities within each single industry.

In this case, too, where we just look at the relationship between economy size and industrial structure, we may of course in the same way as above investigate the question of the influence of 'R&D capability' on industrial structure, given our very simplifying assumption that 'R&D capability' can be measured by our R&D intensity within the different industries component variable. Let us take the case where economy size is measured by GDP first. From Figure 13 we see that the correlation between economy size (GDP) and industrial structure is given by r = 0.74, which we consider as a measure of the effect of economy size on industrial structure. From Figure 14 we see that controlling for 'R&D capability', the direct effect of economy size on industrial structure is still as high as 0.66, the remaining 0.08 being an indirect effect through the effect of 'R&D capability' on industrial structure, which is given by the product $0.48 \cdot 0.17$.

Similarly, we see from Figure 16 that when we measure economy size by ln GDP, the effect of economy size on industrial structure is as high as 0.88. From Figure 17 we see that controlling for 'R&D capability', the direct effect of economy size on industrial structure is hardly diminished at all. It is still 0.82, the remaining 0.06 being an indirect effect through the effect of 'R&D capability' on industrial structure, which is given by the product $0.19 \cdot 0.33$.

This, to repeat, represents, given the basic assumptions of our models, a *minimum* estimate of the (direct) effect of economy size on industrial structure, corresponding to the limiting case assumption of a one-way causal relationship going from 'R&D capability' to industrial structure, but not the other way round. But once again we should emphasize that this result of controlling for the effect of 'R&D capability' crucially depends on the particular assumption that 'R&D capability' can be measured by our R&D intensity within the different industries component variable.

When trying to assess the influence of industrial structure on the relationship between economy size and manufacturing R&D intensity, we should beware of another specific limitation of the present analysis. The data at our disposal has allowed us to divide total manufacturing production into 22 different industries. This is still a rather rough classification, however, and in many cases the same category may cover productive activities which are quite different from one another in many respects. To take just one example, when we compare figures 3 and 4 above, we see that the USA has a much higher R&D intensity than Norway in the motor vehicles industry (industry no. 18). Now, within this category, the USA has a very substantial production of cars, whereas in Norway there is no car production at all. It may very well be the case, then, that within the category motor vehicles, car production as such is characterized by higher R&D intensity than other kinds of production included in the production of motor vehicles category, and that the difference in R&D intensity between USA and Norway in this industry to a large extent reflects a difference in industrial structure which our classification is not detailed enough to capture. Within each of the 22 industries a more detailed classification would be able to distinguish several different industries, with more or less variation in R&D intensity among them. Now, if we had data which allowed us to make a more detailed classification of industries (and ideally a classification which was so detailed that it consisted only of industries that were perfectly homogenous), this would most likely, although not necessarily, have the effect of making the impact of industrial structure on the relationship between economy size and manufacturing R&D intensity appear even *more* important, and conversely the impact of the R&D intensity within the different industries on this relationship less important. On the other hand, this might very well at the same time accentuate the problem of the dependency of the industrial structure on 'R&D capability'.

9. Conclusion, and Policy Implications

It is usual, both in economic and policy analysis, to treat R&D as a kind of autonomous independent factor, which shapes other phenomena in the economy. There is, for example, a large economics literature which examines the impacts of R&D expenditure on productivity growth, trade, and so on.[4] It is much less common to examine the determinants of R&D intensities directly. This is what we have attempted here. Although our attempt to explore the effects of scale and industrial structure on R&D intensities this may seem a somewhat narrowly focused one, in our view attempts to establish the precise determinants of R&D intensities are potentially of considerable policy relevance.

We have shown in this paper that the positive relationship between size of economy and manufacturing R&D intensity to a large extent expresses differences in industrial structure between large and small economies. The positive relationship between economy size and R&D intensity has elsewhere been referred to as reflecting effects of *scale*.[5] We have seen that this relationship cannot exclusively be considered as reflecting effects of scale, but rather reflects effects of industrial structure. Or more accurately: the scale effects are to a considerable degree *mediated* through industrial structure.

[4]For some examples, see C. Freeman (ed), **Output Measurement in Science and Technology** (Amsterdam, 1988), or Z. Griliches (ed) **R&D, Patents and Productivity** (Chicago, 1986), for studies in which R&D is seen as a determining input to economic inputs and processes.

[5] J.A.D. Holbrook, 'The influence of scale effects on international comparisons of R&D expenditures', **Science and Public Policy**, 1992. (Holborn is here referring to total R&D expenditures of a country as a proportion to GDP rather than R&D expenditures in the manufacturing sector as a proportion to manufacturing value added).

Clearly there remain difficult questions of the further interpretation of this. One thing which is involved here is the question of whether, or rather to what extent, the industrial structure of a country itself is dependent on what we have called its 'R&D capability'. It is likely this R&D capability in turn depends on all of the factors which shape the industrial composition and structure of the economy. These will include a wide range of non-R&D aspects of or inputs to innovation activity: infrastructure provision, human resource development, regulatory and policy frameworks, and so on. In all of this, R&D is but one factor among many, and far from being a determining factor, is likely to be shaped and determined by the forces which generate the industrial structure.

If this is the case then the main empirical result reported in this paper - namely the high positive correlation between economy size and our industrial structure component variable, which means that industrial structure is important in mediating the positive relationship between economy size and manufacturing R&D intensity - may be of wider policy significance that might appear at first sight. In the first place, it may be that Community RTD policy should have a wider focus than straightforward R&D subsidy or provision. If policymakers seek improved R&D performance in the Community, then it may be wise to explore non-R&D aspects of industrial innovation activity, to look at the extent to which these factors determine R&D, rather than being determined by it. to go further, some of the key policy issues within the European Community relate to issues of cohesion, a matter which is seen primarily in terms of convergence in per capita incomes. However, convergence must ultimately imply resolving complex questions related to the nature and effects of the differences in underlying economic structure and performance which generate differences in the Community. In this paper we have analysed only one simple dimension of economic differentiation, although it is a dimension which is of considerable importance for innovation and economic growth. But we believe that it opens up the possibility of more complex analyses of factors underlying divergence and convergence in growth rates of output and productivity across the Community.

All of these considerations are relevant to a final policy point. This is that policy-makers should use great care when making inter-country comparisons with R&D input data. It is quite common, especially in small economies, for policy-makers to look at the numbers presented at the beginning of this paper, and to argue that their economy exhibits some failure in R&D performance. In many small economies, policy-makers have the explicit objective of raising manufacturing R&D intensities. Our analysis suggests, however, that there is no necessary failure here. Indeed, given their industrial structures, some small economies are more R&D intensive than we might expect. It is more appropriate - even for research administrators - to look at the factors shaping the underlying activity of the economy, and to consider the factors which shape its overall innovative performance, than to focus on what the raw R&D statistics seem to say.