Innovation Indicator

Methodology Report
October 2011

innovations
indikator

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Deutsche Telekom Stiftung

BDI
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Content

1 Introduction

The Innovation Indicator is a reporting system initiated by the Deutsche Telekom Foundation in collaboration with the Association of German Industry (BDI) and conducted by a consortium consisting of Fraunhofer Institute for Systems and Innovation Research ISI, Center for European Economic Research (ZEW) and Maastricht Economic and Social Research Institute on Innovation and Technology (MERIT).

The Innovation Indicator uses a composite of a selected set of indicators to describe and analyze the performance of national economies in terms of innovation activities. As in many indicator-based reports, the methodology, the data and the modeling have a crucial impact on the results and the discussion of the results. This present report is aiming at presenting and documenting our approach to select, to extract, to normalize, to aggregate and to finally calculate the Innovation Indicator composite. The Innovation Indicator reporting system is first of all designed to provide information and interpretation to decision makers in economy and politics. Therefore, the methodology and data is important as an instrument or a vehicle towards this goal. As the discussions and the interpretation are in the core of the reporting system, we decided to separate this methodology report from the ultimate report. This methodology report targets the scientific community as well as interested and curious readers of the Innovation Indicator reports.

Our broad and principle approach uses the innovation systems heuristic as a starting point to identify relevant sub-systems, most relevant actors and the underlying factors and effects that should effectively be taken into account. The next chapter of this report describes the Innovation Systems perspective and justifies the selection of the sub-systems. Based on this heuristic we have selected a set of variables and indicators that operationalize these actors, factors and effects. To realize a thrifty and effective modeling, we have tested many variables and indicators in an econometric model that follows an economic modeling approach. Chapter 3 describes the model, the underlying theoretical concepts and the implementation of the model to select the final set of indicators. In the consecutive chapter 4 the set of indicators are documented and their sources, meaning and interpretation are presented. It also includes the distribution of countries for each of the individual indicators, which will help the interested reader to see the spread of countries on the indicator scale. Are there many top-performer and only a few medium and poor performers or are all countries clustering in the middle of the distribution with only one top and one poor performer? Finally, chapter 5 presents a discussion of the construction of composite indicators in general as well as a detailed description of the working steps and methods that we applied to calculate the Innovation Indicator and its sub-system results.

2 National Innovation Systems as a Framework

The heuristic of National Innovation Systems (Edquist 1997; Hekkert et al. 2006; Kuhlmann, Arnold 2001; Lundvall 1992; Nelson 1993; Patel, Pavitt 1994) is used as a framework for our approach for two reasons. On the one hand, it names a set of multiple actors and institutions that have a direct or indirect impact on the innovative outcome and performance of national economies. These will be the level of our analyses below the national level, so the Innovation Systems approach allows demarcating the subsystems. On the other hand, it also states that there is, first, a set of influencing factors and not only a single factor – namely systems. So the systems aspect is of crucial importance to our theoretical and empirical approach. Secondly, it also states that these systems are different in their layout, but might aim at similar goals. To put it in other words, the idiosyncrasies of the countries – we are analyzing countries, but the same statement would be correct for regions or sectors – need to be taken into account when innovation systems are compared. There is no single and perfect way to reach the goal of innovation leadership. However, there are some factors that need to be present and that seem to be more supportive while their absence might be hampering innovation. But there is neither such a single and sufficient factor that automatically leads to a good performance – like R&D was supposed to be for a very long time.

For example, you can hardly spend a lot on R&D, if you do not have sufficient necessary human capital. Furthermore, application oriented research needs a link to certain basic research activities, which need to be conducted beyond pure economic interest since they can be seen as a public good.

When we try to compare different countries and innovation systems, we need to accept that these systems are different and that nations may follow a different path towards a similar goal.

Economic theory has long seen innovation – or to be more precise: technological change – as an exogenous factor for the economic development (Abernathy, Clark 1985; Graff 1995; Parayil 2002). The residual factor of growth which could not be attributed to the traditional factors labor and capital has been attributed to the exogenous technical progress. The New Growth Theory and related approaches have endogenized innovation and technical progress and have included them as explanatory variables in the models (Lucas 1988; Romer 1986; 1990). Other approaches like institutional economics have modeled the roles of organizations, norms and other institutions in the development of the economic performance and technological change (Held, Nutzinger 1999; Johnson 1995; Magnusson, Marklund 2005; Nelson 1988; 2001; North 1990; 1992; Pelikan 2004; Werle 2005). Evolutionary economics theorists have made use of this latter discussion and have added the inclusion of boundaries in the development by modeling economic and technological progress as path dependent selection processes (Andersen 1994; 1997; Devezas 2005; Dosi, Orsenigo 1988; Foster 1991; Foster, Metcalfe 2001b; Magnusson 2005; Nelson 1995; Nelson, Winter 1974; Nelson, Winter 1982; Ruttan 2001).

Furthermore, in the early years of innovation research the models to describe and explain innovation processes were rather simple and were assuming a linear innovation process: research expenditure leads to research results, these are further processed in the development department to a marketable product, which finally are sold in markets, and then the process starts anew using the revenues that were generated by the market activities. This very simple model is also today of good service and is helpful to structure discussions or demarcate different stadiums of the innovation process. However, soon it turned out that the empirical reality is more complex. In consequence non-linear or recursive models were introduced, of which each has its specific contribution, but they just focus on a certain part of the innovation process (Kline 1985; Pleschak, Sabisch 1996; Rogers 2003; Schmoch et al. 2000; Schmoch 2003; Tidd 2006).

A model, not so much of the innovation process itself but more on the actors and influencing factors, accrued with the Innovation Systems approach in the 1980s and has especially evolved in the 1990s (Edquist 1997; Freeman 1988; Kuhlmann, Arnold 2001; Lundvall 1992; Nelson 1993). Based on this heuristic, innovations take place embedded in the political, social, organizational and economic systems. This approach is in contradiction to the traditional modernization theory that foresees a clear path for each national economy on the developmental track and it also extends the traditional innovation chain approaches, which were mainly focusing on R&D, technical progress, diffusion, and finally economic growth (Grupp 1998).

Next to the individual interests of companies, which are mainly profit orientation (or at least cost coverage), further actors and their interests in Innovation Systems can be identified. As economic growth helps to secure the overall welfare level, government and other national institutions have an interest in extending the innovation potentials of the economy. The aim of science, formulated in a very general manner, is not primarily profit maximization, but knowledge enhancement and curiosity. However, this knowledge seeking has a broad impact on economic growth and progress. The society or parts of the society influence the Innovation System by formulating their interests, buying goods on consumer markets, or simply by representing the public opinion.

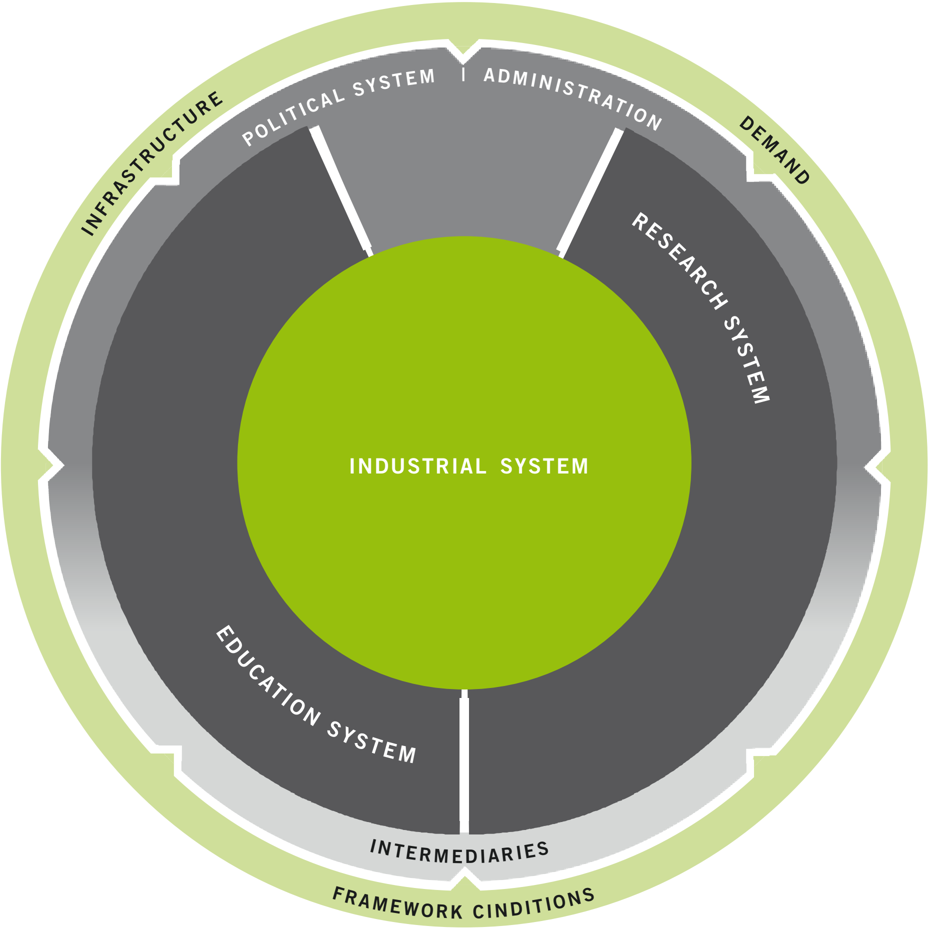
Some basic premises can be derived from the Innovation Systems approach, which are relevant for the analysis and examination of innovation processes. There is no single causality and no exclusive impact of economic factors on the outcome of the Innovation System. Especially at this point the theoretical proximity to the evolutionary theory on economics is evident (Andersen 1994; Foster, Metcalfe 2001a; Mokyr 1990; Nelson 2001; Nelson, Winter 1982; Saviotti, Metcalfe 1991), which also does not see a universal and optimal path to a final goal. Furthermore, recursive processes and effects are central attributes of innovation processes or Innovation Systems. Such recursive effects have been proved empirically, for example by Ophem et al. (2002), who showed that there is not only a positive influence of R&D expenditures on the number of patents but also vice versa a positive – though delayed – impact of patent applications on R&D expenditures. The explanations are: next to the creation of additional resources by selling patent based products, future inventions require additional R&D. A systematic quest for new products and technologies secures the competitiveness also in the future. It is not feasible to follow the track of high technology and innovation at one time and then leave this path and restrict oneself on imitation only, for example. In other words, a path dependency in terms of innovation is clearly imminent to the system.

As a consequence of the Innovation Systems approach and its systemic perspective, several actors and factors have to be taken into account for a comprehensive analysis. Next to economic and legal framework conditions like taxes, funding, or laws, which can be directly or indirectly steered by the political system, social framework conditions need to be included. For sure, companies and branches play central roles which are summarized in the industrial system. Furthermore education and research offer crucial contributions. It is not only research results which are elaborated in universities and public research institutions, which need to be transferred to the industrial system by intermediating mechanisms and institutions (Kulicke et al. 2008; Schmoch et al. 2000; Schmoch 2003). The educational system, which is itself embedded in an environment of political, social and economic systems, is of special interest. But it is also a part of the environment for the other systems. It provides skills and human capital that are used in the research system and is closely related to the labor market and the industry system.

It also has to be acknowledged that innovation does not only take place in companies or firms, but also in public research institutions, public authorities and agencies, or in the political system in general. The initiation of innovations does not necessarily stem from the industry sector. Also consumers, the society, political institutions, or the research system might initiate innovations (Fraunhofer ISI et al. 2006; Lundvall 1988; Moors et al. 2003).

The legal and financial framework conditions perform additional restrictions, which need to be taken into account.

Figure 1: Schematic representation of innovation systems



Source: Own representation

Lundvall (1992) emphasizes the meaning of institutional conditions as an important dimension of innovation systems. He also includes technological paradigms and technological trajectories in his discussion on institutions. The concept of path dependency stems from evolutionary economics. It means that innovations do not emerge out of nothing, but build on existing knowledge and experiences. Innovations also do not happen artificially, but are the result of (to some extent) intended and directed processes. They result from research work, which builds on existing and evolved knowledge within organizations and firms.

Dosi (1982; 1984) has formulated the concept of "trajectories" and states that innovations always build on existing knowledge and therefore evolve cumulatively. From own experiences but also from the experiences of others (spillovers) one can learn and does not always have to start anew again. This is a rational strategy which simplifies the work by relying on experiences also by others when new problems, challenges and research questions are addressed. This also explains why companies, firms and even complete national economies specialize in certain technologies, goods, services or natural resource exploitation. They try to realize scale effects, but especially they try to secure, enhance and use the existing knowledge base.

On the other hand – and innovation research has broadly examined this – such paradigms may also result in lock-in-effects (Arthur 1989; Shapiro, Varian 1999; Shy 2001). This means that if leaving a technological trajectory might be necessary, the alternative technological path is not seen or is not followed, either due to ignorance, arrogance or sunk costs, for example. Within science fields paradigm shifts might occur when a dominant paradigm or design is challenged by a new paradigm, which finally succeeds. Kuhn (1996) had shown this for the big natural science theories and generalized to all scientific areas, while Dosi (1982; 1984) finally applied this concept to innovation research.

Innovations are not a mean in itself. The aim is to generate new products or services for national and international markets, which create an advantage in competition by being cheaper or (technologically) better. So it is either a cost or a quality competition – or anything in between. The non-linearity and the cumulative character of innovation processes require a certain level of absorptive capacities (Cohen, Levinthal 1990), which might be flanked by technical and organizational framework conditions that, first of all, are incorporated in the available human capital.

Against this framework, the actors and factors were selected and also the final demarcation of subsystems (see below) of the Innovation Indicator as it is presented here is based on this approach. In consequence, also the broad number of indicators that were meant for operationalizing these actors and factors were gathered based on this idea. This large number of indicators – also motivated by the economic model that is the second layer of our overall approach – were then put into an econometric model, which helped us to downsize the number of final indicators and identify the relevant factors and indicators for our purpose. A detailed description of the working steps towards this final goal and fulfilling this purpose is given in the following sections.

3 Four steps towards a composite indicator

3.1 The selection process

In order to determine the relevant influencing factors within the original set of innovation indicators and to satisfy the epistemological claim of a parsimonious modeling, a step-by-step methodology for eliminating redundant or irrelevant indicators was chosen.

Conceptual background

The Innovation Indicator aims at benchmarking the capacity of the German economy to innovate against a set of other countries. The Innovation Indicator is intended to disclose strengths and weaknesses of the German innovation system and help innovation policy to identify fields of action for rectifying shortcomings in innovation performance.

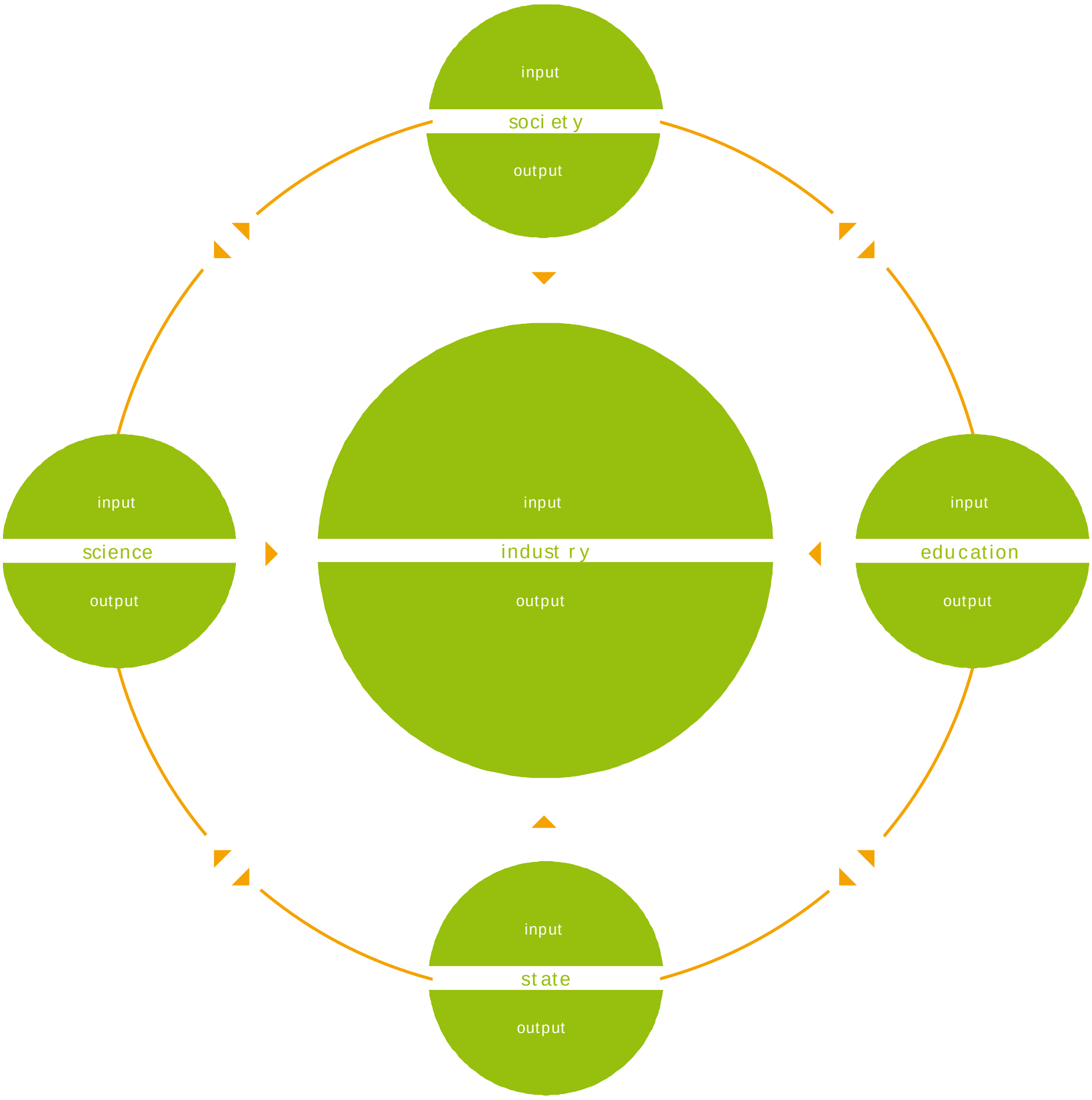
Innovative capacity denotes the ability to generate new knowledge, new technology and new artefacts and to apply these novelties in a useful way. The concept of innovative capacity evaluates both the current capabilities to innovate and the innovative potentials that may affect innovativeness in the longer term (see Furman et al. 2002). Many variables determine innovative capacities of countries. The Innovation Indicator combines these variables into a comprehensive model.

Enterprises and their innovative activities are in the core of the model as they are the group of actors that bring new products, new applications and new business models onto the market and make novelties available to users. Innovation in the enterprise sector includes three main activities: generating knowledge, exploiting knowledge, and utilizing innovation. Generating knowledge is about researching into new technological and organizational solutions while exploiting knowledge is about transferring new insights into commercial operations and products, i.e. innovations. Utilizing innovation refers to the process of generating added value out of innovations by increasing productivity and opening up new markets.

Generating, exploiting and utilizing knowledge and innovations are strongly interlinked and tend to be performed simultaneously (see Kline, Rosenberg 1986). Introducing new products onto the market may change user needs and competitors' activities and open room for complementary innovations, all of which may stimulate new research and new combinations of existing knowledge to utilize new opportunities for innovation and respond to upcoming challenges. Successful innovation activities require specific capabilities within enterprises as well as interaction with other enterprises (users, suppliers, competitors).

Innovation success also depends on factors outside the enterprise sector. Science and education are particularly critical. Innovation is done by people and rest on their creativity and skills. The education system has to provide people with skills and promote their creative potentials. Learning enlarges the knowledge base of the work force which is a main ingredient for the innovative capabilities of organizations. Public science supplies industry with new findings that form a knowledge base for industrial R&D. New technologies resulting from basic research often stimulate innovation activities in the enterprise sector.

Figure 2: Main Elements of a Model of Innovative Capacity of Countries



Source: own presentation

An innovation-friendly environment is another key success factor. Both governments and the society as a whole do play a critical role. Governments can support innovation by establishing an efficient science and education system, and by promoting research and innovation in firms. Regulations and administrative procedures should encourage innovation rather than to build obstacles to innovative efforts. A society that is open to new ways of responding to challenges and willing to adopt new technologies offers fruitful conditions for innovative activities. Innovation-oriented consumers are a major source of innovation and provide a seedbed for testing ideas for new products.

Markets are another key source for innovation. Fierce competition among enterprises will propel the search for solutions that best suit market demand. High market dynamics and demanding customers are further elements of a market environment that triggers innovation.

The Innovation Indicator attempts to measure the various elements of innovative capacity of countries. Some of these elements are strongly related in a way that changes in one element will lead to changes in other elements. We use a model of national innovative capacity to represent the interrelation of elements. The model consists of five pillars, each being represented by a structural equation, where the final outcome is the pillar of utilizing innovation.

Based on this modeling philosophy, our indicator selection approach consists of several steps. As a start, taking the list of indicators of the preceding analyses in earlier years as granted, we reduced the list, dropping indicators that were from a theoretical point of view only weakly linked to the topic of innovation and innovative capacities. At the same time we have also enriched this list with indicators that we regarded as potentially relevant but that were not included in earlier versions of the Innovation Indicator. This step will not be described in greater detail, because it entails a lot of idiosyncratic context knowledge. In any case, this list contained about 100 indicators further considered for inclusion. This corresponds to a reduction of about 80 indicators.

Based on this list, the further reduction to the final list of 38 indicators was performed on the basis of statistical analyses. These indicators are described in more detail in Section 4. The employed procedure contained three distinct steps, which we will describe in the following.

First, we eliminated obviously redundant indicators within the subsystems by investigating correlations (see Figure 3). Second, we eliminated insignificant inputs within the subsystems using regression approaches. Third, we dropped insignificant framework variables in a final regression within the productivity subsystem, where we additionally use the outputs of the other subsystems as relevant explaining inputs.

Redundant indicator

In order to remove obviously redundant indicators, the pair wise bivariate correlations of the variables within the subsystems were calculated. With the help of them, indicators measuring the same construct could be identified as redundant already in an early stage of the analyses.

For indicators, whose correlation exceeded the value of 0.7, two alternate methods were chosen. Multiple highly correlated variables were combined into an index. In the case of a high correlation between two variables, a key variable was selected on the basis of several criteria (e.g. item-specific relevance or data availability).

Figure 3 shows a correlation matrix using the example of the subsystem of "education". The four variables ed3 through ed6 are highly correlated and were therefore combined in an index variable (in this case the composite result of the PISA studies, now variable B9). The variable ed8 was eliminated on the basis of expert opinion.

Figure 3 Pairwise correlations within the subsystem Education-Structure

	ed1	ed2	ed3	ed4	ed5	ed6	ed7	ed8
ed1	1							
ed2	0.037	1						
ed3	0.119*	-0.041	1					
ed4	0.371*	-0.195*	0.800*	1				
ed5	0.244*	0.153*	0.814*	0.672*	1			
ed6	0.393*	0.115*	0.823*	0.752*	0.896*	1		
ed7	0.283*	-0.006	0.155*	0.249*	-0.063*	0.171*	1	
ed8	0.133*	0.914*	-0.071*	-0.130*	0.111*	0.02	-0.068*	1

Significance level: *p<0.5

The variable names used in this table are artificial and just serve as an example.

Irrelevant subsystem inputs

Panel regressions for the subsystems in which input and output indicators have been identified (e.g. research development expenditure and development and patent applications in the sub-economy) were estimated. The output indicators were treated as explained variables and the input indicators as explanatory variables, respectively.

With the help of those panel models, causal relationships between the relevant inputs and outputs of a subsystem could be determined. The significance of the effect of one variable thereby provides information about the relevance of an input indicator to explain the respective output variables. The value of each regression coefficient indicates the strength of this influence. In other words, this means that non-significant variables are considered as redundant effects and can therefore be excluded for further calculations.

Since the data used for analysis are in the form of a country panel, the econometric modeling has to take into account the typical characteristics of this data structure. In detail, the following model is estimated

$$y_{it} = x_{it}\beta + c_i + u_{it} \qquad i = 1, \ldots, n \qquad t = 1, \ldots T \tag{1}$$

where y_{it} is the explained variable of unit i in period t, x_{it} is a vector of explanatory variables, β is a coefficient vector, c_i is a time-constant unobserved firm-specific effect and u_{it} idiosyncratic errors, where the latter two are allowed to be correlated.

For each of the subsystems, several of these fixed-effects input-output regressions were calculated in order to determine the relevant inputs, while at this stage of modeling possibly relevant framework indicators (from the system society, state, or infrastructure) were not taken into account. Based on these models, a reduced list of subsystem-specific input-indicators to be included in the final composite indicator was provided.

Irrelevant framework variables

Based on the preceding analyses, in a final step, we focused on the final objective of innovation – wealth generation. Here the economic productivity was of primary interest. This was measured by two economic output variables, namely gross domestic product per capita and value added per hour worked. The estimation of the models was carried out by the same method as in the previous step. As explanatory variables, however, only the output variables of the subsystems education, public research and technology were used, since these subsystem outputs are thought to describe relevant inputs for the wealth generation process. In addition, the structural variables – the variables to reflect the influence of the state, society and the infrastructure of a country – were included as explanatory variables in the overall models. With these models, it is possible to determine the relevant influencing factors within the dataset, specifically assess their individual effects on the economic performance of a country and reduce non-relevant variables (at least in combination with additional factors) from the dataset. The overall models are shown in the annex to this report.

3.2 The normalization procedure

The first step after the final decision on the relevant indicators is the normalization. This is necessary because the indicators are measured on different scales and in different units.

Several normalization procedures have been used in the past. Among them is the rescaling procedure that stretches or shrinks the original scale on one interval that is constant for all indicators. This procedure has both advantages and disadvantages, where the major drawback is seen in the fact that this procedure is sensitive to outliers or extreme values. However at the same time it preserves the numerical differences between the observed values. Taking $Y_{i,j}$ is indicator j of country i before rescaling and $\overline{Y}_{i,j}$ after rescaling, the simplest formula leading to a transformed indicator on the unit interval is given by

$$\overline{Y}_{i,j} = \frac{Y_{i,j} - \min\left\{Y_{i,j}\right\}}{\max\left\{Y_{i,j}\right\} - \min\left\{Y_{i,j}\right\}} \qquad (2)$$

Another procedure is a scaling method based on the quantile position of one observation. This means that instead of using the observed values (possibly in a rescaled version) the quantile position of this observation is used. That implies that the largest value would receive the value one, because it corresponds to the 100%-quantile. Likewise the smallest value would receive a zero. While this procedure is more robust to outliers as it abstracts from the original values by looking at the order statistics, the loss of information can be large, if the differences between to observed values have a sensible meaning.

Partly because of this latter drawback and partly for reasons of comparability with earlier version of the Innovation Indicator we will stick with a special variant of the rescaling method, where we use as lower interval limit one and as upper seven.

Before coming to the exact formula, we touch a further issue that concerns robustness with respect to changes in the country set. In particular, since (2) is based on empirical minima and maxima the rescaling method is sensitive to changes in country sets, that affect minima or maxima. This implies that whenever countries with extreme values become part of the set, changes in the normalized values are induced that do not correspond to changes in the original indicators.

An easy solution to this problem is to keep the set that is used for normalizing fixed, while measuring new countries against the minima and maxima of the fixed set, say, L. The formula that results from this procedure is given by

$$\overline{Y}_{i,j} = 100 \cdot \frac{Y_{i,j} - \min\limits_{i\in L}\left\{Y_{i,j}\right\}}{\max\limits_{i\in L}\left\{Y_{i,j}\right\} - \min\limits_{i\in L}\left\{Y_{i,j}\right\}} \qquad (3)$$

It should be noted that the normalized indicators usually will not fall into the interval $[0,100]$ for those countries that display more extreme values than the reference set L.

3.3 Aggregation and sensitivity analysis

The next step in the construction of a composite indicator consists of aggregating the rescaled indicators via weights. We will stick to a linear approach here, because as a result of its simplicity it is the most transparent. In this fashion, a composite indicator is simply a weighted average of rescaled indicators. This obviously necessitates the derivation of aggregation weights, which can be quite cumbersome. Therefore, it is often argued that equal weighting is preferable, because it evades the problem of defining weights in a more or less arbitrary fashion. Although, Grupp and Schubert (2010) show that this way of weighting might imply problematic "economic" trade-offs between these indicators, it is definitely one of the most transparent weighting schemes. We will therefore stick to equal weighting. Letting J be the total number of different indicators, this leads to the following formula for the Innovation Indicator II for country i:

$$II_i = \frac{1}{J}\sum_{j=1}^{J}\overline{Y}_{i,j} \qquad (4)$$

In principle rankings and country analyses will be based on this indicator, where, however, we already have highlighted that these are contingent on the choice of equal weights. This necessitates extensive robustness checks.

We will adopt a statistical approach to the question of sensitivity and checks of robustness of the rankings. This approach will be based on the logic of Bayesian statistics, where we treat the weights as random variables with a flat prior, while treating the observed indicator values as fixed.

Constructing such a flat prior is particularly easy, as we can draw each weight independently from a given fixed interval on $[0,c]$, $c > 0$.

In principal c is arbitrary and its choice does not affect the results as long as it is the same for all weights. For simplicity we set $c = 1$. Calling the realizations of this sampling procedure $w_1,\dots,w_J$, it is obvious that the sum of these weights will quite generally be unequal to 1, which is what would be required.

Therefore we introduce the normalization

$$\omega_j = \frac{w_j}{\sum_{j=1}^{J} w_j} \qquad (5)$$

where the sum over all ω_j is by construction identical to 1. Based on these weights we can calculate a new Innovation Indicator. If we repeat this process very often, obviously many such pseudo-random indicators are available, which can be used to make probabilistic statements on how the ranking scheme is affected by random shocks to the weighting scheme.

4 Final list of indicators and indicator description

The following indicators have been selected for inclusion in the Innovation Indicator. Here we will give a short account of what they measure and how they are positioned in a country's innovation system. Comparable to the preceding discussion, we will describe the indicators by subsystem, where several indicators may belong to more than one subsystem. The assigned subsystems are indicated in the brackets at the end of the title of each individual indicator. If an indicator belongs to two subsystems, both of them are named.

Figure 4: Table of individual indicators

B1	Foreign students as a percentage of all tertiary enrolment	Education
B2	Share of employees with at least secondary (non tertiary) education	Education
B3	Population with ISCED 6 level education in mathematics, sciences, and engineering	Education
B4	Tertiary graduates per 55+ year old academic employees	Education
B5	Share of employees with tertiary education	Education
B6	Annual education expenses per student	Education/State
B7	Quality of education system	Education/State
B8	Quality of the mathematical and natural science education	Education/State
B9	Index of PISA results in sciences, reading, mathematics	Education/State
G1	E-readiness indicator	Society
G2	Risk-taking behavior	Society
G3	Number of PCs per 100 inhabitants	Society
G4	Share of post materialists	Society
S1	Public demand for advanced technologies	State
W1	Demand of companies for technological products	Enterprises
W2	Early-stage venture capital relative to GDP	Enterprises
W3	Importance of Marketing	Enterprises
W4	Share of international co-patents	Enterprises
W5	Share of value added in high-tech sectors in total value added	Enterprises
W6	Share of employees in knowledge intensive services	Enterprises
W7	Intensity of competition	Enterprises
W8	GDP per capita	Enterprises
W9	Transnational patents per capita	Enterprises
W10	USPTO patent applications per capita	Enterprises
W11	Value added per hour worked	Enterprises
W12	Trade balance in high-tech goods per capita	Enterprises
W13	Share of university R&D financed by enterprises	Enterprises
W14	Internal business R&D expenditures as share of GDP	Enterprises
W15	B-index for tax-based funding of business R&D	Enterprises/State
W16	Publicly funded R&D in enterprises as a share of GDP	Enterprises/State
F1	Number of researchers in FTE per 1,000 employees	Public Research
F2	Number of SCI publications relative to population	Public Research
F3	Quality of research institutions	Public Research
F4	Field-specific expected impact rate of SCI-publications	Public Research
F5	Public science sector patents per inhabitant	Public Research
F6	Share of international SCI co-publications	Public Research
F7	R&D share in Public Research Institutions and Universities	Public Research/State
F8	Country share among the top 10% of most highly cited publications	Public Research)

4.1 Indicators of the subsystem "education"

B1: Foreign students as a percentage of all tertiary enrolment (Education)

The share of foreign students can be regarded as a performance indicator in at least two ways. First, it expresses the attractiveness of the science system for international students. That is this indicator measures the willingness of an internationally highly mobile group of students to take their courses in the specific national higher education system. Furthermore, international students also approximate international knowledge flows, which in turn could benefit the national systems by endowing them with access to broader knowledge pools.
Source: OECD – Education at a Glance

B2: Share of employees with at least secondary level education, without tertiary educations (Education)

Successful innovation processes do not only need human capital that works at the high ends of educational attainment levels. It also is in need of well-educated population in general. This shall be captured by this indicator that measures, first of all, the structured vocational training. Furthermore, several national education systems are known to have particular strength here, partially also organizing the attainment of certain educational degrees in vocational training structures that are awarded in other countries inside the tertiary university sector. To account for distortions that would occur, also these educational levels are recorded.
Source: International Labour Organization – LABORSTA

B3: Population with ISCED 6 level education in mathematics, sciences, and engineering as share of total population (Education)

ISCED 6 level education refers to the upper-tertiary education, in particular the doctoral and the PhD-training. In that respect the indicator measures the prevalence of the highest level of scientific training in the total population. Additionally, this indicator is restricted to mathematics, sciences, and engineering, because these qualifications are pivotal to the functioning of the innovation system. As such this indicator represents the innovation-relevant elite-part of the human capital that is available to each national innovation system.
Source: OECD – Education at a Glance

B4: Tertiary graduates per 55+ year old academic employees (Education)

In each innovation system existing human capital becomes unavailable when people retire. This necessitates the replacement of qualification holders by an up-and-coming generation.

This indicator measures whether this replacement demand (approximated by the age group of 55+ year old workforce) can be sufficiently fulfilled by the currently available graduates. The higher the ratio between the new graduates and the about-to-retired graduates, the more able should be an innovation system to cope with the dropping out of existing human capital. Demographic unbalances are taken into account by this indicator.
Source: OECD – Education at a Glance; International Labour Organization – LABORSTA

B5: Share of employees with tertiary education (Education)

This indicator measures the share of employees with an education degree attained in a higher-education institution (e.g. universities, polytechnics). Together with the doctoral and PhD-graduates (see B3) this constitutes one of the most relevant resources available to national innovation systems, as it represents highly qualified human capital. We focus here on the employees, because this constitutes the group that is actually available to the labor market.
Source: OECD – Education at a Glance

B6: Annual education expenses per student (Education/State)

This indicator depicts the financial resources that the state provides for the education of the students in the science system. Inasmuch the financial commitment reflects quality standards, this indicator can be thought of as a "hard" indicator of quality of education. It should be noted that this indicator differs from the more conventional indicators, e.g. also reported by the OECD like the annual education expenses as a percentage of GDP. This latter indicator validly measures a relative commitment of the national governments to education, but it cannot be interpreted as a pure quality indicator, because of largely varying levels of GDP. Therefore, a high performance on the OECD-indicator could be due to low GDP rather than absolutely high education expenditures.
Source: OECD – Education at a Glance

B7: Quality of education system (Education/State)

Data source is the World Economic Forum (WEF), which surveys stakeholders and decision makers in several countries, also asking them for their assessment of the quality of the education system. In order to complement the "hard" quality indicator an additional indicator is included that shall measure the more salient feature of the quality of the total educational system based on subjective expert ratings. This indicator is clearly more subjective than the financial indicator B6, but it at the same time it is less affected by differences in national accounting practice.
Source: World Economic Forum – World Competitiveness Report

B8: Quality of the mathematical and natural science education (Education/State)

The source of this indicator is also the WEF survey. This indicator is largely comparable to B7, but focuses on the mathematical and natural science-related education, which lays the basis for the technically and mathematically oriented human capital available to each national innovation system.
Source: World Economic Forum – World Competitiveness Report

B9: Index of PISA results in sciences, reading, mathematics (Education/State)

The PISA results in sciences, reading, and mathematics have become a quasi-standard in performance measurement and comparisons with respect to national education systems. They measure under internationally comparable circumstances the de facto attained performance levels in these three fields separately for a representative sample of 15 years aged pupils. Inasmuch the performance of the 15 years aged pupils today is indicative of the education system as such, this indicator will also be predictive of qualification of the active work force. Thus the PISA indicators constitute a valuable output measure with respect to de facto achieved performance levels. Here an unweighted average of three subfield indicators is used.
Source: OECD – PISA surveys

4.2 Indicators of the subsystem "society"

G1: E-readiness indicator (Society)

The e-readiness indicator measures the opportunities to process governmental services online. It is not only a measure of proliferation of modern communication technologies in broader every-day life but also a measure of the openness of the society with respect to new technologies in general and communication technologies in particular. At the same time the e-readiness indicator is also a measure of the communication infrastructure as it gives an impression of the diffusion of modern communication technologies.
Source: Economist Intelligence Unit

G2: Risk-taking behavior (Society)

Entrepreneurial activities are a prerequisite of successful innovation activities in the economy. However, entrepreneurs often have to operate under considerable uncertainty. As a consequence start-ups and self-employment is likely to occur to a greater extent only, if the people are sufficiently willing to take risks. A further argument favoring risk-taking behavior lies in the fact, that innovation activities in general are risky investments. Thus, innovation activities themselves are more often undertaken by less risk-averse people. A society that is

relatively more able or willing to take risks therefore should provide a climate that is more apt to innovation activities.
Source: European Commission –Eurobarometer

G3: Number of PCs per 100 inhabitants (Society)

PC per inhabitants is like the e-readiness indicator a measure of the openness of the society towards modern communication and computer technologies. A general exposition to these kinds of technologies also ensures that the people are able to appropriately make use of these technologies, which should also strengthen the abilities to work with these technologies in a work context.
Source: OECD – International Telecommunications Union

G4: Share of post materialists (Society)

Postmaterialist values are a concept defined in sociology to monitor the shift of societal values. They measure to what extent members of a society pursue personal aims that go beyond the satisfaction of basic needs (food, shelter, simple consumption). Exemplary for this are environmental protection, but also other ethical goals such as income equality or higher-end consumption needs, such as design questions that go beyond pure functionalistic considerations. It can be argued that the prevalence of postmaterialist values benefit innovation strategies, because they reflect the development level of consumer demands. Additionally, they could reflect the availability of resources in a society that do not directly satisfy basic needs but can be devoted to more developed innovation activities.
Source: World Values Survey Association – World Values Survey; European Commission – Flash Eurobarometer

4.3 Indicators of the subsystem "state"

S1: Public demand for advanced technologies (State)

Government purchases are a main component of aggregate demand, accounting for 15 to 25 percent of total demand. Based on their significance as customers, public procurement can either drive innovation by demanding new products or technologies or hamper the diffusion of innovations when innovativeness is not adequately accounted for in purchasing decisions. Measuring whether and to what degree governments stimulate innovations and demand advanced technologies is difficult, however. Governments usually do not report the innovative content of their purchases. We therefore rely on an assessment of managers. Based on data from the World Economic Forum, managers rated their view on governments' purchasing decisions for the procurement of advanced technology products on a

seven-point scale, ranging from decisions solely based on price (1) to decisions based on technology and encouraging innovation (7).
Source: World Economic Forum – World Competitiveness Report

4.4 Indicators of the subsystem "enterprises"

W1: Demand of companies for technological products (Enterprises)

Economic effects of new technology strongly depend on how rapidly enterprises adopt these new technologies and how far new technologies spread over different sectors. Speed and breadth of technology diffusion is affected by absorption capacities of firms. Absorption capacities include prior experience in technology adoption, technical skills of employees, financial resources and management routines. While some aspects of absorption capacities can be captured by quantitative indicators on employee qualification or capital investment by firms, others are more difficult to grasp by metrics. In order to measure qualitative components of absorption capacities, we rely on managers' assessment on how fit companies in their country are to absorb new technology, ranging form "not able to absorb new technology" (1) to "aggressive in absorbing new technology" (7). The data are taken from the World Economic Forum database.
Source: World Economic Forum – World Competitiveness Report

W2: Early-stage venture capital relative to GDP (Enterprises)

Commercializing new research results by start-up companies often requires substantial investment in early stages of technology development, including R&D, testing and marketing. This investment has to take place before a company is able to earn any returns, and they are associated with high uncertainty over the technological feasibility and market acceptance of new products to be developed. Such investment can rarely be funded from traditional external sources such as credit while the sum of investment typically exceeds the internal funds of these young companies. Venture capital is therefore a critical source of funding. The amount of venture capital investment in early stages of the development of technology companies (i.e. seed and start-up stages) is an important indicator of a country's ability to support technology-based start-ups with sufficient financial means. The indicator relates the amount of early stage venture capital investment to GDP and is taken from the statistics of the European Venture Capital Association.
Source: Eurostat

W3: Importance of Marketing (Enterprises)

The modern understanding of innovation goes beyond the purely technological components which can be described by product and process innovations. In fact, the OSLO-Manual (an OECD issued handbook on the measurement of innovation) distinguishes not only product and process but also organizational and marketing innovations. This follows the notion that every change in products or processes also calls for corresponding adaption in the organization and marketing. The latter is particularly obvious, since new products or processes have to be made known in the market to become a significant determinant of market success. Therefore, in an economy where marketing methods are well-established consumers are usually more informed about current innovations available to them. This should in turn increase the expected profits of innovation by lowering the entry barriers.
Source: World Economic Forum – World Competitiveness Report

W4 Share of international co-patents (Enterprises)

International co-patents are patents that are applied for by actors from at least two different companies. Like international co-publications (see below) this indicator measures the degree of integratedness of the national R&D activities in the global context. As a consequence it measures the ability of companies to benefit from geographically diverse knowledge sources. Additionally, it is an indicator of the national knowledge stocks for foreign partners. The basis is all transnational patents (compare W9).
Source: EPO – PATSTAT database, own calculations

W5: Share of value added in high-tech sectors in total value added (Enterprises)

The sector structure of an economy is an important dimension of a country’s innovative capacity. While each sector is important in its own right through offering products and services needed by firms, consumers or governments, future prospects of sectors differ substantially. From the point of view of the most advanced economies, high-tech sectors are particularly important since they demand resources (in terms of skills and technology) for which most advanced economies have comparative advantages. High-tech sectors are typically closely interlinked with academic research and are a main arena for transferring research findings into new products and processes. They are the most important source of innovation and open-up new markets. Consequently, they show above-average growth rates. Even more important, they are expected to be the growth engines for the future. The share of high-tech sectors in total value added of the enterprises sector (excluding real estate) is calculated based on data from the EUKLEMS data base. High-tech sectors are defined according to the common OECD classification and include both "high-tech" and "medium high-tech" sectors (i.e. chemicals, pharmaceuticals, machinery & equipment,

electronics and computers, electrical equipment, automobiles and aircraft).
Source: OECD – Structural Analysis Statistics

W6: Share of employees in knowledge intensive services (Enterprises)

Knowledge intensive services have tremendously gained in importance as a source of innovations in the economy. Unlike regular service that are characterized by intangibility and non-tradability, knowledge-intensive usually reflect high-value goods that can only be supplied by highly-qualified specialists. Since often these goods are customized towards the needs of the user, these goods are subject to constant change and adaption. An economy that is able to remain competitive in the supply of knowledge-intensive services can therefore be regarded as being highly flexible and able to provide a highly qualified pool of specialized human capital.
Source: EUKLEMS Database

W7: Intensity of competition (Enterprises)

It is well understood in innovation economics that the type of competition is very important for the intensity and the direction of innovation activities. In particular, the promise of future profits leads enterprises to innovate and to attain a leading edge in the production of its products that distinguishes itself from its competitors. At the same time these technological advantages should not protect the company forever from its potential competitors. Rather, in a healthy situation that provides lasting incentives for continuing innovation activities, these advantages should gradually erode by rivals' technological progress. Therefore a well-established competition including a competitive orientation of the market participants are necessary to foster innovation activities.
Source: World Economic Forum – World Competitiveness Report

W8: GDP per capita (Enterprises)

Modern growth theory establishes a clear and causal link between innovation activities and the growth as well as long-term wealth of the economy. According to this theory the larger the investment into innovation activities the larger is also the wealth. Thus the development of GDP per capita, as the leading economic indicator of wealth, should be heavily driven by the ability of enterprises in the economy to successfully introduce innovations. As a matter of fact, the average wealth also should also be an indicator of how many resources are available for reinvestment. Thus, GDP per capita as a wealth indicator also has a potential input interpretation.
Source: World Bank

W9: Transnational patents per capita (Enterprises)

Patents are a major visible output of innovation activities. Although they can be used for securing a stream of temporary monopoly profits that result from the underlying invention or whether they are used in a more strategic manner, they will always reflect a technological invention that has satisfied the criterion of non-obviousness with respect to prior existing technology. However, patents can differ substantially in their economic and technological value. That is why patents are often weighted by quality measures. One simple way is to count only patents that have been applied for internationally. The so-called transnational patents are patents that have been applied for either at the EPO or via the PCT route. In other words, these are patent families with at least a family member at the EPO or WIPO (PCT).
Source: EPO – PATSTAT database, own calculations

W10: USPTO patent applications per capita (Enterprises)

Comparable to W9 USPTO patents are patents that have been applied for at the US-Patent and Trademark Office. Together with the European Patent Office the USPTO is the largest patent office in the world and reflects one of the largest markets. Furthermore, many Eastern Asian countries like Japan, Taiwan, and Singapore have a dedicated focus on the American market. Not including patents directed to that patent office could result in severe downward biases with respect to these countries.
Source: EPO – PATSTAT database, own calculations

W11: Value added per hour worked (Enterprises)

A key output indicator of an economy is productivity, i.e. the ratio between value added and labor input. This indicator denotes the amount of products and services (evaluated at market prices) that were produced by one hour worked as an average across all economic sectors. The data is taken from the EUKLEMS data base. Labor productivity can be regarded as an aggregated indicator for the successful use of technological advance in production. Since output is measured in market prices, the indicator also reflects a country's ability to sell high-priced products, which is typically related to high degree of innovativeness, though a high level of prices could also reflect imperfect competition in product markets not related to innovation.
Source: EUKLEMS database

W12: Trade balance in high-tech goods per capita (Enterprises)

A country's ability to sell higher amounts of technology than it imports indicates a technological advantage in the related product groups. A positive trade balance in new technology

shows that a country is a net source of technology on the world market. On the one hand surplus in new technology trade indicates that a country is able to generate innovations that are demanded internationally. On the other, a surplus may also appear in case of low import demand for new technology. The latter may either indicate a strong domestic technology sector that is capable to supply domestic technology demand, or a low demand for new technology due to little innovation orientation of domestic producers and consumers. Since we control for the latter by other indicators, the trade balance in high-tech goods should rather be understood as a reflection of comparative advantages in the production of high-tech products. We measure a country's position in trade in new technology by subtracting the imports of high-tech goods from the exports. In order to adjust for country size, we consider per capita values. High-tech goods are defined using the OECD classification of high-tech and medium-high-tech goods.
Source: United Nations – COMTRADE database, own calculations

W13: Share of university R&D financed by enterprises (Enterprises)

The share of university R&D financed by enterprises is determined by the ability of the science system to engage in research tasks that are directly useful companies. Thus, this indicator is a measure of the quality of the applied research that leads directly to valuable and commercially usable outputs. Furthermore, since the process of financing R&D quite generally leads to knowledge and technology transfer from the public science sector to the companies, this measure also reveals the intensity of the knowledge flows from the science system to enterprises.
Source: OECD – Main Science and Technology Indicators

W14: Business expenditures on R&D (BERD) as share of GDP

This indicator measures the degree of enterprise involvement in research and development tasks. It reflects the extent to which the national economy focuses on the production of R&D-intensive goods. Additionally, it shows the ability of national enterprises to supply goods of high technological standards that may not be produced elsewhere easily. Since the knowledge base and the competences necessary for production of such goods is generally tied to national specificities, this indicator also reflects long-lasting competitive advantages. Furthermore, R&D activities contribute to the building of so-called absorptive capacities in enterprises allowing them to participate from knowledge that has been produced outside the own company (e.g. in universities). Thus, R&D expenditures are a prerequisite of long-term technological advance.
Source: OECD – Main Science and Technology Indicators

W15: B-index for tax-based funding of business R&D (Enterprises/State)

Government support for private R&D can help enterprises to raise their level of R&D activities and to increase social returns of R&D. Most governments provide direct subsidies for R&D activities (e.g. grants for R&D projects). Indirect measures such as tax incentives can offer an important complement to direct measures since they can address all enterprises independent from sector, size or technology. From the firm's point of view, tax incentives as a mean of public co-funding of R&D expenses are often associated with lower costs compared to sometimes complex application procedures of grant programs. The generosity of tax treatment of firms' R&D expenses is measured by the OECD's so-called B-Index. The B-Index measures the present value of before-tax income that a firm needs in order to cover the cost of spending one unit of currency in R&D and to pay the applicable corporate income taxes. The index considers investment at the margin, with economic rent exhausted, and ignores financing considerations, such as the cost of capital. Subtracting the B-Index from 1 gives the share of government subsidies for private R&D expenditure.
Source: OECD

W16: Publicly funded R&D in enterprises as a share of GDP (Enterprises/State)

It generally argued that the socially desirable level of innovation will not be reached in free market-economy, because innovation is risky and because innovation generates spillovers. This leads to underinvestment. Therefore the governments need to subsidize innovation in order to correct the underinvestment incentives generated by the market, whereby they create own incentives. The share of state-financed R&D in companies is therefore an indicator by how much the governments are able and willing to correct the market incentives using own resources. This indicator is therefore also a measure of the focus the government has towards innovation.
Source: OECD – Main Science and Technology Indicators

4.5 Indicators of the subsystem "public research"

F1: Number of researchers in FTE per 1,000 employees (Public Research)

The number of researchers per 1,000 employees is a leading indicator of input into the science system. It measures the extent of resource devotion to the public science sector. Because of data unavailability we use all scientists including those from the business sector, which is certainly only a rough measure of the input into the public science system but may at least approximate it. Additionally to the input argument the indicator as such does not exclusively relate to genuine research tasks but also to academic teaching. Therefore it measures also the human capital dimension. We relate the researchers to the total em-

ployment in the denominator in order to normalize the indicator with respect to the demand of the whole economy.
Source: OECD – Main Science and Technology Indicators

F1: Number of SCI publications relative to population (Public Research)

The number of publications in the Science Citation Index (SCI) can be understood a measure of scientific research output, because researchers usually codify new and sufficiently important scientific knowledge in terms of publications. The Science Citation Index is one of the most important international databases that indexes about 6,000 journals from many scientific sub-disciplines including the MINT subjects (mathematics, informatics, natural sciences, technology). Since all included journals in the SCI have been selected on the basis of strict quality criteria, this indicator should give a good overview of the scientific output of a country while ensuring a high quality of this output at the same time. The denominator was chosen as total population in order to account for the size of the public research system relative to the economy as such. Therefore this indicator is also a measure of the relative size of the science system.
Source: ThomsonReuters – Science Citation Index, own calculations

F3: Quality of research institutions (Public Research)

This indicator is based on expert and stakeholder opinions on the quality of the national science and research system. Besides the aspects that can be measured using hard and quantitative indicators this figure may additionally capture features that cannot easily be measured using e.g. publication-related indicators. It may for example give an impression of the flexibility, the attractiveness, or of the governance-model of the science system. In this respect this indicator is more encompassing than several of the rather focused output indicators (e.g. F4 or F2). However, it is also more subjective and possibly less reliable.
Source: World Economic Forum – World Competitiveness Report

F4: Field-specific expected impact rate of SCI-publications (Public Research)

The field specific impact rate is a special citation-related indicator. In science researchers indicate that their own work is based on earlier work of others by citing the preceding document. By this mechanism credit is paid to earlier works. Furthermore, a document that receives many citations can be deemed to be very influential. Thus, citations can be understood as a measure of quality of scientific research. This notion can be extended to national science system by calculating averages over all documents with a certain origin. However, citation-behavior (e.g.in terms of frequency or intention) can very greatly between sub-disciplines leading to possibly great distortions when comparing publication portfolios

across country. We solve this problem by calculating citation rates relative to the average in that discipline. In consequence the citation rate of a particular document is evaluated against the benchmark of the average citation rates of documents with the same disciplinary focus.
Source: ThomsonReuters – Science Citation Index, own calculations

F5: Public science sector patents per inhabitant (Public Research)

Besides publications patents are a major output of universities and other public research organizations. These patents often represent very fundamental technologies that may become very influential in future technological trajectories. Therefore, university patents can be regarded as very important. University patents also relate to the role of universities as producers of economically valuable knowledge, rendering this indicator also a measure of the quality of the applied research and the direct usefulness to the society. It also highlights the role of universities as a direct contributor to economic wealth.
Source: EPO – PATSTAT database, own calculations

F6: Share of international SCI co-publications (Public Research)

An international co-publication is a publication that is authored by scientists from at least two different countries. International co-publications reflect streams of international knowledge exchange and international collaboration. Therefore, this indicator, measuring the degree of embeddedness of the national science systems, is also good indicator by how much a national science system can benefit from international knowledge streams. Furthermore, since international collaboration requires a two-sided selection process of the partners, this indicator is also a measure of the value of the national knowledge resources.
Source: ThomsonReuters – Science Citation Index, own calculations

F7: R&D share in Public Research Institutions and Universities as share of total expenditures (Public Research/State)

This indicator reflects the research-orientation of the science system. It reflects the national focus of the science system on their research with respect to the other tasks – in particular teaching. Since an ever-increasing share of R&D in public research institutions needs to be financed by third-party funds – e.g. from industry – this indicator also measures how successful the science system was in acquiring funds for R&D in situations of financial stringencies on the side of the national governance providing the basic funds. Thus, the indicator does not only reflect input in the R&D process but also the degree of competitiveness in acquiring the funds necessary to maintain high standards in research.
Source: OECD – Main Science and Technology Indicators

F8: Country share among the top 10% of most highly cited publications (Public Research)

This indicator measures a country's capacity to produce publications that are among the most highly cited. It is therefore like the citation-based indicator F4 a measure of quality and impact. However, while F4 is a measure of average quality, this indicator only relates to the top 10%. Therefore this indicator is a measure of the ability to produce elite or path-breaking research. Therefore, this indicator looks for widely visible singular contributions to science rather than measuring the overall performance of the research system as such.
Source: ThomsonReuters – Science Citation Index, own calculations

5 Literature

Abernathy, W.J.; Clark, K.B. (1985): Innovation: Mapping in the winds of creative destruction. In: Research Policy, 14 (1), pp. 3-22.

Andersen, E.S. (1994): Evolutionary Economics, London: Pinter Publisher.

Andersen, E.S. (1997): An Evolutionary Approach to Structural Economic Dynamics. In: Conte, R.; Hegelsmann, R.; Terno, P. (eds.): Simulating Social Phenomena. Berlin, pp. 287-294.

Arthur, W.B. (1989): Competing technologies, increasing returns, and lock-in by historical events. In: The Economic Journal, 99, pp. 116-131.

Cohen, W.M.; Levinthal, D.A. (1990): Absorptive Capacity: A New Perspective on Learning and Innovation. In: Administrative Science Quaterly, 35 (1), pp. 128-152.

Crepon, B.; Duguet, E; Mairesse, J. (1998): Research, Innovation and Productivity: An Econometric Analysis at the Firm Level. In: Economics of Innovation and New Technology, 7, pp. 115–158.

Devezas, T.C. (2005): Evolutionary theory of technological change: State-of-the-art and new approaches. In: Technological Forecasting and Social Change, 72 (9), pp. 1137-1152.

Dosi, G. (1982): Technological paradigms and technological trajectories. In: Research Policy, 11, pp. 147-162.

Dosi, G. (1984): Technological Paradigms and Technological Trajectories. The determinants and directions of technical change and the transformation of the economy. In: Freeman, C. (Ed.): Long waves in the World Economy. London: Frances Pinter, pp. 78-101.

Dosi, G.; Orsenigo, L. (1988): Coordination and transformation: an overview of structures, behaviours and change in evolutionary environments. In: Dosi, G.; Freeman, C.; Nelson, R.R.; Silverberg, G.; Soete, L. (eds.): Technical Change and Economic Theory. London: Pinter.

Edquist, C. (1997): Systems of Innovation Approaches - Their Emergence and Characteristics. In: Edquist, C. (Ed.): Systems of Innovation. Technologies, Institutions and Organizations. London: Pinter, pp. 1-35.

Foster, J. (1991): The Institutionalist (Evolutionary) School. In: Mair, D.; Miller, A.G. (eds.): A modern guide to economic thought: an introduction to comparative schools of thought in economics. Aldershot: Edwars Elgar Publishing Limited, pp. 207-232.

Foster, J.; Metcalfe, J.S. (2001): Modern evolutionary economic perspectives: an over-view. In: Foster, J.; Metcalfe, J.S. (Eds.): Frontiers of Evolutionary Economics. Cheltenham: Edward Elgar Publishing, pp. 1-18.

Fraunhofer ISI; CERES (University of Athens); LUND University; PREST (University of Manchester) (2006): Innovation and Public Procurement. Review of Issues at Stake, Final Report of a Study for the European Commission (No ENTR/03/24). Brussels: European Commission.

Freeman, C. (1988): Introduction. In: Dosi, G.; Freeman, C.; Nelson, R.R.; Silverberg, G.; Soete, L. (Eds.): Technical Change and Economic Theory. London: Pinter, pp. 1-8.

Frietsch, R.; Kroll, H. (2010): Recent Trends in Innovation Policy in Germany. In: Frietsch, R.; Schüller, M. (Eds.): Competing for Global Innovation Leadership: Innovation Systems and Policies in the USA, Europe and Asia. Stuttgart: Fraunhofer Verlag, pp. 73-92.

Furman, J.L., Porter, M.E.; Stern, S. (2002): The determinants of national innovative capacity. In: Research Policy 31, pp. 899-933.

Graff, M. (1995): Bildung und technischer Fortschritt als Determinanten wirtschaftlicher Entwicklung. Heidelberg: Physica-Verlag.

Grupp, H. (1997): Messung und Erklärung des technischen Wandels: Grundzüge einer empirischen Innovationsökonomik. Berlin, Heidelberg: Springer-Verlag GmbH.

Grupp, H. (1998): Foundations of the Economics of Innovation - Theory, Measurement and Practice, Cheltenham: Edward Elgar.

Grupp, H.; Schubert, T. (2010): Review and new evidence on composite innovation indicators for evaluating national performance. In: Research Policy, 39 (1), pp. 67-78.

Hekkert, M.P.; Suurs, R.A.A.; Negro, S.O.; Kuhlmann, S.; Smits, R.E.H.M. (2007): Functions of innovation systems: A new approach for analysing technological change. In: Technological Forecasting & Social Change, 74 (4), pp. 413-432.

Held, M.; Nutzinger, H.G. (eds.) (1999): Institutionen prägen Menschen. Bausteine zu einer allgemeinen Institutionenökonomik. Frankfurt am Main.

Johnson, B. (1995): Institutional Learning. In: Lundvall, B.-A. (ed.): National Innovation Systems. Towards a theory of Innovation and Interactive Learning. London: Pin-ter.

Kline, S.J. (1985): Innovation is not a Linear Process. In: Research Management, 28, pp. 36-45.

Kline, S.J.; N. Rosenberg (1986): An overview of innovation: In Landau, R.; Rosenberg, N. (Eds.): The Positive Sum Strategy: Harnessing Technology for Economic Growth. Washington: National Academy Press, pp. 275–305.

Kuhlmann, S.; Arnold, E. (2001): RCN in the Norwegian Research and Innovation System, Background Report No. 12. Oslo: Royal Norwegian Ministry for Education, Research and Church Affairs.

Kuhn, T.S. (1996): Die Struktur wissenschaftlicher Revolutionen, 13. Auflage. Frankfurt am Main: Suhrkamp.

Kulicke, M.; Zimmermann, A.; Kroll, H.; Bührer, S. (2008): Angewandte Forschung an Fachhochschulen im Verbund mit der Wirtschaft (FH3) : Evaluation des BMBF-Förderprogramms 2004-2006. Bonn: BMBF.

Lucas, R.E. (1988): On the mechanics of economic development. In: Journal of monetary economics, 22, pp. 3-42.

Lundvall, B.-A. (1988): Innovation as an interactive process: from user-producer interaction to the national system of innovation. In: Dosi, G.; Freeman, C.; Nelson, R.; Silverberg, G.; Soete, L. (Eds.): Technical Change and Economic Theory. London: Pinter, pp. 349-369.

Lundvall, B.-A. (Ed.) (1992): National Systems of innovation: towards a theory of innovation and interactive learning. London: Pinter.

Magnusson, L. (2005): The Neo-Schumpeterian and evolutionary approach to econom-ics-an introduction. In: Magnusson, L.; Uppsala University (eds.): Evolutionary and Neo-Schumpeterian Approches to Economics. Boston: Kluwer Academic Publishers, pp. 1-9.

Magnusson, L.; Marklund, G. (2005): Innovations,marketes and Institutions. In: Magnusson, L.; Uppsala University (eds.): Evolutionary and Neo-Schumpeterian Approches to Economics. Boston: Kluwer Academic Publishers, pp. 301-321.

Mokyr, J. (1990): Evolution and the Dynamics of Technological Change. In: The Lever of Riches: Technological Creativity and Economic Progress. New York, Oxford: Oxford University Press, pp. 273-299.

Moors, E.H.M.; Enzing, C.; van der Giessen, A.; Smits, R. (2003): User-producer interactions in functional genomics innovations. In: Innovation: Management, Policy & Practice, 5 (2-3), pp. 120-143.

Nelson, R.R. (1988): Institutions Supporting Technical Change in the United States. In: Dosi, G.; Freeman, C.; Nelson, R.R.; Silverberg, G.; Soete, L. (eds.): Technical Change and Economic Theory. London: Pinter, pp. 312-329.

Nelson, R.R. (1995): Recent Evolutionary Theorizing About Economic Change. In: Journal of economic literature, 33, pp. 48-90.

Nelson, R.R. (2001): The coevolution of technology and institutions as the driver of economic growth. In: Foster, J.; Metcalfe, J.S. (Eds.): Frontiers of Evolutionary Economics. Cheltenham: Edward Elgar Publishing, pp. 19-40.

Nelson, R.R. (Ed.) (1993): National Innovation Systems. Oxford: Oxford University Press.

Nelson, R.R.; Winter, S.G. (1974): Neoclassical vs. evolutionary theories of economic growth: critique and prospectus. In: Journal of economic literature (3), pp. 886-905.

Nelson, R.R.; Winter, S.G. (1982): An Evolutionary Theory of Economic Change, Cambridge: Harvard University Press.

North, D.C. (1990): Institutions and Their Consequences for Economic Performance. In: Cook, K.S.; Levi, M. (eds.): The Limits of Rationality. Chicago, pp. 383-401.

North, D.C. (1992): Institutionen, institutioneller Wandel und Wirtschaftsleistung, Tübingen: Mohr.

Ophem, H.v.; Brouwer, E.; Kleinknecht, A.; Mohnen, P. (2002): The Mutual Relation between Patents and R&D. In: Kleinknecht, A.; Mohnen, P. (Eds.): Innovation and Firm Performance. New York: Palgrave, pp. 56-72.

Parayil, G. (2002): Conceptualizing technological change, Lanham: Rowman & Little-field Publications.

Patel, P.; Pavitt, K. (1994): National innovation systems: Why they are important, and how they might be measured and compared. In: Economics of Innovation and New Technology, 3, pp. 77-95.

Pavitt, K. (1991): What makes basic research economically useful?. In: Research Policy. 20, pp. 109–119.

Pelikan, P. (2004): Interconnecting Evolutionary, Institutional and Cognitive Economics: Six Steps towards Understanding the Six Links - Contribution to the 10th Mee-ting of J.A. Schumpeter International Society.

Pleschak, F.; Sabisch, H. (1996): Innovationsmanagement. Stuttgart: Schäffer-Poeschel.

Rogers, E.M. (2003): Diffusion of Innovation, 5th edition. New York: Free Press.

Romer, P.M. (1986): Increasing Returns and Long Run Growth. In: Journal of Political Economy, 94 (5), pp. 1002-1037.

Romer, P.M. (1990): Endogenous Technological Change. In: Journal of Political Economy, 98 (2), pp. S71-S102.

Ruttan, V.W. (2001): Sources of technical Change: induced Innovation, Evolutionary Theory, and Path Dependence. In: Garud, R.; Karnoe, P. (eds.): Path Dependence and Creation. Mahwah: Lawrence Erlbaum Associates, pp. 91-123.

Saviotti, P.P.; Metcalfe, J.S. (1991): Present Development and trends in Evolutionary Economics. In: Saviotti, P.P.; Metcalfe, J.S. (Eds.): Economic and Technological change. Chur, Switzerland: Harwood Academic Publisher GmbH, pp. 1-31.

Schmoch, U. (2003): Hochschulforschung und Industrieforschung. Perspektiven und Interaktion. Frankfurt: Campus.

Schmoch, U.; Licht, G.; Reinhard, M. (Eds.) (2000): Wissens- und Technologietransfer in Deutschland. Stuttgart: Fraunhofer IRB Verlag.

Shapiro, C.; Varian, H.R. (1999): Information Rules. A Strategic Guide to the Network Economy. Boston, Mass.: Harvard Business School Press.

Shy, O. (2001): The economics of network industries. Cambridge, New York, Melbourne: Cambridge University Press.

Tidd, J. (2006): Innovation Models, Discussion Paper 1/1. London: Imperial College.

Werle, R. (2005): Institutionelle Analyse technischer Innovationen. In: Kölner Zeitschrift für Soziologie und Sozialpsychologie, 57 (2), pp. 308-332.

Annex

Table A1 Fixed Effects Regression Model in the Subsystem Economy - Technology

dV	*Transnational patents per capita (W9)*		*USPTO patent applications per capita (W10)*	
	Coef.	SE	Coef.	SE
Main Effects				
W15	68.610 *	39.040	-394.100 **	193.200
W16	-13.300 ***	3.074	-1.814	1.904
W5	2815.000 ***	686.700	-1463.000	5570.000
W6	-478.200	448.100	13420.000 ***	4691.000
X1	0.619	3.839	-9.097	7.237
L1.W8	0.005	0.004	0.005	0.007
W14	41.850 **	19.850	31.930	137.900
F1	-39.920 ***	12.840	-25.230	21.510
W2	-695.000 **	257.800	-1925.000 ***	400.000
X2	-8.525	10.310	-20.600	18.320
Population	0.000 **	0.000	0.000	0.000
Squared Effects				
X1	-0.113	0.090	-0.145	0.184
F1	2.529 **	1.129	1.433	1.802
W2	3870.000	2460.000	10324.000 ***	3764.000
W16	0.367 ***	0.096		
W15			575.100 **	237.900
W6			-43551.000 ***	13272.000
W14			-57.890	57.190
W5			-9546.000	36310.000
Constant	-236.6	206.8	-209.800	424.000
Obs.	80		80	
Groups	4		4	
R-squared within	0.982		0.95	
F	67.32		19.92	

Significance level: ***p<0.01, **p<0.05, *p<0.1

L1 means that the variable is lagged by one year.

Table A2 Fixed Effects Regression Model in the Subsystem Economy - Innovation/Market

dV	*Trade balance in high-tech goods per capita (W12)*		*Share of value added in high-tech sectors in total value added (W5)*	
	Coef.	SE	Coef.	SE
Main Effects				
W3	-369.400	361.800	-0.035**	0.016
W4	-1460.000	1673.000	0.119***	0.030
W7	645.700**	281.700	0.005*	0.003
X3	2.771	9.866	0.000	0.000
W2	-17006.000**	7707.000	-0.122**	0.056
X4	1201.000	2005.000	0.001	0.002
W6	47562.000***	9875.000	1.874***	0.259
Population	0.000**	0.000	0.000***	0.000
Squared Effects				
X3	-0.065	0.083	0.000	0.000
W2	-8226.000	84958.000	0.709	0.488
X4	-188.700	160.700		
W3			0.003**	0.001
W4			-0.282***	0.053
W6			-4.850***	0.537
Constant	-1635.000	7501.000	0.048	0.060
Obs.	105		84	
Groups	5		4	
R-squared within	0.695		0.971	
F	5.08		47.63	

Significance level: ***p<0.01, **p<0.05, *p<0.1

Table A3 Fixed Effects Regression Model in the Subsystem Public Research

dV	*Number of SCI publications relative to population (F2)*		*Field-specific expected impact rate of SCI-publications (F4)*		*University patents per inhabitant (F5)*	
	Coef.	SE	Coef.	SE	Coef.	SE
Main Effects						
F7	658.900 ***	82.130	0.170	0.157	-0.014	0.064
F6	493.900 **	235.500	3.648 ***	0.451	0.101 ***	0.038
F3	10.020	7.988	0.076 ***	0.015	0.020 ***	0.007
W13	0.044	3.402	0.022 ***	0.007	-0.004 ***	0.001
X5	0.051	2.174	0.000	0.004	-0.001	0.001
Population	0.000 ***	0.000	0.000	0.000	0.000 ***	0.000
Squared Effects						
F7					-0.035	0.042
W13					0.000 ***	0.000
F3					-0.003 ***	0.001
X5					0.000	0.000
Constant	1750.000 ***	267.900	1.674 ***	0.513	-0.120 ***	0.041
Obs.	216		216		212	
Groups	12		12		12	
R-squared within	0.936		0.993		0.655	
F	99.65		935.1		10.77	

Significance level: ***p<0.01, **p<0.05, *p<0.1

Table A4 Fixed Effects Regression Model in the Subsystem Education

dV	*Population with ISCED 6 level education in mathematics, sciences, and engineering (B3)*		*Share of employees with at least secondary level education, without tertiary educations (B2)*		*Share of employees with tertiary education (ISCED5a+6) (B5)*	
	Coef.	SE	Coef.	SE	Coef.	SE
Main Effects						
B6	0.026 ***	0.009	-1127.908	1133.189	1195.794 **	487.644
B7	0.000	0.000	1.005 **	0.503	-0.338	0.216
B8	0.000	0.000	1.187 ***	0.412	0.589 ***	0.177
B9	0.000 **	0.000	0.061	0.037	-0.006	0.016
B1	0.000	0.000	0.423 **	0.169	0.149 **	0.073
Population	0.000	0.000	0.000	0.000	0.000	0.000
Squared Effects						
B8	0.000	0.000	-0.009 *	0.005		
Constant	0.000	0.000	-8.729	22.014	5.854	9.473
Obs.	154		154		154	
Groups	14		14		14	
R-squared within	0.319		0.721		0.503	
F	3.39		20.00		7.86	

Significance level: ***p<0.01, **p<0.05, *p<0.1

Table A5 Overall Fixed Effects Regression Model on the Final Economic Output

dV	GDP per capita (W8)		Value added per hour worked (W11)	
	Coef.	SE	Coef.	SE
W9	7.691 *	4.147	0.004	0.006
W10	0.569	3.918	0.012 **	0.005
W12	-0.859 **	0.352	0.000	0.000
W5	62954.520 ***	19783.780	91.601 ***	27.620
F2	-3.615	3.096	-0.006	0.004
F4	-182.198	550.595	-0.547	0.769
F5	20451.420 **	8846.528	13.752	12.351
B3	-3514294.000	4256618.000	-3456.418	5942.637
X6	18.276	28.436	-0.005	0.040
X7	-1.238	1.705	-0.001	0.002
X8	-1016.691 *	524.250	-1.129	0.732
W2	4464.387	4209.464	-0.507	5.877
S1	637.967 *	328.417	0.523	0.459
X9	700.737	1114.555	3.318 **	1.556
X10	5874509.000	183000000.000	85549.150	255427.500
F7	-3770.844 **	1693.483	-3.376	2.364
W16	99.348 *	57.762	0.130	0.081
X11	-796.732	1000.891	-0.848	1.397
X12	221.745	215.961	0.069	0.302
G1	-88.684	374.508	-1.377 **	0.523
X13	-30718.740 *	17388.300	2.455	24.276
X14	175.856	275.293	0.373	0.384
W1	2564.792 ***	771.889	2.008 *	1.078
X15	7.828	23.813	0.004	0.033
X16	-175.590 ***	49.161	-0.203 ***	0.069
B4	-8.356 **	3.732	-0.002	0.005
X17	12.734	49.116	-0.011	0.069
X18	-12.240	8.429	-0.010	0.012
G2	18.524	11.993	-0.017	0.017
G3	34.216 ***	11.607	0.062 ***	0.016
G4	-13.216	44.436	-0.084	0.062
B2	389.597 ***	106.896	0.433 ***	0.149
B5	0.967	51.791	0.019	0.072
Population	-0.001 ***	0.000	0.000	0.000
Constant	59131.430 ***	12885.460	49.516 ***	17.989
Obs.	121		121	
Groups	9		9	
R-squared within	0.997		0.977	
F	420.3		55.1	

Significance level: ***p<0.01, **p<0.05, *p<0.1

Table A6 List of variables not used as a response variable or dropped due to insignificance in the models

Variable Name	Variable Label
X1	Share of 25-64 year old persons with tertiary education on total population
X2	Average patent forward citation rate (transnational patents)
X3	Total Entrepreneurial Activity Index (Number of adults [18-64 years old] per 100 involved in a nascent firm or young firm or both)
X4	Degree of market dominance (Corporate activity in your country is (1) dominated by a few business groups or (7) spread among many firms)
X5	Share of enterprise financed R&D in public research institutions
X6	Flight departures per inhabitant
X7	Index of railroad line and sealed road kilometers by square kilometer
X8	Evaluation of the financial system (The level of sophistication of financial markets in your country is (1) poor by international standards or (7) excellent by international standards)
X9	Composite Indicator for product-market regulation
X10	Number of ISO convenorships
X11	Index of governance indicators
X12	Perception of corruption index (two years moving average)
X13	Domestic demand for high-tech and medium-to-high-tech products in total domestic demand
X14	Buyers sense of entitlement (Buyers in your country make purchasing decisions (1) based solely on the lowest price or (7) based on a sophisticated analysis of performance attributes)
X15	Attitude towards the formation of an enterprise (two years moving average)
X16	Share of female graduates (ISCED 5a, 5b and 6) on all graduates (25-39 years old)
X17	Share of females (25-39) with tertiary education in science and technology
X18	Preference for self-dependence