Composite indicators. Methodology and Applications to R&D indicators

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Workshop on Entrepreneurship Indicators:
R&D and Technology
Copenhagen, 30 and 31 October 2008
Whereabouts
Methodology from: Joint OECD-JRC handbook.

- 5 years of preparation,
- 2 rounds of consultation with OECD high level statistical committee,
- finally endorsed March 2008 with one abstention
• Composite indicators’ fortune
How many of them are around?
Searching “composite indicators”

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<tr>
<th></th>
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Use: an example, from the Economist web edition, October 15

**Business travel ranking**
(The most and least attractive destinations for business travellers)

**Distance-learning MBAs**
(A ranking of the top distance-learning MBA programmes)

**Democracy index**
(The world's most and least democratic countries)

**Operational risk ratings**
(Rating the risk of doing business in 150 markets)

**E-readiness**
(The best countries for conducting electronic business)

**Global house-price indices**
(Tracking house-price inflation around the world)

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### The Economist's house-price indicators

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<tr>
<th>Country</th>
<th>Latest 2007</th>
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<th>1997-2006 or latest</th>
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<td>France</td>
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<td>Spain</td>
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<tr>
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<td>-0.8</td>
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<tr>
<td>New Zealand</td>
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<tr>
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<tr>
<td>Britain</td>
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<td>10.5</td>
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<td>United States (S&amp;P Case-Shiller national index)</td>
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<td>-3.4</td>
<td>86</td>
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<tr>
<td>United States (S&amp;P Case-Shiller ten-city index)</td>
<td>-17.0</td>
<td>-3.3</td>
<td>125</td>
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</tbody>
</table>

Sources: ABBA; ESRI; Hypoport; Japan Real Estate Institute; Nationwide; Nefissa; NVM; OFHEO; Quotable Value; StatCan; Swiss National Bank; Standard & Poor's; government offices.
Another example, about Mauritius, Economist October 16

Economist.com

THE 1.3m people of Mauritius love to prove famous people wrong. On independence from Britain in 1968, pundits such as a Nobel prize-winning economist, James Meade, and a novelist, V.S. Naipaul, did not give much of a chance to this tiny, isolated Indian Ocean island 1,800km (1,100 miles) off the coast of east Africa. Its people depended on a sugar economy and enjoyed a GDP per person of only $200. Yet the island now boasts a GDP per person of $7,000, and very few of its people live in absolute poverty. It once again ranks first in the latest annual Mo Ibrahim index, which measures governance in Africa. And it bagged 24th spot in the World Bank’s global ranking for ease of doing business—the only African country in the top 30, ahead of countries such as Germany and France. How does it pull it off?
Ideally, a composite indicator should be based on:

- Solid theoretical framework,
- Underlying data of good quality,
- Tested methodology.

When these conditions are met, it can be used for advocacy and analysis.

• The steps to build CIs
A good technical preparation for a CI can make it more robust (to uncertainties in data, weights,…) more resilient (remain relevant over time), more defensible (in dialogue with stakeholders…)
Step 1. Developing a solid theoretical framework

What is badly defined is likely to be badly measured …

The challenges are:

• To integrate a broad set of (probably conflicting) points of view while keeping within a manageable construct. A model.

⇒ a storyteller

⇒ a representation/narrative meaningful to a community of peers

Examples …
E-business readiness (EC)

Definition: Capability of a company to engage in electronic transactions with the objective of increasing business competitiveness.

Aim: evaluation of a composite indicator to monitor country progress in the implementation of the i2010 initiative...
Summary innovation Index

A theoretical framework consisting of 5 groups was discussed and agreed.

**Innovation drivers**, to measure the structural conditions required for innovation potential

**Knowledge creation**, to measure the investments on human factors and on R&D activities, considered as the key elements for a successful knowledge-based economy

**Innovation & entrepreneurship**, to measure the efforts towards innovation at the microeconomic level

33 countries: EU-27, US, JP, CH, IS, NO, TR
Summary innovation Index

**Application**, to measure the performance, expressed in terms of labour and business activities, and their value added in innovative sectors

**Intellectual property**, to measure the achieved results in terms of successful know how, especially referred to high-tech sectors

33 countries: EU-27, US, JP, CH, IS, NO, TR
Step 1. Developing a solid theoretical framework

After Step 1. the developer should have...

• A clear understanding and definition of the multidimensional phenomenon to be measured.
• A nested structure of the various domains.
• A list of selection criteria for the underlying indicators, e.g., input, process, output.
Step 2. Selecting indicators

*A composite indicator is above all the sum of its parts…*

Excerpt: The strength of a composite indicator can largely depend on the quality of the underlying data. [...] The theoretical framework should guide the choice of the underlying indicators. The selection process can be quite subjective and therefore should involve stakeholders.
Enterprise survey 2007 (Eurostat), yearly since 2003, Adoption and Use composite indicators

E-business readiness composite indicator

Adoption of ICT

- a1 - % of firms that use Internet
- a2 - % of firms that have web/home page
- a3 - % of firms using ≥ 2 security facilities
- a4 - % of employees using computer
- a5 - % of firms with broadband connection
- a6 - % of firms with LAN

Use of ICT

- b1 - % of firms purchasing products/serv. via Internet
- b2 - % of firms receiving orders via Internet
- b3 - % of firms with IT linked with other internal IT
- b4 - % of firms with IT linked with external IT
- b5 - % of firms using Internet for banking
- b6 - % of firms selling products via Internet
<table>
<thead>
<tr>
<th>Code</th>
<th>Description</th>
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</thead>
<tbody>
<tr>
<td>a1</td>
<td>% of firms that use Internet</td>
</tr>
<tr>
<td>a2</td>
<td>% of firms that have web/home page</td>
</tr>
<tr>
<td>a3</td>
<td>% of firms using $\geq 2$ security facilities</td>
</tr>
<tr>
<td>a4</td>
<td>% of employees using computer</td>
</tr>
<tr>
<td>a5</td>
<td>% of firms with broadband connection</td>
</tr>
<tr>
<td>a6</td>
<td>% of firms with LAN</td>
</tr>
</tbody>
</table>

Adoption of ICT
b1 - % of firms purchasing products/serv. via Internet
b2 - % of firms receiving orders via Internet
b3 - % of firms with IT linked with other internal IT
b4 - % of firms with IT linked with external IT
b5 - % of firms using Internet for banking
b6 - % of firms selling products via Internet

Use of ICT
Summary Innovation Index

- Data from Eurostat Science and Technology Indicators and Community Innovation Survey (CIS).

- A set of 53 indicators analyzed (FA)
- A reduced list of 26 indicators was discussed by developers and members of GSO (an expert group) with DG ENTR.
Step 2. Selecting indicators

After Step 2. the developer should have...

- Checked the **quality** of the available data.
- Discussed the strengths and weaknesses of each selected indicator.
- Metadata
Step 3. Multivariate analysis

Analysing the underlying structure of the data is an art ...

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<th>Cumulative %</th>
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Step 4. Imputation of missing data.

The idea of imputation could be both seductive and dangerous …

Almost all datasets contain missing data.

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<tr>
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<th>a3</th>
<th>a4</th>
<th>a5</th>
<th>a6</th>
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<td>0.52</td>
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<td>0.43</td>
<td>0.11</td>
<td>0.76</td>
<td>0.02</td>
</tr>
</tbody>
</table>
Three common approaches to deal with missing data:

- **case deletion** (removes either country or indicator from the analysis)

- **single imputation** (e.g. Mean/Median substitution, Regression, etc.)

- **multiple imputation** (e.g. Markov Chain Monte Carlo algorithms).
Step 5. Normalisation of data

*Avoid adding up apples and oranges …*

- Ranking
- Standardization
- Re-scaling
- Distance to reference country
- Categorical scales
- ...
Step 6. Weighting and aggregation

The relative importance of the indicators can become the substance of a negotiation …

Weights based on statistical models

- Principal component/Factor analysis
- Data envelopment analysis
- Regression approach
- Unobserved components models
Step 6. Weighting and aggregation

Weights based on opinions: participatory methods

- Budget allocation
- Public opinion
- Analytic hierarchy process
- Conjoint analysis
Step 6. Weighting and aggregation

Weights based on Multi Criteria Analysis

To know more buy:
Step 7. Robustness and sensitivity

*Uncertainty analysis can be used to assess the robustness of composite indicators …*

Space of alternatives

- Weights
- Imputation
- Aggregation
- Including/excluding variables
- Normalisation

Performance index

Spain | Italy | Greece
Monitoring e-Business Readiness of European enterprises

Sensitivity analysis of countries position
To know more buy:

Or read:

Step 8. Links to other variables

*Composite indicators can be linked to other variables and measures*

Comparing effectively complex dimensions: Canadian welfare and Canadian Composite Learning Index
From Ludger Wößmann, Contribution of Education and Training to Innovation and Growth, see: www.education-economics.org
Step 9. Back to the details

**De-constructing composite indicators can help extend the analysis …**

All countries by sector

- **Manufacturing** (sec D)
  - All sectors
    - **Transport, storage and communication** (sec I)
    - Real estate, Renting and Business activities (sec K)
- **Provision of short-stay accommodation** (sec H)
- **Wholesale and retail trade** (sec G)
- **Construction** (sec F)
- Motion picture, video, radio and television activities (sec O)
Monitoring e-Business Readiness of European enterprises

Enterprise survey 2007 (Eurostat), yearly since 2003, Adoption and Use composite indicators
THE 2007 SUMMARY INNOVATION INDEX (SII)

Dotted lines show EU performance.
Step 10. Presentation and dissemination
COMPARATIVE ANALYSIS OF INNOVATION PERFORMANCE of THE EUROPEAN COUNTRIES

THE 2007 SUMMARY INNOVATION INDEX (SII)
Why the ten steps?

To combat lack of transparency, which makes them and the associated the policy inference, arbitrary and objectionable.

The three pillars of a well-designed CI are:
- Solid theoretical framework,
- Underlying data of good quality,
- Tested methodology.

Methodology should include assessment of the CI robustness.

CI can be refuted by practitioners (examples of WEF GCI and Ecological Footprint)
• No more methodology. The KEI study
Knowledge Economy: measures and drivers

Giuseppe Munda and Michaela Saisana
Main research questions:

- Is it possible to measure the knowledge economy?
- What are the drivers of the knowledge economy?
- How does knowledge economy relate to other complex dimensions?
- Is it possible to reduce the total number of individual indicators of KEI conceptual framework without loosing any relevant information?
- Are rankings useful at all for deriving policy suggestions?
Figure 1. KEI Conceptual framework of a Knowledge-based Economy

Knowledge-based Economy Index

A1. Production and diffusion of information and communication technology (ICT)
- Economic impact of ICT (A1a)
- Internet use by firms (A1b)
- Internet use by individuals (A1c)
- Government ICT (A1d)

A2. Human resources, skills and creativity
- General education (A2a)
- Human resource in S&T education (A2b)
- Skills (A2c)
- Creativity (A2d)
- Mobility (A2e)

A3. Knowledge production and diffusion
- Research and experimental development (A3a)
- Patents (A3b)
- Bibliometrics (A3c)
- Knowledge flows (A3d)
- Total investment in intangibles (A3e)

A4. Innovation, entrepreneurship and creative destruction
- Entrepreneurship (A4a)
- Demand for innovative products (A4b)
- Financing of innovation (A4c)
- Market innovation outputs (A4d)
- Organisational indicators (A4e)

B1. Economic Outputs
- Income (B1a)
- Productivity (B1b)
- Employment (B1c)

B2. Social performance
- Environment (B2a)
- Employment and economic welfare (B2b)
- Quality of life indicators (B2c)

C1. Internationalization
- Trade (C1a)
- Knowledge production and diffusion (C1b)
- Economic structure (C1c)
- Human resources (C1d)
1. Production and diffusion of ICT
2. Human resources, skills and creativity
3. Knowledge production and diffusion
4. Innovation, entrepreneurship and creative destruction
5. Economic outputs
6. Social performance
7. Internationalisation
We do not trust one model to build the Knowledge Economy Index, thus we opt for a “multi-modelling principle”
Methodological scenarios for the development of the KEI composite

<table>
<thead>
<tr>
<th></th>
<th>Sub-dimensions included</th>
<th>Dimensions included</th>
<th>Pillar Structure</th>
<th>Normalisation</th>
<th>Weighting</th>
<th>Aggregation function</th>
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</thead>
<tbody>
<tr>
<td></td>
<td>All (total 29)</td>
<td>All (total 7)</td>
<td>Preserved</td>
<td>z-scores</td>
<td>Factor analysis</td>
<td>Additive (linear)</td>
</tr>
<tr>
<td></td>
<td>One-at-a-time excluded</td>
<td>One-at-a-time excluded</td>
<td>Not preserved</td>
<td>Min-max</td>
<td>Equal weighting</td>
<td>Multiplicative</td>
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<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Raw data</td>
<td>Data envelopment analysis</td>
<td>Non-compensatory multi-criteria analysis</td>
</tr>
</tbody>
</table>

The *frequency matrix* of a country’s rank in each of the seven dimensions and the overall KEI was calculated across the ~2,000 scenarios.
| Rank 1 | Rank 2 | Rank 3 | Rank 4 | Rank 5 | Rank 6 | Rank 7 | Rank 8 | Rank 9 | Rank 10 | Rank 11 | Rank 12 | Rank 13 | Rank 14 | Rank 15 | Rank 16 | Rank 17 | Rank 18 | Rank 19 | Rank 20 | Rank 21 | Rank 22 | Rank 23 | Rank 24 | Rank 25 | Rank 26 | Rank 27 | Rank 28 | Rank 29 |
|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|
| Sweden | 54     | 46     |        |        |        |        |        |        |        |        |        |        |        |        |        |        |        |        |        |        |        |        |        |        |        |        |        |        |        |
| Denmark| 55     | 30     | 14     |        |        |        |        |        |        |        |        |        |        |        |        |        |        |        |        |        |        |        |        |        |        |        |        |        |        |
| Luxembour | 36     | 4      | 14     | 25     | 4      | 7      | 7      | 4      |        |        |        |        |        |        |        |        |        |        |        |        |        |        |        |        |        |        |        |        |        |
| Finland | 18     | 23     | 29     | 9      | 11     | 11     |        |        |        |        |        |        |        |        |        |        |        |        |        |        |        |        |        |        |        |        |        |        |        |
| USA     | 11     | 32     | 2      | 4      | 39     | 9      | 4      |        |        |        |        |        |        |        |        |        |        |        |        |        |        |        |        |        |        |        |        |        |        |
| Japan   | 4      | 7      | 18     | 32     | 36     | 4      |        |        |        |        |        |        |        |        |        |        |        |        |        |        |        |        |        |        |        |        |        |        |        |
| UK      | 2      | 5      | 16     | 38     | 39     |        |        |        |        |        |        |        |        |        |        |        |        |        |        |        |        |        |        |        |        |        |        |        |        |        |
| Netherlands | 86     | 4      | 4      | 14     | 7      |        |        |        |        |        |        |        |        |        |        |        |        |        |        |        |        |        |        |        |        |        |        |        |        |        |
| Ireland | 4      | 61     | 14     | 4      | 9      | 9      |        |        |        |        |        |        |        |        |        |        |        |        |        |        |        |        |        |        |        |        |        |        |        |
| Austria | 18     | 50     | 18     | 7      | 7      |        |        |        |        |        |        |        |        |        |        |        |        |        |        |        |        |        |        |        |        |        |        |        |        |        |
| Belgium | 11     | 4      | 11     | 57     | 16     | 2      |        |        |        |        |        |        |        |        |        |        |        |        |        |        |        |        |        |        |        |        |        |        |        |
| France  | 4      | 14     | 18     | 11     | 54     |        |        |        |        |        |        |        |        |        |        |        |        |        |        |        |        |        |        |        |        |        |        |        |        |        |
| EU15    | 4      | 57     | 39     |        |        |        |        |        |        |        |        |        |        |        |        |        |        |        |        |        |        |        |        |        |        |        |        |        |        |        |
| EU25    | 4      | 4      | 14     | 32     | 39     | 7      |        |        |        |        |        |        |        |        |        |        |        |        |        |        |        |        |        |        |        |        |        |        |        |
| Germany | 7      | 79     | 4      | 7      | 4      |        |        |        |        |        |        |        |        |        |        |        |        |        |        |        |        |        |        |        |        |        |        |        |        |        |
| Slovenia | 7      | 41     | 38     | 14     |        |        |        |        |        |        |        |        |        |        |        |        |        |        |        |        |        |        |        |        |        |        |        |        |        |        |        |
| Estonia | 4      | 36     | 25     | 21     | 11     | 4      |        |        |        |        |        |        |        |        |        |        |        |        |        |        |        |        |        |        |        |        |        |        |        |
| Malta   | 7      | 13     | 9      | 21     | 23     | 27     |        |        |        |        |        |        |        |        |        |        |        |        |        |        |        |        |        |        |        |        |        |        |        |
| Cyprus  | 36     | 7      | 4      | 23     | 23     | 7      |        |        |        |        |        |        |        |        |        |        |        |        |        |        |        |        |        |        |        |        |        |        |        |
| Spain   | 4      | 4      | 32     | 25     | 29     | 7      |        |        |        |        |        |        |        |        |        |        |        |        |        |        |        |        |        |        |        |        |        |        |        |
| Czech. Rep. | 4      | 7      | 30     | 39     | 5      | 7      | 7      |        |        |        |        |        |        |        |        |        |        |        |        |        |        |        |        |        |        |        |        |        |        |
| Latvia  | 20     | 36     | 11     | 21     | 7      | 5      |        |        |        |        |        |        |        |        |        |        |        |        |        |        |        |        |        |        |        |        |        |        |        |
| Italy   | 29     | 18     | 9      | 29     | 9      | 7      |        |        |        |        |        |        |        |        |        |        |        |        |        |        |        |        |        |        |        |        |        |        |        |
| Greece  | 4      | 4      | 29     | 18     | 21     | 7      | 14     |        |        |        |        |        |        |        |        |        |        |        |        |        |        |        |        |        |        |        |        |        |
| Lithuania | 44     | 13     | 32     | 11     |        |        |        |        |        |        |        |        |        |        |        |        |        |        |        |        |        |        |        |        |        |        |        |        |        |        |        |
| Hungary | 2      | 13     | 13     | 57     | 2      | 14     |        |        |        |        |        |        |        |        |        |        |        |        |        |        |        |        |        |        |        |        |        |        |        |
| Portugal| 4      | 4      | 7      | 11     | 61     | 14     |        |        |        |        |        |        |        |        |        |        |        |        |        |        |        |        |        |        |        |        |        |        |        |
| Slovakia| 4      | 7      | 18     | 71     |        |        |        |        |        |        |        |        |        |        |        |        |        |        |        |        |        |        |        |        |        |        |        |        |        |        |        |

**Legend:**
- Frequency lower 15%
- Frequency between 15 and 30%
- Frequency between 30 and 50%
- Frequency greater than 50%
Median and associated 5th and 95th percentiles for the rank distribution

Same results as before, different way of presenting them
Spearman rank correlation coefficients between KEI and its seven dimensions (median ranks across ~2,000 simulations)

<table>
<thead>
<tr>
<th>KEI</th>
<th>Production and diffusion of ICT</th>
<th>Human resources, skills and creativity</th>
<th>Knowledge production and diffusion</th>
<th>Innovation, entrepreneurship and creative destruction</th>
<th>Economic outputs</th>
<th>Social performance</th>
<th>Internationalisation</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.90</td>
<td>0.95</td>
<td>0.91</td>
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<td>0.68</td>
<td>0.78</td>
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<tr>
<td>Knowledge production and diffusion</td>
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<td>0.42</td>
<td>0.69</td>
<td>0.55</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Innovation, entrepreneurship and creative destruction</td>
<td>0.17</td>
<td>0.06</td>
<td>0.04</td>
<td>0.40</td>
<td>0.59</td>
<td>0.48</td>
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<tr>
<td>Economic outputs</td>
<td>0.59</td>
<td>0.48</td>
<td></td>
<td>0.61</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>Social performance</td>
<td>0.61</td>
<td>0.48</td>
<td></td>
<td></td>
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<tr>
<td>Internationalisation</td>
<td>1.00</td>
<td>1.00</td>
<td></td>
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<td></td>
</tr>
</tbody>
</table>

All dimensions play a role but surely the less influential seems to be the ‘innovation, entrepreneurship and creative destruction dimension’.

All coefficients are significant (\( p < 0.05, n = 29 \)).
Is KE relevant at all for a good overall economic performance?

The answer seems to be “YES”. Except Germany, Italy and Spain which have a high level of GDP per capita without any particular good performance on a KE. All the other high level GDP countries seem to perform well in the KEI composite (Luxembourg probably an outlier)
While the number of Ph.Ds seems to play a role in explaining the success of a KE (all countries with an high number of Ph.Ds, except Portugal, are top countries in the KEI median ranking), the same result does not apply to percentage of working population with a tertiary education (very clear the case of Italy where the number of working population with a tertiary education is extremely high, but the number of Ph.Ds is small). Participation to life long learning seems also to be a success factor, although not for all top countries.

In sum, the human capital theory seems to be corroborated by the KEI results roughly.
Checking the **Schumpeterian theory:**

‘Gross domestic expenditure on research and experimental development’ relates with KEI median.

**Countries which invest in research are top countries in a KBE.** Research is a key driver for a KBE surely, thus the *endogenous growth idea* (the Schumpeterian theory) seems also corroborated.
Is a KE an **eco-efficient** one?
The *Jevons’ paradox* teaches us that an ▲ in efficiency in using a resource leads, in the medium to long term, to an ▲ in consumption of that resource (rather than a ▼). No Kuznets curve …

These arguments seem corroborated by the KEI measure. In fact, as one can see, no clear relationship between environmental performance and a KBE exists.
Does a KE influence unemployment?

In the short term technological progress and job creation are conflicting objectives (Kok report on Europe) but they might be compatible in the long period if a right balance (i.e. compromise) between flexibility and employment security is found.

Compatibility between technological progress and job creation. All top countries in the KEI measure are presenting an extremely low long term unemployment rate.
External benchmark:
Human Development Index.

The relationship found seems again a corroboration of the human capital theories, in fact the correlation between KEI and the HDI is extremely high (though possibly spurious!).
• JRC-IPTS (Seville) work on companies R&D expenditures scoreboard.
Mixed scores for European research

A survey shows positive trends for private-sector research and development in the European Union. But as Andrea Chipman reports, there’s more to the data than meets the eye.
Industrial Research and Innovation at JRC - Seville

http://iri.jrc.ec.europa.eu/

- The EU Industrial R&D Investment Scoreboard: analysis of 1000 EU and 1000 non-EU top investing companies in R&D
- The EU Survey of Business R&D
- Economic and policy analysis of corporate R&D.
EU's R&D intensity deficit is largely explained by the different industrial structure (sectoral composition effect).

**Breakdown of EU-US gap in R&D intensity into sectoral composition and underinvestment effects.**

- **Sectoral composition effect:** 88%
- **Underinvestment effect:** 12%

**Total:** -1.8%

Note: In this figure, only companies of similar R&D size are considered, i.e. the top EU (391) and the US (563) with R&D investment above a common threshold (€23 million in the latest year).

Some Results (2): Econometrics of R&D & firm productivity

- R&D rises productivity much more in high-tech sectors than in low-tech ones

Graphs by R&D Intensity sector groups

Industrial Research and Innovation

http://iri.jrc.ec.europa.eu/

More info on the R&D investment scoreboard from

Pietro.MONCADA-PATERNO-CASTELLO@ec.europa.eu
More reading at (just google composite indicators):

http://composite-indicators.jrc.ec.europa.eu