European Trend Chart on Innovation

2002 European Innovation Scoreboard
Technical Paper No 6
Methodology Report

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The European Trend Chart on Innovation

Innovation is a priority of all Member States and of the European Commission. Throughout Europe, hundreds of policy measures and support schemes aimed at innovation have been implemented or are under preparation. The diversity of these measures and schemes reflects the diversity of the framework conditions, cultural preferences and political priorities in the Member States. The 'First Action Plan for Innovation in Europe', launched by the European Commission in 1996, provided for the first time a common analytical and political framework for innovation policy in Europe.

Building upon the Action Plan, the *Trend Chart on Innovation in Europe* is a practical tool for innovation policy makers and scheme managers in Europe. Run by the European Commission (Innovation Directorate of DG Enterprise), it pursues the collection, regular updating and analysis of information on innovation policies at national and Community level, with a focus on innovation finance; setting up and developing innovative businesses; the protection of intellectual property rights; and the transfer of technology between research and industry.

The Trend Chart serves the "open policy co-ordination approach" laid down by the Lisbon Council in March 2000. It delivers summarised and concise information and statistics on innovation policies, performances and trends in the European Union. It is also a European forum for benchmarking and the exchange of good practices in the area of innovation policy.

The Trend Chart products

The Trend Chart on Innovation has been running since January 2000. It tracks innovation policy developments in all EU Member States, plus Bulgaria, Cyprus, Czech Republic, Estonia, Hungary, Iceland, Israel, Latvia, Liechtenstein, Lithuania, Norway, Poland, Romania, Slovak Republic and Slovenia. The Trend Chart website (www.cordis.lu/trendchart) provides access to the following services and publications:

- the European Innovation Scoreboard and other statistical reports;
- regular country reports for all countries covered;
- a database of policy measures across Europe;
- a "who is who?" of agencies and government departments involved in innovation;
- regular trend reports covering each of the four main themes;
- benchmarking reports from the Trend Chart workshops;
- a news service and thematic papers;
- the annual reports of the Trend Chart.

The present report was prepared by Anthony Arundel, Catalina Bordoy and Hugo Hollanders of MERIT (www.merit.unimaas.nl). The information contained in this report has not been validated in detail by either the Member States or the European Commission.

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European Innovation Scoreboard

The European Innovation Scoreboard (EIS) was developed at the request of the Lisbon European Council in 2000[1]. It focuses on high-tech innovation and provides indicators for tracking the EU's progress towards the Lisbon goal of becoming the most competitive and dynamic knowledge-based economy in the world within the next decade.

The EIS contains 17 main indicators, selected to summarize the main drivers and outputs of innovations. These indicators are divided into four groups: Human resources for innovation (5 indicators); the creation of new knowledge (3 indicators of which one is divided into EPO and USPTO patents); the transmission and application of knowledge (3 indicators); and Innovation finance, outputs and markets (6 indicators).

The EIS complements the *Enterprise Policy Scoreboard*[2] and other benchmarking exercises of the European Commission. It mainly uses Eurostat data, or private data of sufficient reliability if official data is not available. Six indicators are drawn from the European Commission's Structural indicators.

All indicators have been updated based on data availability as of September 15, 2002. Four indicators could not be updated due to delays in the execution of the third Community Innovation Survey[3]. As a result, the 2002 EIS does not provide trend results for these indicators and it does not contain a summary innovation index similar to the one offered in 2001. Subject to the availability of new CIS data, the 2003 EIS is expected to offer again an updated composite innovation index and a comparison between the index and average trends for each country, which was one of the most interesting features of the 2001 EIS.

The EIS is complemented by six technical papers:

(1) Technical Paper No 1: Member States and Associate Countries

Detailed results for current and trend data, innovation leaders, relative strengths and weaknesses per country, convergence and divergence analysis between member states and different groups of member states, and country pages with trend diagrams and main policy changes.

(2) Technical Paper No 2: Candidate Countries

Detailed results for current and trend data, innovation leaders, relative strengths and weaknesses per country, and country pages with both current and trend graphs.

(3) Technical Paper No 3: EU Regions

Detailed results for currently available data, leading regions, two tentative composite innovation indicators, indicator graphs, and preliminary steps towards the 2003 regional scoreboard.

(4) Technical Paper No 4: Indicators and Definitions
Full definitions and graphs for all indicators.

(5) Technical Paper No 5: Thematic Scoreboard "Lifelong Learning for Innovation"
Prototype of a complementary scoreboard on "Lifelong Learning for Innovation".

(6) Technical Paper No 6: Methodological Report

Overview of five different methods for constructing composite indices, and review of the similarities and differences between the EIS and other European Commission scoreboards.

All technical papers are available from the Trend Chart website (www.cordis.lu/trendchart).

[1] A first provisional EIS was published in September 2000: COM(2000) 567. The first full version of the EIS was published in October 2001: SEC(2001) 1414.
[2] SEC(2002) 1213.
[3] These are indicators 3.1, 3.2, 3.3 and 4.3.

Table of Content

1. Introduction

This report looks at several methodological issues involving the European Innovation Scoreboard (EIS). Section 2 below evaluates different methods of calculating a composite innovation index[4]. Most of the analyses use the 2001 EIS because a composite index was not calculated for 2002, due to a lack of updated data for the four indicators from the Community Innovation Survey. The European Commission has developed two other scoreboards for entrepreneurship and research. Section 3 compares these two scoreboards with the EIS. Section 4 provides a brief evaluation of the macro-economic relationship between innovation and economic growth, productivity and GDP. These preliminary analyses will be expanded in 2003. Finally, Section 5 provides full definitions for all indicators in the EIS.

2. Composite Innovation Indices

The advantage of a composite index is that a single number summarizing the relative standing of a nation can attract attention and build political support for appropriate policies. For these reasons, the 2001 EIS included a "Summary Innovation Index" (SII). This index was very successful in attracting the attention of the media and policy makers. However, it also attracted some criticism over its ability to accurately summarize national innovative capabilities in a single number. This accuracy partly depends on two choices in the design of a composite index: the method of calculation and the weights or contribution of each indicator to the composite index.

2.1. Methods for calculating composite indices

All methods of calculating a composite index must address two issues:

1. Convert different units of measurement into the same unit.
2. Develop a rule for treating interval level data, particularly when there are outliers (values that differ substantially from the mean).

The first problem is relatively simple to solve and can be met by using percentages or standardized values such as z scores. The more difficult choice is how to treat interval data. Even if we weight each indicator so that it contributes equally to the composite index, the method of treating interval data can give greater *de facto* weights to high values of an indicator. The severity of this problem increases when there are large outliers. It is possible to calculate a composite index so that it is insensitive to outliers that differ substantially from the mean, but most of these methods are statistically more complex and less transparent than other methods.

Does it matter if outliers give *de facto* greater weight to some indicator values than to others? The answer to this question partly depends on how innovative capabilities work. For example, assume that country *A* does extremely well in public R&D so that this indicator is

[4] Part of this section draws on a MERIT project for DG Research, *Methodological Review of DG Research's Composite Indicators for the Knowledge-Based Economy,* June 2002.

an outlier, but very poorly in all other innovation indicators. In contrast, country *B* has an average performance in all indicators. A composite index that is sensitive to outliers could rate *A* higher than *B*, while an index that is not sensitive to outliers could rate *B* higher than *A*.

Current theories of innovation stress that innovation is an interconnected process, requiring a wide range of capabilities and inputs. If true, the fact that *A* does poorly on most indicators should substantially reduce the efficiency and impact of public R&D, resulting in poor innovative outcomes. Country *B* should do better than country *A*, and consequently the method for calculating a composite index should minimize the effect of outliers.

Optimally, we would like to have a composite indicator that is simple to understand and which is unaffected by outliers. The SII used in the 2001 EIS meets these requirements. The SII uses the simplest method possible: the percentage of indicators that are 'above average' minus the percentage that are below average. In order to adjust for sampling variation, all indicators within plus or minus an arbitrarily selected threshold of 20% of the EU average are counted as 'average' and do not influence the SII[5]. The SII is adjusted to vary between a maximum of +10 and a minimum of –10.

One of the main criticisms of the SII is that it converts interval level data into ordinal level data, resulting in a loss of information. Whether or not this feature is a problem depends on how the SII compares to other methods of constructing a composite index. The basic question is if other methods of calculating a composite index give substantially different results.

Table 1 describes the SII plus four other methods of constructing a composite index. The four other methods were identified from a review of published studies that developed composite indices for innovation, economic, or environmental goals. Some of the differences in the methods are minor. For example, method 4 is a re-scaled version of method 3, while method 5, or the "best performance method", is a special case of method 4.

In some cases the differences between methods are based on what they assume about innovative processes. For example, method 5 implicitly assumes that the lowest attainable value is zero while the maximum possible value is observed within the dataset. Conversely, method 3 implicitly assumes that both the minimum and maximum values can reach the theoretical maximum (or minimum). The advantage of method 5 is largely due to its stress on an optimum level for most innovation indicators that is substantially below the theoretical maximum. For example, business R&D intensities could theoretically approach 100%, but this would be economically disastrous and enormously inefficient.

[5] The DG Enterprise scoreboard follows a conceptually similar approach to identify member state's strengths and weaknesses, although it does not provide a composite index.

Table 1. Five methods for calculating a composite innovation index

	Advantages	Disadvantages
1. Number of indicators above the mean minus the number below the mean (SII). $CI_i^t = \frac{y_i^t}{\sum_{j=1}^m q_j}$, where	Simplest method, unaffected by outliers either below or above the mean. $y_i^t = \#\left\{j \; s.t. \frac{x_{ij}^t}{x_{EUj}^t} > 1+p\right\} - \#\left\{j \; s.t. \frac{x_{ij}^t}{x_{EUj}^t} < 1+p\right\}$	Loss of interval information, leaving only ordinal level data for each indicator; arbitrary nature of the thresholds.
2. Summing percentage differences from the mean $CI_i^t = \frac{\sum_{j=1}^m q_j y_{ij}^t}{\sum_{j=1}^m q_j}$, where	Simple to construct. $y_{ij}^t = \frac{x_{ij}^t}{x_{EUj}^t}$	Values less than the mean contribute less than values above the mean. One result is that large positive values count considerably more than small negative values. This effectively destroys equal weighting and makes the index sensitive to positive outliers.
3. Standardized values (z scores) for each indicator $CI_i^t = \frac{\sum_{j=1}^m q_j y_{ij}^t}{\sum_{j=1}^m q_j}$, where	Maintains interval level information. $y_{ij}^t = \frac{x_{ij}^t - x_{EUj}^t}{\sigma_{EUj}^t}$	Variables with a large variance have a *de facto* greater weight; index sensitive to both positive and negative outliers.
4. Re-scaled values. The re-scaled scores vary within the identical range for each indicator (0 to 1). $CI_i^t = \frac{\sum_{j=1}^m q_j y_{ij}^t}{\sum_{j=1}^m q_j}$, where	Maintains interval level information, lowest sensitivity to outliers of the methods that maintain interval level data. $y_{ij}^t = \frac{x_{ij}^t - \min(x_j^t)}{range(x_j^t)}$	Statistically more complex than other methods.
5. Best performance. (Special case of Method 4) $CI_i^t = \frac{\sum_{j=1}^m q_j y_{ij}^t}{\sum_{j=1}^m q_j}$, where	Maintains interval level information. Simpler version of method 4. $y_{ij}^t = \frac{x_{ij}^t}{Max(x_j^t)}$	Sensitive to positive outliers.

Notes: x_{ij}^t is the value of indicator *j* for country *i* at time *t*. q_j is the weight given to indicator *j* in the composite index. y_{ij}^t equals the value of the transformed indicator for country *i* at time *t*. In equation 1, *p* = an arbitrarily chosen threshold above and below the mean.

There are also variations for each of the methods given in Table 1. For example, the Environmental Performance Index[6] of the World Economic Forum uses a re-scaled percentage method. In any case, the best alternatives to the SII are likely to use re-scaling to reduce sensitivity to one or two outliers.

In terms of the method of calculation, the 'gold' standard is Method 4, based on re-scaled values, because it uses interval level data while minimizing sensitivity to outliers. However, it is statistically complex compared to the alternatives and more difficult to link to assumptions about innovation processes. This makes it less transparent.

Do the different methods of calculating a composite index give different results? Table 2 gives the R^2 values from correlations between each of the five methods of constructing a composite index. All five methods use the identical 2001 EIS data for 17 countries (15 EU countries and the US and Japan). As shown in Table 2, all methods produce very similar results, with R^2 values ranging from 0.89 between Methods 2 (percentage differences from the mean) and 4 (re-scaled values), to 0.99 between Methods 3 (z-values) and 4 and between methods 4 and 5 (best performance). Also, the SII is highly correlated with the other four methods, especially with methods 4 and 5. To further illustrate the strong correlation between the different composite indices, Figure 1 graphs the correlation between Method 4 and the SII[7]. These results suggest that all five methods generate very similar composite indices.

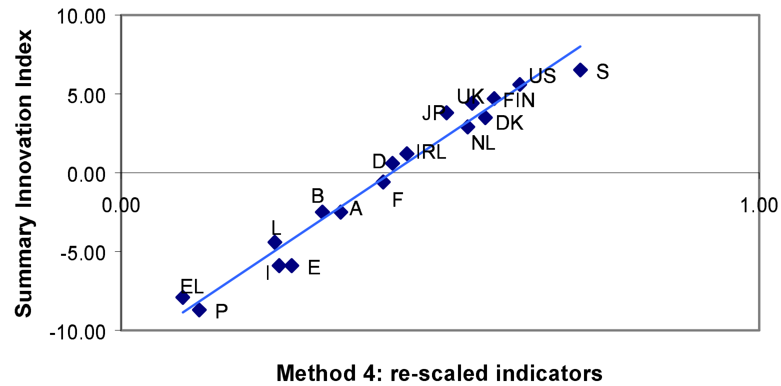
Table 2. Correlation matrix (R^2 values) for five methods for calculating a composite innovation index (2001 EIS)

	SII	Method 2 (% difference from mean)	Method 3 (Z-values)	Method 4 (Re-scaled values)	Method 5 (Best performance)
SII	1				
Method 2	0.89	1			
Method 3	0.95	0.92	1		
Method 4	0.97	0.89	0.99	1	
Method 5	0.97	0.93	0.98	0.99	1

[6] World Economic Forum, Pilot Environmental Performance Index, Yale Centre for Environmental Law and Policy, 2002.

[7] Unlike the unscaled z score method, in which the composite index can vary from a negative to a positive number, all of the values of the re-scaled values are positive. This is due to re-scaling the original indicators so that each indicator has an equal range. In this case, the range is between 0 and 1, but it is possible to select a range that would run from –1 to +1.

Figure 1: Correlation between the SII and Method 4



2.2 Rank order results

The most common interpretation of a composite index is based on their rank order – which country is first, second, third, etc. in terms of innovativeness. For this reason, we also evaluated the effect of the method of calculating the innovation index on the rank order of the innovativeness of each country. Table 3 gives the rank orders generated by the SII and three other methods of computing the innovation index. Although the SII generates two sets of ties in the rank orders (Italy and Spain fall in position 3; Austria and Belgium fall in position 5), these have been adjusted to optimize the match with the re-scaled ranking.

For 17 countries, the maximum possible number of changes in the rank order is 144 units[8], with a 1 unit change equal to a change in one position, such as from fourth to fifth place. The maximum number of changes for a single country is 16 units, for example if Portugal shifted from last to first place.

All rank orders between the four methods are very similar. There are only 12 unit changes between the SII and Method 4, 10 unit changes between the SII and Method 5, and 18 unit changes between the SII and Method 3[9]. For a single country, the maximum observed number of unit changes in the rank order compared to the SII is two. For example, Japan changes from position 13 in the SII to position 11 using Method 4[10].

[8] For 17 countries, the maximum number of changes occurs when the country which was in the first place (rank order=17) in one year shifts to the last one (rank order=1) in the next one; when the country with rank order 16 in one year shifts to position 2 in the next one; when the country with rank order 15 shifts to rank order 3; and so on. By adding up the number of changes in the position for each country (i.e, (17-1)+(16-2)+(15-3)+...) one obtains 144.

[9] The number of unit changes between the SII and method 2 (not included in the table) is 22.

[10] The maximum number of unit changes between all of the methods is three, which occurs for Japan in a comparison between methods 4 and 3 (Japan is in position 11) and method 5 (Japan is in position 14).

These comparisons show that the simple SII provides rank order results that are very comparable to the more complex statistical methods used in Methods 3, 4 and 5. Moreover, as Table 3 reveals, independently of the method used, one can always identify three groups of countries: a group which always ranks in the top places (Sweden, US, Finland), a second group which ranks in the bottom places (Portugal, Greece, Spain and Italy), and a third group which ranks in the middle (Belgium, Austria, France, and Germany). A few other countries are slightly more sensitive to the choice of method for calculating the composite index (Denmark, the UK, Ireland).

Table 3. Rank order of four methods of calculating a composite index (1 = least innovative and 17 = most innovative)

	SII	Re-scaled (Method 4)	Z scores (Method 3)	Best performance (Method 5)
Portugal	1	2	2	2
Greece	2	1	1	1
Spain	3	5	5	5
Italy	4	4	4	4
Luxembourg	5	3	3	3
Belgium	6	6	6	6
Austria	7	7	7	7
France	8	8	9	8
Germany	9	9	10	9
Ireland	10	10	8	10
Netherlands	11	12	13	11
Denmark	12	14	14	13
Japan	13	11	11	14
UK	14	13	12	12
Finland	15	15	15	15
US	16	16	16	16
Sweden	17	17	17	17
Total unit changes compared to the SII		*12*	*18*	*10*

Notes: light grey = one unit change in the rank order compared to the SII. Darker grey = two unit change in the rank order.

2.3 Changes over time

A robust composite index must also be useful for looking at changes over time. In order to explore these effects, we computed the composite index using the SII, method 4 (the 'gold' standard, and method 5 (best performance index) for 2001 and 2002. To maintain comparability, the four CIS indicators (i.e., category 3 indicators and indicator 4.3) have been excluded from both the 2001 and 2002 results.

We expect changes in the rank order among countries from two factors: real changes between countries that have developed over time, and changes that are an artifact of the calculation method.

Table 4 reports the rank orders for 2001 and 2002 using the three methods. The SII and the re-scaled method have almost the same number of units in the change of the rank order, whereas Method 5 presents twice the number of unit changes as the SII. Denmark improves 3 places in 2002 when using the best performance method, whereas it only increases one position with the SII and there is no difference with Method 4. This increase in the rank order for Denmark is basically due to the increase in the venture capital indicator (which increased by more than 600% between 2001 and 2002), and in the number of S&E graduates (which increased by 76% over the same period). The same indicators explain also the increase of three units in the rank order for Finland using the best performance method.

Table 4. Effects of the calculation method on changes over time

	SII		Re-scaled (Method 4)		Best performance (Method 5)	
Rank	**2001**	**2002**	**2001**	**2002**	**2001**	**2002**
1	P	P	GR	GR	P	GR
2	GR	GR	P	P	GR	P
3	I	E	I	I	I	I
4	E	I	L	E	L	E
5	L	L	E	A	E	A
6	A	A	A	L	A	L
7	F	D	B	D	F	D
8	D	IRL	D	F	IRL	F
9	B	F	IRL	IRL	D	B
10	IRL	B	F	B	B	IRL
11	DK	NL	J	NL	DK	NL
12	NL	DK	DK	DK	UK	J
13	J	US	NL	J	NL	UK
14	UK	UK	UK	UK	FIN	DK
15	US	J	US	US	SWE	US
16	FIN	FIN	FIN	SWE	J	SWE
17	SWE	SWE	SWE	FIN	US	FIN
Total unit changes	14		15		28	

The largest differences over time are for Japan, which also shows a change in direction depending on the method used. The rank order for Japan *falls* 4 places with the best performance method and *increases* two places with the other two methods. The reason for this switch in direction is that the best performance method only considers the maximum value of the original indicators to compute the corresponding transformed indicators, whereas the re-scaled method considers also the minimum value and the range. This makes method 5 more sensitive to outliers and also more volatile over time. An example is given in Table 5, which shows the transformed indicators for indicator 1.1 for Japan, computed according to methods 4 and 5. Since the percentage increase in 2002 of the original indicator is lower than the percentage increase of the maximum value, the best performance indicator falls. On the contrary, the decrease in the minimum value more than compensates the increase in the maximum value, and as a result the re-scaled indicator increases.

Table 5. Transformed values of indicator 1.1 for Japan

	2001	2002	Transformed values			
			Method 4		Method 5	
			2001	2002	2001	2002
Original indicator 1.1	11	12.5	0.48	0.5	0.62	0.54
Maximum	17.8	23.2				
Minimum	4.7	1.8				
Range	13.1	21.4				

2.4 Composite indices by innovation category

Table 6 provides the rank order of each country, using the SII and method 4, within each of the four categories of innovation indicators: 1) human resources, 2) knowledge creation, 3) the transmission and application of new knowledge, and 4) innovation finance, outputs and markets. The 2001 EIS data are used. There is little difference between the SII and Method 4 for both categories 1 and 2, with respectively 10 and zero unit differences in the rank order.

As these examples show, Method 4 is more sensitive to outliers than the SII, which is due to the fact that the former maintains interval level information. The number of outliers is especially large within category four indicators, which, together with the fact that method 4 is more sensitive to outliers than the SII, explains the differences in the rank orders between the two methods. These results also show that the differences in the rank orders of the composite index using all 17 indicators can be partly traced back to outliers among the category 4 indicators.

Table 6. Rank orders by category

Rank	Category 1 *Human resources*		Category 2 *Knowledge creation*		Category 3 *Transmission and application of new knowledge*		Category 4 *Innovation finance, output and markets*	
	SII	Re-scaled	SII	Re-scaled	SII	Re-scaled	SII	Re-scaled
1	P	P	GR	GR	B	P	DE	I
2	GR	GR	P	P	E	GR	P	GR
3	L	I	L	L	GR	E	I	DE
4	I	L	E	E	P	L	F	J
5	E	A	I	I	I	B	G	F
6	A	E	IRL	IRL	L	I	A	A
7	NL	B	A	A	F	UK	E	P
8	B	NL	B	B	FIN	F	L	L
9	DE	DE	UK	UK	A	FIN	B	E
10	F	F	DK	DK	NL	NL	DK	IRL
11	US	IRL	F	F	UK	A	J	B
12	IRL	DK	DE	DE	DE	DE	IRL	FIN
13	DK	US	NL	NL	IRL	IRL	FIN	DK
14	J	J	US	US	SW	SW	UK	UK
15	FIN	FIN	J	J	DK	DK	NL	US
16	SWE	SWE	SWE	SWE	n.a	n.a.	SWE	NL
17	UK	UK	FIN	FIN	n.a	n.a	US	SWE
Total units change	10		0		20		34	

2.5 Weighting indicators

How to weight the indicators in a composite index is essentially an unsolvable problem unless we have a measure of the latent, underlying phenomena that we want to measure. Under these conditions, we can run a regression analysis, with suitable lag times, in which the indicators are the independent variables and the measure of the latent phenomena is the dependent variable. The regression coefficients are then used as the weights. In this case, the purpose of the exercise would change. Instead of trying to estimate the composite index (which as the dependent variable would be known), we would want to know how much each indicator contributed to the composite index. This information could be used to determine the policy importance of each indicator.

Except for one study[11], most compilations of innovation indicators that have developed a composite index either give equal weightings to each indicator or give a subjective weighting in simple units such as '0.5' or '0.75'[12]. The rationale for this is that it is impossible to carefully calculate weights without a measure of the latent phenomena. We can only make educated guesses at what the weights might be. However, a few of the critics of the SII suggested that Principal Component Analysis (PCA) could be used to compute appropriate weights for the constituent indicators.

PCA is a statistical technique that linearly transforms an original set of variables into a substantially smaller set of uncorrelated variables that represents most of the information in the original set of variables (Dunteman 1989[13]). This technique allows one to analyze the interactions among variables and determine the existence of redundancies in a given data set.

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[11] The study by Porter and Stern (*The New Challenge to America's Prosperity: Findings from the Innovation Index*. Council on Competitiveness, Washington DC, 1999) claims to identify a latent measure of innovativeness. Their study uses international patenting as the measure of innovativeness and regresses several indicators against it. The quality of their method is based on whether or not patents, by themselves, are an accurate output measure for innovativeness. We think that the evidence is against them, both because patents only capture one of many aspects of innovation and because patents are an intermediate rather than a final output measure for innovative activities.

[12] The State New Economy Index 2000 (Progressive Policy Institute; http://www.neweconomyindex.org) uses weights of both 0.5 and 0.75.

[13] George H. Dunteman, 1989. *Principal components analysis*. SAGE publications, Number 07-069.

In general, the purpose of using PCA is to reduce the dimensionality of the original data set while keeping most of the information contained in it. More specifically, PCA generates a series of new variables (principal components) that are linear combinations of the original variables, with the first principal components explaining most of the variance in the original variable set. In the context of elaborating composite indices, PCA may have two uses: on one hand, find appropriate weights for the constituent indicators, and, on the other hand, identify a subset of indicators that represent the total set of indicators.

Note that the goals of PCA and of constructing a composite index are in fact the same: to obtain a new variable that summarises the information contained in a given set of variables (indicators). For that reason, PCA could be used to develop appropriate weights for the constituent indicators. However, PCA is a statistical technique and, as such, it uses statistical measures, mainly the variance explained by a set of variables and the correlations between these variables. Hence, the weights produced from PCA will be based on these statistical measures and not on the influence of each variable (indicator) on what we are trying to measure. In the case of the Innovation Scoreboard the appropriate weights for the 17 indicators in the SII should correspond to the contribution of each indicator to innovation performance. These weights should then be based on a subjective assessment of the value of each indicator for the outcome of interest.

Key indicators

One application of PCA is to use it to select a subset of indicators to represent the total set of variables. The correlation matrix (see Appendix A) of the set of eighteen indicators (two indicators for patenting) reveals high correlations (correlation coefficients higher than 0.7) between the indicators, suggesting that we can represent the variation in the total set of indicators by a much smaller set of indicators. Of note, only the *internal structure* of the data is considered in selecting the subset of variables. Other criteria, such as the effectiveness of each indicator in predicting a dependent variable, or, in our case, the *Summary Innovation Index*, are not used.

PCA was applied to the set of eighteen indicators for the fifteen EU countries (using 2001 data) and the following subset of six 'key' indicators was selected[14]:

1.1. New S&E graduates (‰ of 20 – 29 age class)
2.3a. EPO high tech patent applications (per million population)
2.3b. USPTO high tech patent applications (per million population)
3.1. SMEs innovating in-house (% of manufacturing SMEs)
4.2. New capital raised on stock markets

[14] Since the variables (indicators) are not in the same metric and the variances differ widely from one another, PCA was conducted using standardized variables (zero mean and unit variance).

4.3. 'New to market' products (% of total sales by manufacturing firms from innovative products).

These indicators explain 96.9% of the total variation[15]. Therefore, this analysis produces a subset of key indicators that represent most of the information contained in the whole set of indicators.

These results suggest that the EIS could be altered to simply include these six indicators. However, even though six indicators explain most of the variance, these indicators do not provide enough information on the different factors that are linked to building innovative capabilities at the national level. The complete list of 17 indicators is useful for the design of appropriate policies and can help to identify national strengths and weaknesses.

2.6 Conclusions

The results of the above analyses show that all methods for calculating a composite innovation index (using all 17 indicators) produce similar results, even though outliers are treated differently. This result is encouraging and shows that the indices are comparatively robust. It simply does not matter much which method of calculation is used. The choice can then be based on both simplicity and ease of understanding and on insensitivity to outliers.

However, there are small differences by method in the rank order of a few countries by one or two units. Introducing changes over time or limiting the index to a single category can increase differences in the rank order. In addition to the choice of the calculation method, other research (results not given here) has shown that these small differences in the rank order can be caused by minor changes in the choice or definition of the indicators, or due to one or two indicators (as shown in section 2.3 for Japan). The important lesson to be drawn is that *small differences in the rank order of a composite index are meaningless*. This creates a problem for presenting the results. The 2001 SII attracted substantial media attention due to the fact that a single indicator is much simpler to present than complex tables. Yet, if small differences in a composite index are due to minor, erratic variations, or to differences in the calculation method, we cannot conclude that there is any real difference in two countries with a similar composite index – such as the 2001 SII of 4.7 for Finland and 4.4 for the UK.

The presentation of a composite index for innovation must therefore emphasize this fact. Perhaps it would help if the countries were combined into simple groups, such as leaders,

[15] The amount of variation explained by a subset of variables is defined as the sum f their variances and the ariation they explain in each of the discarded variables. Since the variance of a standardized variable is equal to one, the amount of variation explained is equal to $n_r + \sum_{i=1}^{d} R_{i,r}^2$, where n_r is the number of retained variables and $R_{i,r}^2$ is the squared multiple correlation of the ith discarded variable with the *r* retained variables.

followers, and laggards. This would be possible if the countries clump together with gaps between each group.

A major reason why each method of calculation produces similar results is due to consistency between innovative indicators: countries with a high index score do very well on almost all indicators, countries with a moderate index score have average results for most indicators, and countries with a low index score do poorly on almost all of them. Therefore, changing the method of calculation does not alter the composite index or rank order by very much. In addition, these characteristics mean that changing the weights are unlikely to have much of an effect either. As an example, both the Joint Research Centre and the OECD have recently explored the effect of several thousand iterations of randomly assigned weights for a Technology Achievement Index and an Innovation Index[16]. The OECD analyses find a reasonable correlation between the Innovation Index with predefined weights and the average of the randomly assigned weights. In addition, the confidence bands for 90% of the randomly estimated composite indices place each of 26 countries in a similar rank order. The JRC uses the method to identify a few countries where the weighting scheme has a large effect on the index (wider uncertainty bounds). This occurs in a few countries with a mix of indicators ranging from well above to well below the average. With a few exceptions, these results suggest that innovation is an interconnected process, as proposed by current innovation theory.

The summary innovation index results for changes over time and for each innovation category show larger differences between each method of calculation. The analyses of the changes between 2001 and 2002 show that the best performance method is more sensitive to positive outliers, created by volatility over time. Of greater concern is that the change in the rank order of a country over time can move in opposite directions, depending on the method of calculation. The results by innovation category show that some of the volatility can be traced to a few indicators. Their effect is magnified when the composite index is based on only a few indicators. This suggests that composite indices should not be developed for sub-categories that contain a small number of indicators with a large degree of variation.

At this time, there is no solution to the weighting issue because we lack a dependent variable for innovation processes that we could use to test the relative contribution of each indicator. PCA analysis is useful in identifying key indicators, but it does not provide a solution to the weighting problem. The fact that leading countries do well and lagging countries do poorly on most indicators suggests that different weighting schemes will not have much of an impact on the results. This conclusion is supported by the OECD and JRC experiments using randomized weighting schemes. The greatest differences are likely to be observed among a few countries, such as Germany and France, which do well on some indicators and poorly on

[16] Applied Statistics Group, Joint Research Centre of the European Commission, Report on Current Methodologies and Practices for Composite Indicator Development, June 2002; OECD, Draft Working Paper, Composite Indicators of Country Performance: A Critical Assessment, November 2002.

others. Higher weights on indicators for which Germany does well (Business R&D and EPO patents) and lower weights on indicators where Germany does poorly (lifelong learning and venture capital) would improve Germany's score on a composite index. In the 2003 EIS, we will experiment with different weighting schemes in order to identify countries whose composite index is sensitive to different weighting schemes.

3. Comparison with other Commission Scoreboards

The European Commission has developed several collections of indicators (or scoreboards) for addressing specific policy areas. In addition to the EIS, these include DG Research's *Indicators for Benchmarking of National Research Policies*[17] (hereafter referred to as the Research Scoreboard) and DG Enterprise's *Enterprise Policy Indicators*[18] (hereafter referred to as the Enterprise Scoreboard).

Each of the Commission's scoreboards serves a different purpose. The EIS measures the innovative capabilities of European countries in both the public and private sectors. The goal of the Enterprise Scoreboard is to measure factors that are "key contributors to enterprise growth, performance, and presumably competitiveness". Finally, the Research Scoreboard focuses on benchmarking national research policies.

The EIS contains 17 indicators (the two variants of the patent indicator count as one indicator), the Research Scoreboard has 17 indicators, and the Enterprise Scoreboard has 21 indicators. All three scoreboards draw on some of Eurostat's Structural Indicators but they also contain other indicators, or variations of the Structural Indicators. In addition, the EIS contains some indicators that are identical or similar to those in the Research and Enterprise Scoreboards.

These areas of overlap between the three scoreboards raise questions about why we need three different but similar scoreboards. This section evaluates the similarities and differences between the three scoreboards, the reasons for the similarities, and suggests a few improvements in their production.

3.1 Similarities and differences

Table 7 gives the number of indicators in the Research and Enterprise Scoreboards that are identical or similar to the indicators in the EIS. For example, 7 (41%) of the Research Scoreboard indicators are not found in the EIS, while 1 indicator is identical to an EIS indicator. The remaining nine indicators measure similar factors, although they differ in the exact definition of the indicator. For example, one Research Scoreboard indicator uses medium-high and high technology value added, while the EIS indicator is limited to high technology value-added. The latter is a subset of the former indicator. Similarly, the Research Scoreboard gives the percentage of all firms that innovate, while the EIS use the percentage of manufacturing SMEs that innovate. Although conceptually similar, these differences in how each indicator is defined can result in large differences in the actual values of the indicator.

[17] DG Research, Towards a European Research Area: Key Figures 2001, European Commission, Brussels, 2001.
[18] DG Enterprise (Unit A5), A Pocketbook of Enterprise Policy Indicators, European Commission, Luxembourg, 2001.

Table 7. Comparison between the EIS and the Research and Enterprise Scoreboards

Occurrence in EIS		Enterprise		Research	
Identical		24%	5	6%	1
Similar but different		19%	3	53%	9
Not found in EIS		57%	13	41%	7
	Total	*100%*	*21*	*100%*	*17*

Table 8 provides the opposite perspective to that of Table 7. It gives each indicator in the EIS and notes which indicators in the Research and Enterprise Scoreboards are identical (***), similar (+), or not at all related (blank). The last column of Table 8 shows which EIS indicators are identical to or similar to Eurostat's Structural Indicators. The footnotes describe the differences between the EIS indicators and those of the other Scoreboards. In total, 59% of the 18 EIS indicators are identical to or similar to an indicator in the Research Scoreboard, compared to a 45% overlap between the EIS and the Enterprise Scoreboard.

3.2 Reasons for the similarities

There are two explanations for the similarities between the scoreboards. First, many indicators are conceptually related to several outcomes. For example, research drives some types of innovation, which in turn can influence enterprise performance. Therefore, all three scoreboards contain similar (although not always identical) indicators for public and private R&D and for patenting. Second, there are a limited number of good quality indicators that are available for most EU countries. This means that all scoreboards must draw on the same set of indicators. The result is that each scoreboard often has to use an indicator that is not perfectly suited to its goals. For example, both the EIS and the Research Scoreboard include an indicator for employment in high technology services, but both have to make compromises.

The EIS, with a focus on innovation, limits the high technology services employment indicator to three high technology service sectors. The indicator ranges from a low of 1.2% of total employment in Portugal to a high of 4.8% in Sweden. However, an ideal version of this indicator would capture high-skilled employment in other service sectors, such as banking and retail. Unfortunately, this type of data is not available. Faced with a similar problem, DG Research adopts a much broader definition of 'knowledge-intensive services' that includes sectors in which a large fraction of employees only have low-level skills. As a result, the indicator ranges from a low of 19% of total employment in Portugal to a high of 45% in Sweden.

Table 8. Similarities between the EIS indicators and other EC indicators

Innovation Scoreboard (EIS)	Enterprise 2001	Research 2001	Structural Indicators
S&E graduates / 20 - 29 year age class		+ [R1]	***
Percent 25-64 year olds w tertiary education	***		
Percent 25-64 year olds in educational training	***		***
Share workforce in med/high-tech manuf.		+ [R2]	
Share workforce in high-tech services		+ [R3]	
Public R&D/GDP	***	+ [R4]	*** [S1]
Business R&D/GDP	***	+ [R5]	*** [S1]
High-tech EPO patents per capita	***	+ [R6]	+ [S2]
High-tech USPTO patents per capita		+ [R7]	+ [S3]
Percent SMEs innovating in-house			
Percent Manuf. SMEs in innovation co-operation		+ [R8]	
All innovation expenditures/sales			
High-tech venture capital /GDP	+ [E1]	+ [R9]	+ [S4]
New capital raised /GDP			+ [S5]
New-to-market product sales/all sales			
Percent households with internet access	+ [E2]		***
ICT expenditure/GDP	+ [E3]		***
High-tech manuf. value-added/all manuf v-added		+ [R10]	

*** = identical, + = similar. Notes: The definition of the EIS for 2002 is compared to the 2001 definitions of the Enterprise and Research scoreboards and to the 2002 definitions of the Structural Indicators. In contrast, data comparisons are based on the 2001 versions of the three scoreboards.

E1. All venture capital versus high technology venture capital in the EIS.
E2. Percent of households with broadband access versus all households with home access in the EIS.
E3. The enterprise scoreboard appears to use the same indicator as the EIS, but the data differ slightly, possibly because different years are used.
R1. Percent of new science and technology PhDs among 25 to 34 year olds versus percent of Science and engineering post-secondary graduates out of 20 to 29 year olds.
R2. The research scoreboard uses high-tech manufacturing.
R3. The research scoreboard uses a broad definition of knowledge intensive services that includes all health sector workers etc, while the EIS is limited to three high technology business sectors.
R4. Share of the government budget allocated to R&D versus non-BERD R&D as a percentage of GDP in the EIS.
R5. BERD as a percentage of industrial output versus BERD as a percentage of GDP in the EIS.
R6. All EPO patents versus high technology patents in the EIS.
R7. All USPTO patents versus high technology patents in the EIS.
R8. Percent of all firms involved in innovation cooperation versus the percent of manufacturing SMEs in the EIS.
R9. All venture capital versus high technology venture capital in the EIS
R10. The research scoreboard includes medium-high technology industries versus high tech industries only in the EIS. Also, whereas the EIS takes total manufacturing value added as the denominator, the research scoreboard takes total GDP.
S1: The definitions for the Structural indicators on R&D were changed on October 2002: COM(2002): 551. The new definitions disaggregate R&D expenditures according to source of finance. The data used in this analysis still reflects the old definition which disaggregated expenditures according to sector of spending.
S2. All EPO patents versus high technology patents in the EIS.
S3. All USPTO patents versus high technology patents in the EIS.
S4. All venture capital versus high technology venture capital in the EIS
S5. Total new capital raised versus only capital raised by new firms or by firms on parallel markets in the EIS.

Some of the differences between the EIS and the other two scoreboards is also due to the internal structure and goals of the EIS. The EIS tries to cover all aspects of innovation, which includes innovation as a creative activity, such as the development and manufacture of ICT, and innovation as diffusion, such as the adoption of ICT and other new technology by other firms. Some indicators are shifted towards one of these two types of innovation to limit the amount of overlap *within* the EIS indicators. For example, the indicators for innovation and cooperation rates among firms only use SMEs, since almost all large firms are both innovative and involved in innovation cooperation. This shifts the indicator towards capturing diffusion rather than creative activities. In contrast, the Research Scoreboard uses the percent of all firms involved in innovation cooperation because its focus is on innovation as a creative activity, where large firms are more active than SMEs.

3.2.1 EIS and the Research Scoreboard[19]

The higher level of overlap between the EIS and the Research Scoreboard than between the EIS and the Enterprise Scoreboard is due to the closer proximity between research and innovation than between innovation and enterprise growth, performance and competitiveness. However, the high level of overlap between the EIS and the Research Scoreboard is misleading, since many of the definitions are very different, resulting in very different actual values for similar indicators.

Some of the differences between similar indicators in the EIS and Research Scoreboard are due to different goals. For example, the EIS uses the percentage of all Science and Engineering (S&E) post-secondary graduates as an indicator of human resources. This includes diploma, bachelor, masters, and PhD degrees. A broad definition of S&E graduates is used because many of these skill levels, such as ICT technicians, will be important to the diffusion of new technology. In contrast, the comparable indicator in the Research Scoreboard is limited to PhD graduates because this scoreboard focuses on the creation of new technology. Similarly, the Research Scoreboard uses the percentage of all firms that cooperate as a measure of scientific and technological productivity, whereas the EIS limits the indicator to SMEs as a measure of diffusion, as noted above.

3.2.2 EIS and the Enterprise Scoreboard

In total, 45% of the 18 EIS indicators are identical or similar to one of the 21 indicators in the Enterprise Scoreboard. The latter divides the 21 indicators into seven categories with three indicators each: access to finance, administrative and regulatory environment, well-

[19] For 2002, DG Research has been experimenting with different methods of constructing a composite index for two measures: investment in a knowledge-based economy and performance in the transition towards a knowledge-based economy. Five indicators are proposed for investment: S&E researchers per capita, new PhDs, total R&D expenditures, total education expenditures, and IT expenditures. Three indicators are proposed for performance: patenting, publications, and employment in high technology sectors. At this time, it is not possible to assess the overlap between the EIS and the 2002 Research Scoreboard because the final indicators to include in the latter have not been chosen or fully defined.

functioning markets, innovation, entrepreneurship, human capital, and access to IT. There is no overlap between the Innovation and Enterprise Scoreboards for three of the seven categories (administrative and regulatory environment, well-functioning markets, and entrepreneurship). In contrast, all three of the innovation indicators in the Enterprise Scoreboard occur in the EIS, and two of the three human capital indicators. The Enterprise Scoreboard includes innovation and human capital indicators because both can influence performance, while the EIS includes both because they are essential components of innovation.

3.2.3 EIS and Eurostat's Structural Indicators

Eurostat's Structural Indicators provide a source of high-quality data for all three Scoreboards. The question here is why the EIS does not use the Structural Indicator's version of four indicators: two for patenting and two for innovation finance. The reason is that the Structural Indicators are not fully focused on innovation. The two patent indicators include all patent classes, many of which are used by sectors that only patent a small percentage of their innovations. In these sectors, patent use could be a better measure of appropriation conditions and competitive strategies than of innovation. The two finance indicators include all types of finance, such as venture capital for retail and tourism, which together account for the majority of venture capital. Again, the EIS versions of these two indicators focus more closely on higher-level innovative activities.

3.3 Room for Improvement?

Although much of the overlap between the three scoreboards is inevitable, there is room for improvement if there is greater coordination between the three. For example, the Research Scoreboard could focus more closely on research inputs, the EIS on innovation as diffusion and measures of innovation outputs, and the Enterprise Scoreboard on regulatory, entrepreneurial, and market conditions. The justification for this approach is that all three scoreboards cover factors that influence the economic performance and competitiveness of European economies. For this reason, the three scoreboards are inherently linked. One option is to fully recognize these linkages and construct modules of indicators for each of the main 'themes' (as described in the Research Scoreboard), 'categories' (as in the EIS), or 'areas' (as in the Enterprise Scoreboard) and then to share modules when constructing composite indices. Table 9 provides an outline of the current themes, categories and areas of each scoreboard. The left hand column gives the main underlying themes. The information under each scoreboard gives the name of the theme, category or area that contains at least one indicator of relevance to the main themes.

The shaded cells in Table 9 indicate 'core areas' that could be the main responsibility of each scoreboard, with other indicators obtained as modules. For example, the core area of the EIS could be to develop indicators for innovation as diffusion plus innovation outputs. Indicators for human resources and creative innovation would still be included in the EIS, but they would be obtained as modules from DG Research. This would require a few adjustments to the existing structure of each theme in each scoreboard. For example, the EIS includes indicators on high technology employment within the human resources category. These two indicators would need to be shifted to innovation outputs. Similarly, DG Enterprise would need to develop indicators for innovation finance that focuses on innovation, in addition to its broader indicators that cover all types of finance.

Table 9. Thematic coordination between the three scoreboards

Main Themes	Definition of theme in each scoreboard		
	DG Research	EIS	DG Enterprise
Human resources	Human resources in R&D and attractiveness of S&T professions	Human resources	Human capital
Creative innovation	1. Public and private investment in R&D 2. Scientific and technological productivity	Creation of new knowledge	Innovation
Innovation as diffusion		Transmission and application of new knowledge	
Innovation outputs	Impact of R&D on economic competitiveness and employment	Innovation finance, outputs and markets	Access to IT
Finance		Innovation finance, outputs and markets	Access to finance
Administrative and regulatory environment			Administrative and regulatory environment
Entrepreneurship			Entrepreneurship
Well-functioning markets			Well-functioning markets

Of note, coordination between the different scoreboards would reduce some of the fine-tuning of related indicators that improves the fit between these indicators and the goals of each scoreboard.

4. Economic Impact of Innovation

The justification for policy actions to support innovation is that innovation is partly responsible for improvements in the quality of life and in quantitative measures of well-being such as higher GDP per capita, productivity, and economic growth.

The link between innovation and growth has been extensively explored from both a theoretical and an empirical perspective. Although several different measures of innovation have been used in empirical research, including R&D spending, patenting, and the technological balance of payments, most empirical research has focused on the effect of innovation on productivity, either at the firm, industry or country level. The literature on this issue[20] finds that innovation has a significant effect on productivity, whether measured by R&D spending, patenting or innovation counts. The OECD Growth Project[21] has recently explored the possible sources of divergence in the levels of GDP per capita among OECD countries. Although an individual factor cannot be identified as the main source of growth divergences, innovation and technology are pointed out as significant factors in increased growth performance.

Tables 10 through 12 provide correlation results between the 17 innovation indicators plus the SII and three macro-economic variables at the national level: 2000 GDP per capita (Table 10), 2001 hourly productivity (Table 11) and the growth in total employment between 2000 and 2001 (Table 12)[22]. We use two, three, and five-year time lags when possible, to allow adequate time for innovation activities to influence macro-economic conditions. Of note, none of the correlations using the SII are statistically significant, while only a few of the correlations for individual indicators are significant.

The very low number of significant correlations is partly due to two limitations, the simplicity of the analysis, which does not control for the effect of other variables, and limitations with the innovation indicators themselves. First, macro-economic variables such as GDP and labour productivity are based on many factors other than innovation, such as capital investment and existing capital stocks. Including other factors in the analysis is beyond the scope of this project – our main purpose here is to identify any major patterns that might be visible, even without controlling for other variables. Second, the EIS indicators are imperfect measures of all innovative activities at the national level. They are weak on innovation as diffusion, which could be the mechanism followed by some countries, such as Italy, to innovate. This could explain why Sweden, characterized by a high innovative capability, and

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[20] For a review of this literature, see Mairesse, J. and Mohnen, P. (1995). *R&D and productivity: a survey of the econometric literature*, Université du Québec: mimeo; or Cameron, G. (1998) *Innovation and Growth: a survey of the empirical literature* (manuscript).

[21] http://www.oecd.org/subject/growth. See the report: *A new Economy?; The Changing Role of Innovation and Information Technology in Growth*, OECD 2000.

[22] Sources: The data for productivity per hour worked and for employment growth are from Eurostat's structural indicators (http://europa.eu.int/comm/eurostat/). GDP per capita (PPS) data is from the OECD.

Italy, with a low innovative capability, both have similar per capita GDP. The EIS indicators also *intentionally* focus on innovation in high technology manufacturing sectors, whereas between 60% and 70% of economic activity in the countries covered by the EIS is in the service sectors.

Table 10 shows the correlations between the innovation indicators and GDP per capita. In general, the correlation coefficients are all quite low. Only two indicators are significant and positively correlated with GDP per capita: the percentage of the working-age population with tertiary education (only for a two-year lag) and business expenditure on R&D (for both a three and five year lag).

Table 10. Correlations between innovation indicators and 2000 GDP per capita

	2 year lag	3 year lag	5 year lag
SII	0.31	-[1]	-
1.1 S&E graduates	-0.06	-0.20	0.01
1.2 Tertiary education	0.59*	0.25	0.13
1.3 Lifelong learning	0.246	0.05	0.17
1.4 Employment in med-high/high tech manufacturing	-0.17	-0.14	-0.14
1.5 Employment in high-tech services	0.27	0.23	0.09
2.1 Public R&D expenditures	0.025	0.35	0.41
2.2 Business expenditure on R&D	0.26	0.58*	0.59*
2.3.1 EPO high-tech patent applications	0.01	0.10	0.07
2.3.2 USPTO high-tech patent appl.	0.26	0.25	0.27
3.1 SMEs innovating in-house[2]	-	0.20	-
3.2 % manuf. SMEs in innovation cooperation [2]	-	0.20	-
3.3 Innovation expenditures [2]	-	0.50	-
4.1 High-tech venture capital investment	0.15	-	-
4.2 New capital raised on stock markets	0.16	-	-
4.3 'New to market' products [2]		-0.29	-
4.4 Home internet access	0.19	-	-
4.5 ICT expenditures	0.43	0.47	0.47
4.6 Percent of manuf. value-added from high-tech		0.09	-

Notes: * and ** denote significant correlations at the 0.05 and 0.01 levels, respectively.
1: Insufficient data for analysis.
2. The lag time for indicators 3.1, 3.2, 3.3 and 4.3 varies by country between two years for the Netherlands, Greece and Spain and four years for all other EU countries.

Although not significant, three results suggest possible connections between innovative activities and per capita GDP. First, the trend in the correlation for public R&D increases with the number of lag years, suggesting that public R&D could increase GDP per capita, but that it takes much longer than private R&D to have an effect. This is plausible, since publicly-funded R&D is often farther from commercialization than private R&D. Furthermore, one of the main outputs of the public research sector are trained scientists in leading edge research. These individuals could be employed by the private sector once they finish their studies.

Second, although the employment share in medium-high and high technology manufacturing is always negative. This could be due to lower average incomes in this sector than in alternatives, such as finance. Third, although not significant, the correlation coefficients for ICT investment are comparatively high. This variable could be significant if the number of observations (countries) was larger.

Table 11 gives the correlation results for hourly labour productivity in 2001. The correlations between the innovation indicators and hourly productivity are all very small, no matter the time lag is used. Only the indicator for new capital raised on stock markets is significant and positively correlated with productivity when a two-year lag is used. Possibly new capital tends to go into more productive investment, but there is not enough information on this result to make reliable conclusions.

Table 11. Correlations between innovation indicators and 2001 hourly productivity

	2 year lag	3 year lag	5 year lag
SII	-[1]	0.00	-0.04
1.1 S&E graduates	-0.14	-0.12	-0.14
1.2 Tertiary education	0.00	0.15	0.10
1.3 Lifelong learning	-0.05	0.11	-0.11
1.4 Employment in med-high/high tech manufacturing	-0.14	-0.17	-0.17
1.5 Employment in high-tech services	0.39	0.19	0.14
2.1 Public R&D expenditures	0.80	-0.17	-0.02
2.2 Business expenditure on R&D	0.24	-0.34	0.18
2.3.1 EPO high-tech patent applications	-0.02	-0.06	-0.10
2.3.2 USPTO high-tech patent appl.	-0.18	-0.17	-0.19
3.1 SMEs innovating in-house[2]	-	0.15	-
3.2 % manuf. SMEs involved in innovation cooperation[2]	-	0.05	-
3.3 Innovation expenditures[2]	-	0.30	-
4.1 High-tech venture capital investment	0.11	0.05	-
4.2 New capital raised on stock markets	0.59*		-
4.3 ‘New to market’ products[2]	-	-0.11	-
4.4 Home internet access	0.09	0.12	-
4.5 ICT expenditures	0.28	0.15	-
4.6 Percent of manuf. value-added from high-tech	0.19	-	-

Notes: * and ** denote significant correlations at the 0.05 and 0.01 levels, respectively.
1: Insufficient data for analysis.
2. The lag time for indicators 3.1, 3.2, 3.3 and 4.3 varies by country between two years for the Netherlands, Greece and Spain and four years for all other EU countries.

Table 12 gives the results for employment growth for 2001. The analyses are likely to be very problematic, because so many other factors will influence employment growth, including demographics, immigration, and taxation policy. There is only one positive and significant relationship between the innovation indicators and employment growth: for new capital raised on stock markets. This is a plausible relationship, because this capital should be invested in new firms, production, or research.

Table 12. Correlations between innovation indicators and employment growth (2000 to 2001)

	2 year lag	3 year lag	5 year lag
SII	-[1]	-0.12	-0.18
1.1 S&E graduates	-0.40	-0.60	-0.50
1.2 Tertiary education	-0.10	0.13	-0.02
1.3 Lifelong learning	-0.15	-0.18	-0.16
1.4 Employment in med-high/high tech manufacturing	-0.39	-0.42	-0.45
1.5 Employment in high-tech services	0.17	-0.01	-0.13
2.1 Public R&D expenditures	-0.33	-0.29	-0.17
2.2 Business expenditure on R&D	-0.03	-0.19	-0.06
2.3.1 EPO high-tech patent applications	-0.09	-0.11	-0.15
2.3.2 USPTO high-tech patent appl.	-0.23	-0.20	-0.17
3.1 SMEs innovating in-house[2]	-	-0.25	-
3.2 % Manuf. SMEs in innovation cooperation[2]	-	-0.16	-
3.3 Innovation expenditures[2]	-	0.07	-
4.1 High-tech venture capital investment	0.28	0.27	-
4.2 New capital raised on stock markets	0.77**	-	-
4.3 'New to market' products[2]	-	0.44	-
4.4 Home internet access	-0.01	0.04	-
4.5 ICT expenditures	0.18	0.11	-
4.6 Percent of manuf. value-added from high-tech	0.33	-	-

Notes: * and ** denote significant correlations at the 0.05 and 0.01 levels, respectively.
1: Insufficient data for analysis.
2. The lag time for indicators 3.1, 3.2, 3.3 and 4.3 varies by country between two years for the Netherlands, Greece and Spain and four years for all other EU countries.

5. Definition and Sources for the EIS Indicators

1.1 New S&E graduates (‰ of 20-29 years age class)

Definition: The reference population is all age classes between 20 and 29 years inclusive. Tertiary graduates in Science & Engineering (S&E) are defined as all post-secondary education graduates (ISCED classes 5a and above) in life sciences (ISC42), physical sciences (ISC44), mathematics and statistics (ISC46), computing (ISC48), engineering and engineering trades (ISC52), manufacturing and processing (ISC54) and architecture and building (ISC58). Due to a change in definition a comparison with the 2001 Scoreboard results is not possible. This indicator is identical to Structural indicator 2.4: Science and technology graduates.

Interpretation: The indicator is a measure of the supply of new graduates with training in Science & Engineering (S&E). Due to problems of comparability for educational qualifications across countries, this indicator uses broad educational categories. This means that it covers everything from graduates of one-year diploma programmes to PhDs. A broad coverage can also be an advantage, since graduates of one-year programmes are of value to incremental innovation in manufacturing production and in the service sector.

1.2 Population with tertiary education (% of 25-64 years age classes)

Definition: The percentage of the total working age population (25-64 years age classes) with some form of post-secondary education (ISCED 5 and 6).

Interpretation: This is a general indicator of the supply of advanced skills. It is not limited to science and technical fields because the adoption of innovations in many areas, particularly in the service sectors, depends on a wide range of skills. Furthermore, it includes the entire working age population, because future economic growth could require drawing on the non-active fraction of the population. International comparisons of educational levels however are notoriously difficult due to large discrepancies in educational systems, access, and the level of attainment that is required to receive a tertiary degree. Therefore, differences among countries should be interpreted cautiously.

1.3 Participation in life-long learning (% of 25-64 years olds)

Definition: The reference population is all age classes between 25 and 64 years inclusive. A reference period of four weeks has been chosen in order to avoid distortion of information due to recall problems. The reference period is the last four weeks preceding the survey, except for France, the Netherlands (until 1999) and Portugal for which information is collected only if education or training is under way on the date of the survey. Education includes initial education, further education, continuing or further training, training within the company, apprenticeship, on-the-job training, seminars, distance learning, evening classes, self-learning, etc. as well as other courses followed for general interest: language, data-processing, management, art/culture, health/medicine courses. Before 1998, education was related only to education and vocational training which was relevant for the current or possible future job of the respondent. This indicator is identical to Structural indicator 1.7.

Interpretation: A central characteristic of a knowledge economy is continual technical development and innovation. Under these conditions, individuals need to continually learn new ideas and skills - or to participate in life-long learning. All types of learning are valuable, since it prepares people for "learning to learn". The ability to learn can then be applied to new tasks with social or economic benefits. The limitation of the indicator to a brief window of four weeks could reduce comparability between countries due to differences in adult education systems. Little is known at this time about such differences, but differences in the timing of national holidays, preferred times for adult education courses, the average length of adult courses, and other unknown factors could influence the results and reduce comparability. Technical Paper N° 5 of the 2002 EIS further elaborates on the issue of "Lifelong Learning for Innovation".

1.4 Employment in medium-high and high-tech manufacturing (% of total workforce)

Definition: The medium-high and high technology sectors include chemicals NACE (24), machinery (NACE 29) office equipment (NACE 30), electrical equipment (NACE 31), telecom equipment (NACE 32), precision instruments (NACE 33), automobiles (NACE 34), and aerospace and other transport (NACE 35). The total workforce includes all manufacturing and service sectors.

Interpretation: The percentage of employment in medium-high and high technology manufacturing sectors is an indicator of the share of the manufacturing economy that is based on continual innovation through creative, inventive activity. The use of total employment gives a better indicator than using the share of manufacturing employment alone, since the latter will be affected by the hollowing out of manufacturing in some countries.

1.5 Employment in high-tech services (% of total workforce)

Definition: This indicator focuses on three leading edge sectors that produce high technology services: post and telecommunications (NACE 64); information technology including software development (NACE 72); and R&D services (NACE 73). The total workforce includes all manufacturing and service sectors.

Interpretation: The high technology services both provide services directly to consumers, such as telecommunications, and provide inputs to the innovative activities of other firms in all sectors of the economy. The latter can increase productivity throughout the economy and support the diffusion of a range of innovations, particularly those based on ICT.

2.1 Public R&D expenditures (GERD - BERD) (% GDP)

Definition: The indicator is the percentage of GDP due to public R&D spending. The latter is defined as the difference between total R&D expenditures (GERD) and business enterprise expenditures (BERD). It thus includes higher education expenditure in R&D (HERD), government expenditure in R&D (GORD) and private non-profit expenditure in R&D (PNRD). Note that this definition has changed compared to the 2001 EIS as it now also includes private non-profit expenditure in R&D (PNRD). This indicator was identical to the initial Structural indicator 2.2: R&D expenditure. The definition of Structural indicator 2.2 was changed in October 2002: the R&D indicators are now disaggregated by source of finance rather than the sector carrying out the R&D expenditure. This change in definition could, due to time constraints, not be taken into account in the 2002 EIS.

Interpretation: In addition to the production of basic and applied knowledge in universities and higher-education institutions, publicly funded research offers several other outputs of direct importance to private innovation: trained research staff and new instrumentation and prototypes.

2.2 Business expenditure on R&D (BERD) (% GDP)

Definition: This indicator measures the R&D expenditure (from all sources of funding) of the business sector (manufacturing and services) as a percentage of GDP. This indicator was identical to the initial Structural indicator 2.2: R&D expenditure. The definition of Structural indicator 2.2 was changed in October 2002 : the R&D indicators are now disaggregated by source of finance rather than the sector carrying out the R&D expenditure. This change in definition could not, due to time constraints, be taken into account in the 2002 EIS.

Interpretation: The indicator captures the formal creation of new knowledge within firms. It is particularly important in the science-based sectors (pharmaceuticals, chemicals and some areas of electronics) where most new knowledge is created in or near R&D laboratories.

2.3.1 EPO high-tech patent applications (per million population)

Definition: The indicator is defined as the number of patent applications (reference year is year of filing) at the EPO in high-technology patent classes per million population. The national (and regional) distribution of the patent applications is assigned according to the address of the inventor. The high technology patent classes include pharmaceuticals, biotechnology, information technology, and aerospace. The following IPC subclasses are included:

- B41J: typewriters; selective printing mechanisms, i.e. mechanisms printing otherwise than from a form; correction of typographical errors
- G06C: digital computers in which all the computation is effected mechanically
- G06D: digital fluid-pressure computing devices
- G06E: optical computing devices
- G06F: electric digital data processing
- G06G: analogue computers
- G06J: hybrid computing arrangements
- G06K: recognition of data; presentation of data; record carriers; handling record carriers
- G06M: counting mechanisms; counting of objects not otherwise provided for
- G06N: computer systems based on specific computational models
- G06T: image data processing or generation, in general
- G11C: static stores
- B64B: lighter-than-air aircraft
- B64C: aeroplanes; helicopters
- B64D: equipment for fitting in or to aircraft; flying suits; parachutes; arrangements or mounting of power plants or propulsion transmissions
- B64F: ground or aircraft-carrier-deck installations
- B64G: cosmonautics; vehicles or equipment therefore
- C12M: apparatus for enzymology or microbiology
- C12N: micro-organisms or enzymes; compositions thereof; propagating, preserving, or maintaining micro-organisms; mutation or genetic engineering; culture media

- C12P: fermentation or enzyme-using processes to synthesize a desired chemical compound or composition or to separate optical isomers from a racemic mixture
- C12Q: measuring or testing processes involving enzymes or micro-organisms
- H01S: devices using stimulated emission
- H01L: semiconductor devices; electric solid state devices not otherwise provided for
- H04B: transmission
- H04H: broadcast communication
- H04J: multiplex communication
- H04K: secret communication; jamming of communication
- H04L: transmission of digital information, e.g. telegraphic communication
- H04M: telephonic communication
- H04N: pictorial communication, e.g. television
- H04Q: selecting
- H04R: loudspeakers, microphones, gramophone pick-ups or like acoustic electromechanical transducers; deaf-aid sets; public address systems
- H04S: stereophonic systems

Interpretation: This indicator complements indicator 2.2 on business R&D in that patenting captures new knowledge created anywhere within a firm and not just within a formal R&D laboratory. The indicator also measures specialisation of knowledge creation in fast-growing technologies.

2.3.1A EPO patent applications (per million population)

Definition: The indicator is defined as the number of all patent applications at the EPO per million population. The national (and regional) distribution of the patent applications is assigned according to the address of the inventor. This indicator is used for the Candidate countries as an alternative for indicator 2.3.1 as the numbers for high-technology EPO patent applications are too small.

Interpretation: This indicator complements indicator 2.2 on business R&D in that patenting captures new knowledge created anywhere within a firm and not just within a formal R&D laboratory.

2.3.2 USPTO high-tech patent applications per million population

Definition: The indicator is defined as the number of patent applications at the US Patent and Trade Mark Office (USPTO) in high-technology patent classes, per million population. The high technology patent classes are the same as those for indicator 2.3.1.

Interpretation: Indicator 2.3.1 on EPO patent applications favours European versus American and Japanese firms. The present indicator provides the equivalent for American firms and measures US patenting activity by European inventors.

3.1 SMEs innovating in-house (% of manufacturing SMEs)

Definition: Innovative manufacturing firms are defined as those who introduced new products or processes either:

2. In-house or
3. In combination with other firms

Note: This indicator does not include new products or processes developed by other firms (option 1 in the CIS questionnaires; compare question 2 in the CIS 2 questionnaire and question 2.1 in the CIS 3 questionnaire). Only SMEs with 20-249 employees are taken into account in CIS 2. Small and medium-sized enterprises (SMEs) are characterised as those enterprises with 20-249 employees.

Interpretation: The CIS defines innovative manufacturing firms quite broadly as those who introduced new products or processes developed by 1) other firms, 2) in house, or 3) in combination with other firms. The present indicator is more focused in two respects. It is limited to SMEs because almost all large firms innovate and because countries with an industrial structure weighted to larger firms would tend to do better. And it is limited to firms with in-house innovative activities that either develop product or process innovations themselves or in combination with other firms.

3.2 Manufacturing SMEs involved in innovation co-operation

Definition: The indicator is the percentage of all manufacturing SMEs (including non-innovators) with 20 or more employees that had any co-operation agreements on innovation activities with other enterprises or institutions in the three years before the survey (compare question 11 in the CIS 2 questionnaire and question 8.1 in the CIS 3 questionnaire).

Interpretation: Complex innovations, particularly in ICT, often depend on the ability to draw on diverse sources of information and knowledge, or to collaborate on the development of an innovation. This indicator measures the flow of knowledge between public research institutions and firms and between firms and other firms. The indicator is limited to SMEs because almost all large firms are involved in innovation co-operation. This indicator also captures technology-based small manufacturing firms, since most are involved in co-operative projects. However, the indicator will miss high-technology firms with no product sales, such as many biotechnology firms, because these firms are assigned to the service sector.

3.3 Innovation expenditures (% of all turnover in manufacturing)

Definition: This indicator includes all manufacturing firms with 20 or more employees. Innovation expenditures includes the full range of innovation activities: in-house R&D, extramural R&D, machinery and equipment linked to product and process innovation, spending to acquire patents and licenses, industrial design, training, and the marketing of innovations. Total innovation expenditure by all firms in each country is divided by total turnover. This includes firms that do not innovate, whose innovation expenditures are zero by definition (compare question 6 in the CIS 2 questionnaire and question 4.1 in the CIS 3 questionnaire).

Interpretation: Several of the components of innovation expenditure, such as investment in equipment and machinery and the acquisition of patents and licenses, measure the diffusion of new production technology and ideas. Overall, the indicator measures total expenditures on many different activities of relevance to innovation. The indicator partly overlaps with indicator 2.2 on R&D expenditures. A better version would exclude R&D, but concerns over data reliability have prevented this option.

4.1 High-tech venture capital investment (‰ of GDP)

Definition: The percentage of GDP due to venture capital in high technology firms active in the following sectors: computer related fields, electronics, biotechnology, medical/health, industrial automation, financial services. Venture capital is the sum of early stage capital (seed and start-up) plus expansion capital.

The data for this indicator were taken from EVCA's "Mid-Year Survey of Pan-European Private Equity & Venture Activity". More recent data for high-tech venture investments including replacement and buyout capital are available in EVCA's "Yearbook: Annual Survey of Pan-European Private Equity & Venture Capital Activity". The Yearbook however does not provide disaggregated data to calculate high-tech venture capital investments according to the EIS definition and these data have thus not been used.

Interpretation: One of the main barriers to innovation is the ability of new technology-based firms to raise adequate funding. This indicator measures the supply of private venture capital to these firms. The total supply of capital will be higher because of bank and private-placement financing. The main disadvantage is that there are many alternative methods of financing new technology-based start-up firms that are not covered by this indicator. Firms can also go abroad to raise venture capital. An additional concern is the lack of information on the accuracy of the venture capital data.

4.2 New capital raised on stock markets (% of GDP)

Definition: This indicator is the amount of new capital raised by domestic firms on domestic stock markets as a percentage of GDP. It excludes investment funds and unit trusts. And, in order to focus the indicator on new innovative firms, the indicator excludes capital raised by existing firms on the main stock exchanges. Three types of new capital are included:

- capital raised by newly admitted firms to the main stock exchanges
- capital raised on parallel markets by already listed firms
- capital raised on parallel markets by newly admitted firms.

The focus on new capital that is probably raised by innovative firms in high technology sectors differentiates this indicator from the Structural indicator "Capital raised on stock markets", which includes all capital raised on stock markets, including capital raised on the main markets. Parallel stock exchanges focus on high technology sectors.

Interpretation: New capital is a major source of investment for many firms, but particularly for fast growing firms in high technology sectors. The indicator is strongly influenced by volatility in capital markets: it includes stocks that have little to do with technology. Firms raising capital in foreign markets will distort the results.

4.3 'New to market' products (% of sales by manufacturing firms)

Definition: The amount of product sales (or total turnover), by manufacturing firms with more than 20 employees, from innovations that are new to the firm's market. These are limited to products that are both new to the firm itself and new to the firm's market. (compare question 5 in the CIS 2 questionnaire and question 1.4 in the CIS 3 questionnaire).

Interpretation: This is a direct output measure of innovation that is not distorted by market speculation (as would the market value of a firm). The product must be new to the firm, which in many cases will also include innovations that are world-firsts. The main disadvantage is that there is some ambiguity in what constitutes a 'new to market' innovation. Smaller firms or firms from less developed countries could be more likely to include innovations that have already been introduced onto the market elsewhere.

4.4 Home internet access (% of all households)

Definition: Percentage of households who have internet access at home. All forms of use are included. Population considered is equal to or over 15 years old. This indicator is identical to Structural indicator 2.3: Level of internet access.

Interpretation: Internet use by the domestic population is a measure of the ability to access an enormous wealth of data on-line, including business-to-consumer e-commerce and government-to-citizen online services. In the future, much more sophisticated measures of internet use will be needed. Better data is needed on what the internet is used for and if the population is aware of several efficiency enhancing uses.

4.4A Internet access (% of population)

Definition: Percentage of population with any form of internet access. All forms of use are included. Population considered is equal to or over 15 years old. This indicator is used for the Candidate countries as an alternative for indicator 4.4 due to better data availability.

Interpretation: Internet use by the domestic population is a measure of the ability to access an enormous wealth of data on-line, including business-to-consumer e-commerce and government-to-citizen online services. In the future, much more sophisticated measures of internet use will be needed. Better data is needed on what the internet is used for and if the population is aware of several efficiency enhancing uses.

4.5 ICT expenditures (% of GDP)

Definition: This indicator measures total expenditures on Information and Communication Technology (ICT) as a percentage of GDP. ICT includes office machines, data processing equipment, data communication equipment, and telecommunications equipment, plus related software and telecom services. This indicator is identical to Structural indicator 2.7.

Interpretation: ICT is a fundamental feature of knowledge based economies and the driver of current and future productivity improvements. An indicator for ICT investment is crucial for capturing innovation in knowledge-based economies, particularly due to the diffusion of new IT equipment, services, and software. One disadvantage of this indicator is that it is ultimately obtained from private sources (IDC), with a lack of good information on the reliability of the data. Another disadvantage is that some expenditures are for final consumption and may have few productivity or innovation benefits. It would be preferable to have data on ICT investment rather than ICT expenditure, but reliable investment data are not yet available.

4.6 Percent of manufacturing value-added from high technology

Definition: The percentage of total value added in manufacturing in four high technology industries: pharmaceuticals (NACE 24.4), office equipment (NACE 30), telecommunications and related equipment (NACE 32), and aerospace (NACE 35.3).

Interpretation: Value-added is the best measure of manufacturing output, whereas other indicators such as total production can be biased by 'screwdriver' plants with little value-added. The requirement for good data on value added creates a lag of two or more years longer than for GDP and other economic data. The main disadvantage of the main indicator is that a hollowing-out of manufacturing, as in the UK, can lead to relatively good results, if low and medium technology industries no longer survive.

4.6A Stock of inward FDI (% of GDP)

Definition: The indicator is defined as the stock in inward Foreign Direct Investment (FDI) as a percentage of GDP. UNCTAD defines FDI "as an investment involving a long-term relationship and reflecting a lasting interest and control by a resident entity in one economy (foreign direct investor or parent enterprise) in an enterprise resident in an economy other than that of the foreign direct investor (FDI enterprise or affiliate enterprise or foreign affiliate). FDI implies that the investor exerts a significant degree of influence on the management of the enterprise resident in the other economy. Such investment involves both the initial transaction between the two entities and all subsequent transactions between them and among foreign affiliates, both incorporated and unincorporated." This indicator is used for the Candidate countries as an alternative for indicator 4.6.

Interpretation: The inflow of FDI steers production towards higher value-added goods, or increases production efficiency. Both can depend on the transfer of foreign technology and provide a potential for conducting industrial research in the host country. Stock data are a better proxy for the rate of penetration of FDI and also neutralize large variations in annual inflows.

Appendix A. Correlation matrix between the EIS indicators for the EU Member States

	1.1	1.2	1.3	1.4	1.5	2.1	2.2	2.3a	2.3b	3.1	3.2	3.3	4.1	4.2	4.3	4.4	4.5	4.6
1.1	**1**																	
1.2	.332	**1**																
1.3	.069	.704**	**1**															
1.4	.279	.410	.302	**1**														
1.5	.397	.742**	.746**	.417	**1**													
2.1	.016	.597*	.631*	.406	.636*	**1**												
2.2	.222	.773**	.662**	.666**	.809**	.767**	**1**											
2.3a	.101	.703**	.586*	.360	.562*	.780**	.668**	**1**										
2.3b	.071	.804**	.795**	.478	.725**	.884**	.892**	.873**	**1**									
3.1	-.017	.102	.262	.579*	.424	.264	.291	.111	.191	**1**								
3.2	.123	.611*	.722**	.368	.777**	.462	.633*	.408	.594*	.586*	**1**							
3.3	.139	.585*	.705**	.524	.799**	.762**	.880*	.477	.769**	.494	.780**	**1**						
4.1	.344	.759**	.731**	.372	.698**	.473	.652*	.459	.675**	.016	.328	.464	**1**					
4.2	-.355	.153	.202	-.308	-.056	.049	-.278	-.033	-.019	.075	.200	-.027	-.059	**1**				
4.3	.088	-.475	-.299	.020	-.245	-.232	-.295	-.204	-.305	-.060	-.339	-.141	-.338	-.085	**1**			
4.4	-.055	.585*	.856**	.218	.796**	.646*	.652*	.528*	.690**	.523*	.746**	.752**	.617*	.234	-.367	**1**		
4.5	-.027	.293	.503	-.204	.135	.439	.331	.097	.402	-.307	.150	.435	.420	.290	-.225	.317	**1**	
4.6	.517	.413	.290	.122	.696*	-.017	.542	.135	.295	.209	.494	.498	.405	-.410	-.251	.411	.044	**1**

** Correlation is significant at the 0.01 level (2-tailed).
* Correlation is significant at the 0.05 level (2-tailed).