Workpackage 4

Summary Report on the Way Forward: Innovative Use of KBE Indicators

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1. Introduction

Many of the possible indicators for a knowledge-based economy (KBE) that could either assist policy development or academic research do not exist or they are inadequate. This report first identifies incomplete, unsatisfactory and missing indicators for each of the five main drivers of a KBE plus the main economic and social outcomes. This is followed by four case studies of possible solutions for missing indicators.

Incomplete indicators are only available for a few target countries or for only one year, making it impossible to evaluate trends over time. Unsatisfactory indicators partly address a characteristic, driver or outcome, but are often proxies for the underlying phenomenon that we would like to measure, or the available data do not cover many important aspects of the phenomenon. Identifying missing indicators can be particularly challenging, as these indicators simply do not exist, although we can imagine how to collect the necessary data.

There are three areas where there is a near total lack of useful indicators: for entrepreneurship and creative destruction, organisational innovation, and for social impacts. In respect to the latter, there are very few indicators on the ways and means of how citizens adapt to the KBE. There are also major gaps in indicators for environmental and sustainable development. Other examples, which are more difficult to define, include indicators for measuring how businesses react to the increasing competitiveness and potential for growth in the KBE, and how citizens are tackling the challenges and exploiting the advantages of living and working in a KBE.

Section 3 below evaluates and suggests possible solutions when there are no available indicators for a key component of a KBE, or when there is a complete lack of satisfactory indicators for an important phenomenon or characteristic of a KBE. The problem of missing indicators is most acute in the areas of human resources, knowledge transfer, and the relationship between innovation and entrepreneurship.

New indicators can be developed by combining existing data in new ways, or from conducting new surveys. The latter are expensive and increase response burdens on firms, so wherever possible we concentrate on the former option. There are also two conceptual solutions to missing indicators. The first is to develop quick, 'back of the envelope' solutions that would require extensive further research to complete. The second is to take a limited number of issues and to develop concrete examples of how to solve the indicator 'gap'. Section 3 concentrates on the second option, and uses in-depth analysis to identify missing indicators and to propose different methods of developing new indicators.

The results of these in-depth studies have influenced projects by the OECD, the European Commission, and Eurostat to develop new indicators for a KBE.

2. Incomplete, unsatisfactory and missing indicators

Policy actions to support a KBE require good empirical data on the drivers, characteristics, and impacts of knowledge activities. Some relevant knowledge activities, such as R&D, are covered by a large number of indicators, although there are still gaps, such as for R&D investments abroad. In contrast, very few indicators are available for other knowledge activities such as organizational innovation.

This section defines incomplete, unsatisfactory and missing indicators and then identifies areas of insufficient indicator coverage for the main characteristics of a KBE, as well as for the main outcomes.

Incomplete indicators are only available for a few target countries or for only one year, making it impossible to evaluate trends over time. Even the more 'successful' indicators, in terms of scope and coverage, are not available for several countries. Examples include indicators such as R&D spending of affiliates as a percent of total BERD, co-patenting by individuals in different countries, and information on the inflow of knowledge workers. Table 1 in Annex A provides an overview of incomplete indicators. No further discussion of them is provided in this report.

Unsatisfactory indicators partly address a characteristic, driver or outcome, but are often proxies for the underlying phenomenon that we would like to measure, or the available data do not cover many important aspects of the phenomenon. There are a number of areas with such indicators related to, for example, the diffusion of productivity-enhancing technologies, demand conditions, commercialization of publicly-funded research, mobility of skilled workers, e-learning, and the industry-science relationship. Table 2 in Annex A identifies key unsatisfactory indicators.

There are probably more areas where indicators are unsatisfactory than there are areas where indicators are entirely missing. However, identifying *missing indicators* can be particularly challenging, as these indicators simply do not exist, although we can imagine how to collect the necessary data. There are three areas where there is a near total lack of useful indicators: for entrepreneurship and creative destruction, organisational innovation (although rapid improvements have been made in this area in the past few years), and for social impacts. In respect to the latter, there are very few indicators for how citizens adapt to the KBE. There are also major gaps in indicators for environmental and sustainable development. Other examples, which are more difficult to define, include indicators for measuring how businesses react to the increasing competitiveness and potential for growth in the KBE, and how citizens are tackling the challenges and exploiting the advantages of living and working in a KBE. The state-of-the-art regarding missing indicators relates to evaluating proxy indicators and proposals for collecting new indicators. Table 3 in Annex A provides an overview of key missing indicators.

The following sections describe the main issues with indicator availability for each of the main drivers of a KBE.

2.1 Production and diffusion of ICTs

ICTs play a crucial role in regional and national economic and social well-being in the KBE. European policy needs timely and qualitative indicators on the factors of production and diffusion of ICTs to ensure Europe's competitiveness and growth.

Part of the problem is that we are trying to identify indicator needs in an area where agreement has yet to be reached on definitions. For example, IT workers can be defined by either qualification, by occupation or by firm (sector). Different definitions lead to different conclusions about this workforce. A RAND Europe (2005) report illustrates this issue further. According to the study, the share of IT and ICT practitioners that acquired their skills through higher education within the field of computing is low. Also, 58% of IT practitioners and 77% of ICT practitioners are employed outside of the core IT industry sector.

The lack of composite indicators on IT and ICT employment and employees undermines the development of useful supply and demand scenarios for policy. From meeting firms' labour needs for domestic supply, to putting immigration policy in place to facilitate mobility of ICT workers, to the education system priorities to respond to supply demands, the need for indicator development in this area is clear. Given the problem with linking ICT workers and ICT occupations and labour markets, supply-demand analysis may prove to be a liability for policy makers.

2.2 Human resources, skills and creativity

Human resources indicators cover people who create, diffuse and apply knowledge. Human resource indicators are of central importance to economic and social and health policy and for the public and private sector policy planners and decision makers alike. Skills and knowledge are central to innovation and economic growth. Skills and life-long learning are important for all citizens in the KBE.

We need indicators on the stock and flow of people who create and apply knowledge, including R&D performers, but also the rest of the 'team', from the undergraduate engineer to the technical assistant. However, there are substantial problems of comparability across countries due to differences in definitions.

We also need indicators on the ability of society to adopt and adapt to new technologies and organizational systems.

Statistical systems are based on developing national data to meet gaps in indicator needs, either for overcoming problems with unsatisfactory coverage or missing indicators. However, non-national data can sometimes be used to provide new indicators of relevance to policy. For example, the numbers of scientists and engineers lost to a country through emigration are often best examined according to the receptor country immigration files.

General education indicators

Education indicators will continue to be important for policy. Policy needs data on the domestic supply of talent for the economy, but also on the 'educational health' of its population at large. Policy needs to know if students continue to shy away from the fields of expertise that will help them grow and benefit in the KBE and of changes in attitudes towards science and engineering education and how this differs for men and women. EU policy needs to know where weakness in Europe's education pipeline may develop in order to put in place measures to address them. Literacy and math scores vary across Europe just as the attraction of science and technology courses for students varies.

There are a range of indicators available on 'traditional' education pipelines (e.g. ISCED). There is also information on foreign students, but comparable indicators on characteristics of those who earn degrees are sketchy for the EU-25. Furthermore, there are practically no EU-25 indicators on less 'traditional' aspects of education and innovation systems. For example, vocational, on-the-job training, and life long learning indicators are weak. Historically, training indicators have been difficult to develop because of issues of definition and 'interpretation' of training on the part of firms. Training is, however, becoming increasingly crucial for the KBE, and therefore important to measure. We also need indicators of trends in non-traditional learning such as might be measured by professional certification and private sector e-learning, as well as indicators that discriminate from 'business as usual' training to creativity and innovation motivated learning.[2]

Creativity indicators

The focus here is on our skilled human capital, such as researchers and skilled workers with high levels of expertise. Despite the recognition of the importance of human capital to economic and social growth and well being in the KBE, creativity indicators remain some of the least developed. A harsh review might suggest that there has been little done to measure human capital and skilled workers beyond the traditional educational rankings (e.g. level of education) at the EU level. Economists continue to focus on 'highly-skilled' jobs without even considering the role of the 'mix' of skills required in specific sectors or occupations. Indicator development continues to be driven by the traditional low-medium-high skill measures promoted by organizations such as the OECD and followed by the EU for many years. Very few indicators have been developed that consider the role of human beings and their skills for the challenges of European MNEs operating in a global market.[3]

Mobility indicators

The mobility of scientists and engineers – between firms, countries and between firms and the public research sector – is commonly believed to diffuse knowledge and consequently support innovative capabilities, but indicator development remains weak. There are two dimensions to the policy interest in mobility. There are policies to promote mobility where the situation is seen as win-win, benefiting all parties. Examples include programmes to encourage mobility within Europe and hence knowledge exchange, or programmes to facilitate public sector and private sector, or government-university exchanges, to encourage knowledge diffusion. Then there is mobility that benefits one party but may cost the other party(s). Flows from public research to private research due to lack of R&D support may undermine public research needs. A key policy interest concerns skilled researchers moving abroad (e.g. outside of ERA) to carry out their research and the apparent lack of attraction ERA has for highly skilled foreign researchers. Much of the indicators are based on anecdotal evidence and ad hoc surveys. Mobility indicators are critical for R&D policy needs from education to immigration to R&D investment.

Inter-occupation

There are indicators from surveys like the LFS on general occupation shifts, often including information on level of education, broad field of specialization, age and gender. However, there are no EU-wide occupation indicators on the types of skills within occupations or how this has been changing over time. There are also difficulties with international comparability because different countries apply different edits on their occupation categorization. For example, the occupation of engineer may include a variety of fields and a variety of skill

[2] Perhaps one of the reasons Americans are so successful is that they have been quick to recognize the essential role of education and systemic weaknesses. For example, their policies are 'friendly' to the import of foreign students. The U.S. has extensive indicators on education and R&D and continues to improve its S&T taxonomy and indicator development.

[3] That is not to say there are no lights on the horizon. For example, the OECD and Eurostat are developing a survey to follow the careers of skilled workers, although again they focus on the small percentile – the PhD graduates. There is no argument that PhD-qualified researchers are critical for innovation, technology and science for economic, health and social life, but indicators on all levels of trained workers are badly needed.

levels. The traditional practice is to group occupations according to high, medium and low skilled, which is rather tenuous when sector variation is considered.[4]

In the KBE, the skills 'mix' and adaptability of knowledge workers is critical. Arnal et al. (2001) speak of the new approach to production processes as needing to be 'lean' and more responsive to market changes. Today, researchers can be expected to bring together a research team, carry out research, train members of the research team and also have financial and management responsibilities. Occupation indicators, beyond the more traditional indicators grouped around high, medium and low skilled occupations, are extremely limited and available for only a limited number of EU member countries.

Inter-sector

Mobility between firms and sectors is a method of knowledge diffusion. There are EU level data on job-to-job mobility, including mobility of persons employed in science and technology, but few characteristics about the persons are known and indicators for factors of mobility are basically non-existent.[5] Indicators that consider the impact of 'human' knowledge flows between public sector research and private firms are not available for most EU countries. Another area where we lack indicators is on the timing, duration and impact of the physical movement of skilled workers.[6]

International

Mobility is stressed by the Aho report, which sets a target for 10% of scientists and engineers moving in each year. Yet mobility can have a negative impact: highly skilled people can leave a country, or too much mobility could be economically inefficient.

There are some indicators available at the EU level, but they are limited to students. There are no data to develop indicators according to the area of specialization of training of the students. For the EU, there is little information on where students go after graduation. Indicators for all tertiary foreign students include data on the country of origin, but the disadvantage of such data is that 1) they refer to all tertiary or all PhD students, rather than specifically to S&E students, and 2) there is no information on whether or not the students remain in the country after graduation.[7] One study (see MERIT, Brain Drain Study 2003) suggests students tend to stay and work in the country where they obtained their PhD, or that they are less likely to return to their native country after studying abroad. Factors of international mobility also seem to be different for Europeans when compared with their American or Asian colleagues.

We have limited indicators on general international mobility of workers, although we know that a mere 1.5% of EU-25 citizens live and work in a country other than their own. Indicators on characteristics and factors of international mobility are scarce. Those that are

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[4] For example, occupations in management in one R&D sector may have a rather different human resources profile in another. One may even find that in one sector it is considered medium skill level and in another high skill level; international differences exacerbate the situation.

[5] For example, salaries could be used for composite indicators, but salary is not necessarily the primary factor for the mobility of scientists and engineers.

[6] A Danish study suggests that employment growth in firms with industry-science relations (ISR) is higher than in firms with no ISR interactions — a 2003 survey by the Danish Centre for Research and Research Policy shows that growth in employment was more than double for those with ISR interactions compared with those for no ISR interactions (figures compared 2000-2002 employment averages to 1999).

[7] US policy makers can rely upon indicators of the National Science Foundation that not only tell of the post-graduate plans of their PhD science and engineering graduates including the sector they plan to work in, but they also have these indicators for Europeans who earn their PhD in the United States.

available are typically from ad hoc surveys in some of the largest member states, which have a vested interest in tracking their scientists and engineers.[8]

Another dimension to the discussion of international mobility is that researchers need to explore opportunities to acquire skills and experience in their most productive years of their career. At the same time, Europe could profit from its researchers abroad by having ongoing relationships and creating networks of access and knowledge exchange. We can find no indicators for the EU (except for ad hoc or special surveys) on the factors that drive or attract European talent abroad, or the factors that might influence foreign talent to come to work in Europe. This is critical information for a range of policy, from R&D to immigration.

2.3 Knowledge production and diffusion

Knowledge production is a key focus of science and technology policy. Relevant policies include support for the public research infrastructure, including the training of students at all levels up to doctorates, subsidies for R&D conducted by firms, and institutional programmes for intellectual property protection, such as the patent, design, and copyright systems. The diffusion of knowledge (in contrast to the diffusion of innovations) is supported by public programmes to encourage the commercialization of public sector research, including funding of technology transfer offices (TTOs) at universities and government research institutes, changes to legislation to encourage the patenting of publicly-funded inventions, and a variety of policies to encourage knowledge sharing among firms.

R&D, patents and bibliometrics

This family of indicators has been under development for several decades, and consequently, there are only a few areas where the indicators are unsatisfactory, mainly concerning R&D.[9]

Indicators for public sector expenditures by field are insufficient, with current data based on dividing GBAORD data (Gross budget appropriations or outlays for R&D) among major NAB categories (Nomenclature for the analysis of science budgets). These categories are not detailed enough to permit an estimate of the amount of public R&D expenditures for key generic technologies such as ICT or biotechnology. Furthermore, comparability in how governments classify outlays for health R&D is required.[10] A related problem also applies to the data for business sector R&D (BERD).[11]

Another problem for international comparisons is the quality of data for R&D in the business services sector. Many service firms, e.g. in NACE 73 (R&D services) or even in wholesale and retail trade, perform R&D, but the purpose of the R&D is to develop new and improved manufactured products. In some countries the R&D surveys collect data on the purpose of the service sector R&D and assign R&D conducted under NACE 73 on pharmaceuticals, for instance, to the pharmaceutical manufacturing sector. Other countries, including the US, assign all R&D to a firm's principal economic activity, which is determined by the sector of the largest share of employees. Using this definition, a major computer manufacturer can be assigned to wholesale services if it has more employees in wholesale than in manufacturing. These differences partly explain why the US appears to perform much more service sector R&D than many EU countries. Business sector data on R&D would be both more accurate

[8] For example, a study in France suggests researchers are leaving because of an absence of adequate opportunities in France.
[9] For a more extensive discussion of R&D indicator improvements, see Arundel et al., 2006a.
[10] Young (2001) notes that many countries assign health R&D to different NAB categories, rendering international comparisons meaningless.
[11] For example, comparable data for biotechnology are not yet widely available. However, the situation is improving, with 14 OECD countries including a question on biotech R&D expenditures in their official R&D survey.

and more comparable if all countries used the product-based approach instead of the principal activity approach. Other methods of disaggregating R&D data by region or firm size would also assist policies, such as those supporting regional clusters or SMEs.

The third problem with R&D data is that it does not adequately cover the continuous globalisation of R&D. R&D statistics are currently based on national jurisdictions, whereas large multinational firms can conduct a substantial share of their R&D in other countries. For the firm, its global R&D expenditures are more relevant, in terms of its R&D intensity or innovative success, than its domestic R&D expenditures alone.

Patent data have several well-known limitations: not all innovations are patented, many patents have no economic value, and the number of patents per innovation is highly variable. The first two problems can partly be overcome by using 'triadic' patents, or patents for the same invention that are applied for or granted in the world's three major patent jurisdictions, the European Patent Office, the US Patent and Trademark Office, and the Japanese Patent Office. Unfortunately, triadic patent data has a lag time of four to five years before it is available. For instance, the most recent triadic patent data in late 2005 was for 2001.

Knowledge flows

Indicators for knowledge flows are a fairly new area. Most indicators to date are based on the EU's Community Innovation Survey (CIS) and cover links with public research institutes and collaboration. A problem with many of these indicators is that they provide no information on the type of knowledge that is obtained, or on its purpose.[12]

A key requirement is an indicator on the role of knowledge diffusion in the development of innovations. For instance, firms can develop an innovation entirely within house or in collaboration with other firms or with public research institutions. Constructing such an indicator within the CIS could provide a measure of the share of firms that rely on the diffusion of knowledge for their innovations.

Indicators for knowledge flows between firms and the public research sector can be constructed using co-patenting, co-publishing, or the CIS data. However, these indicators measure only formal knowledge exchange. They completely fail to capture the role of 'public science', such as open publication and dissemination of knowledge by university academics.

Knowledge flows from the public to the private sector can also occur through spin-offs and licensing. We are not aware of any internationally comparable data for these two methods at the EU level. The OECD ran a pilot survey in 2001 to gather such data, but there was no follow-up and only eight EU countries participated in this study (OECD, 2003). Since 2006, the Association of Science and Technology Professionals (ASTP) has been running a survey of its members to replicate data obtained on a regular basis for the United States.[13]

2.4 Entrepreneurship and creative destruction

Innovation is widely believed to be central to European competitiveness. Many pro-innovation policies are based on subsidizing knowledge production, either directly or through fiscal benefits for R&D, but innovation is also supported through promoting the adoption of productivity enhancing technologies or ICT, other information services, and subsidies to SMEs for hiring scientists and engineers or acquiring new technology. A few countries also

[12] This could be particularly important when firms are part of a value-added chain. Their innovation strategies can be determined by the requirements of their suppliers or customers.
[13] The survey results show that it is feasible to obtain data on spin-offs at a relatively low cost, and for example, an indicator of the number of spin-offs and licenses per million Euros of R&D expenditures can be calculated. However, the ASTP membership does not include the majority of European universities and research institutes.

provide government support for innovative start-ups, such as venture capital. Entrepreneurship is difficult to support, but it might be included in the future as a course topic at the university level, together with patenting, for science and engineering students. Entrepreneurship is also supported directly through government provision of grants, loans and early-stage financing to small innovative firms and indirectly through tax relief to investors in venture capital firms.

Technical innovation

Indicators for innovation expenditures, the sales share of innovative products, and the share of firms that innovate are available from the CIS. The main problem is that there is a need for disaggregated indicators on how firms aggregate. In addition to in-house innovation, firms can also innovate through the uptake and successful adoption of new technology by developed by other firms or the public sector (embodied technology diffusion). Currently, an indicator for 'adoptive' innovators is not available, but it would be simple to construct from CIS data. We also lack an indicator on the effects of process innovation, e.g. in terms of cost savings.[14]

Entrepreneurship

Entrepreneurship, possibly one of the most important drivers of innovation and one of the most difficult to measure, involves individual attitudes to risk, opportunities that reduce risk, receptiveness to new ideas, and access to capital. Most indicators of entrepreneurship measure individual attitudes on risk or self-employment.[15] There are virtually no indicators for entrepreneurship within existing firms, such as the rate of formation of new spin-off firms or the rate of introduction of new products.

In addition to the role of entrepreneurship in establishing firms, the policy goal is for these firms to succeed and grow rapidly. While the CIS is a possible source of data that can identify innovative fast-growing firms, the difficulty is to define 'highly innovative SMEs'. Indicators are still limited to fast-growing SMEs with very high R&D intensities, and there are no indicators for different types of fast growing innovative firms such as those that score high on the efficient adoption of new technology.[16]

Venture capitalists and TTOs at universities and research institutes complain that the problem in Europe is not a lack of ideas for innovative new firms, but a lack of experienced managers who can guide the development of an invention through to commercialisation. We are not aware of any indicators covering the availability or quality of such managers.

Entrepreneurship depends not only on the ability to establish new firms, but on the replacement of older less efficient firms, i.e. a process called creative destruction, or 'churn'. This process assists productivity growth and increases value-added from product innovation Blanchard (2004). Firm exit is often dependent on the regulatory environment, which can reduce churn and thereby discourage entrepreneurs from entering a market. Currently, the necessary data to calculate churn are only available for a limited number of EU countries.

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[14] Germany has included a relevant question in its version of the CIS (Aschhoff et al, 2006), but similar questions have not been adopted in other EU countries.

[15] The indicators of individual attitudes to entrepreneurship do not differentiate between establishing a 'mom and pop' shop and establishing a firm with an innovative business strategy.

[16] These missing indicators are crucial because depending on national conditions, the fastest growing SMEs may not be R&D intensive, but technology adopters, or possibly firms that rely heavily of knowledge diffusion over in-house creative activities.

Demand for innovative products

The risk of innovation and the willingness of established firms to invest in innovation or entrepreneurs to set up a new innovative firm, crucially depends on the expected market demand for innovative products. Nevertheless, there are few relevant indicators for demand, even though demand can be influenced by both regulatory policy and by public procurement.

A substantive body of literature, starting with Porter in the early 1990s, argues that sophisticated domestic demand for innovative products is an essential driver of innovation.[17] Where domestic demand is inadequate, firms can also develop international markets. The problem for Europe might lie more in encouraging innovative firms to enter global markets than a lack of domestic demand. Conversely, local demand conditions could be essential to firms that do not innovate. This gap in innovation demand indicators must be addressed.

Government procurement policies have a potentially important role in encouraging innovation. However, there are no indicators for governmental demand for innovation, which could be particularly important for countries that are not at the leading edge of consumer innovation demand. We have no measures of how government is setting the example (e.g. as in the case of ICT adoption for some countries) or not, and how government adoption compares with national demand.

A potential aggregate measure of demand by businesses is gross fixed capital formation (GFCF).[18] The value of GFCF as a measure of demand depends on the reasonable assumption that almost all new capital equipment will contain technical improvements over existing stock. The disadvantage of GFCF is that it includes expenditures that are not related to innovation, particularly land and buildings. It would be much more useful to have an indicator for GFCF that is limited to capital equipment.

2.5 Organisational innovation

Organisational innovation can be a key factor in both productivity growth (Brynjolfsson and Hitt, 2000; Murphy, 2002) and the ability of firms to profit from product and process innovation. Research on the KBE shows that work reorganisation is important at today's workplaces. So far, it has been difficult to find timely and comparable indicators on new work practices. Surveys tend to be carried out on an ad hoc basis and at national levels. A 1996 survey of European managers in ten EU countries found that workplaces with direct participation in management outperformed (also in terms of innovation) those without direct employee participation in management. Due to its potential impact on firm performance and employment, we need indicators on the level of responsibility given to employees.[19]

Up until the fourth CIS, referring to the activities of firms between 2002 and 2004, there were very few internationally comparable indicators for organizational innovation. CIS-4 provides new options for constructing indicators on organisational innovation on 1) knowledge management, 2) organization of work, and 3) relationships with other firms or public institutions. CIS-4 also asks about four types of outputs of organisational innovation, so it is possible to determine which of the three types of organisational innovation have the greatest impacts on quality or production costs. The main limitation for CIS indicators on organisational innovation is the lack of time series.

[17] This theme was most recently restated in the Aho Report.
[18] GFCF is defined as the acquisitions less disposals of buildings, structures, machinery and equipment, mineral exploration, computer software, literary or artistic originals and major improvements to land such as the clearance of forests.
[19] An intriguing possibility is that low responsibility could also be responsible for possible European weaknesses in commercialization and mobility.

The CIS indicators for organizational innovation have been updated since CIS-4. The next CIS, to be implemented in 2009 and covering firm activities between 2006 and 2008 inclusive, will include questions on three types of organizational innovation (business practices, work responsibilities, and external relations) and five objectives of organizational innovation.

Although the CIS will provide useful data for benchmarking organizational innovation, the questions, due to space constraints, lack depth. For instance, the question on workplace responsibilities can identify a change but they do not identify whether or not the firm increased or reduced worker responsibility. Work on developing a focused questionnaire survey on organizational innovation is underway as part of the European Commission's MEADOW project.

2.6 Economic and social outputs

Available economic indicators include national production (GDP), productivity, and employment, plus value-added and productivity indicators at the sector level. All are generally acceptable for measuring the output of a KBE.

There is also a wide range of available indicators for social performance, including environmental indicators, employment and welfare, and quality of life indicators. The most serious problem concerns the latter. The available quality of life indicators measure aspects such as life expectancy, accidents, or living conditions that do not get to the heart of social satisfaction. One option is to use indicators for happiness, which are available for many countries, both within Europe and abroad from the World Values Surveys.[20] An alternative approach is to improve the usefulness of monetary measures such as GDP as a measure of well-being. The OECD (2006) recently evaluated several alternative versions of GDP that seek to overcome several of the limitations of the indicator: the current definition of GDP assigns leisure a zero value, does not accurately measure income available to household consumption, makes no allowance for income distribution, and does not consider negative externalities.[21]

Environmental innovation

Although there are many indicators for environmental impacts (CO2 production, air pollutants, etc), there are very few indicators for environmental innovation. Patent data are difficult to use for this purpose because environmental innovations are very difficult to identify, requiring pain-staking analysis. The primary requirement is for indicators on the effect of environmental innovation on production costs.

The KBE and the citizen

There are very few indicators that measure the direct effect of the concept of the KBE on individual citizens. One example is the effect of tele-working, which has several relevant socio-economic dimensions, including human resources, ICTs and the environment. There are, however, few official indicators on tele-working. Research on the topic tends to be at the national level, and/or on an ad hoc basis, and the definitions vary. Indicators on tele-working

[20] However, economic research is still resistant to using such indicators, although an economics course on happiness is accordingly one of the most popular courses on offer at Harvard.

[21] Possible adjustments to GDP include its replacement with Gross National Income (GNI), which measures actual domestic income (this change has a significant negative effect for Luxembourg and Ireland and positive effect for Switzerland), weighting methods to adjust for income inequality, or an adjustment that assigns a monetary value to leisure time.

should assess the benefits and costs to citizens and firms, also for reasons beyond productivity and workplace change.[22]

2.7 Other challenges – Public sector innovation and globalisation

Governments are a major purchaser of innovations and a major provider of services that can benefit from adopting technological or organizational innovations. However, there are almost no comparable indicators for innovation in the public sector, with the exception of indicators for the e-economy, such as the provision of public services on-line. As almost all public sector organizations are large, there are enormous opportunities for productivity gains through organisational innovation and technology adoption. We would also benefit from indicators of the benefits of innovation in the public sector. To what extent have on-line services (e.g. filing tax forms) actually made life easier for citizens at large? Does public ICT innovation mean that a service office in a rural community is lost resulting in loss of jobs, or does the on-line library service perhaps mean access and education where before there was none?

Innovation activities are increasingly global as firms perform more of their innovation activities in foreign countries. Existing indicators such as R&D spending of affiliates as a percent of total BERD, the percentage of total business R&D funded from abroad, co-patenting by individuals in different countries and co-authorship share for international scientific articles are still generally limited to the EU-15. Moreover, these indicators share a common problem: the degree of internationalisation is correlated to the size of the domestic economy. Small countries have higher levels of co-patenting and co-authorship than large countries because there are fewer opportunities to find a co-author or co-inventor in the domestic market. So while there are some indicators for globalisation, they are weak and additional sources for indicators need to be developed.

[22] For example, does tele-working present wider job opportunities or is it evolving into a practice used by firms to outsource repetitive functions and limit the employee's advancement and skills' upgrading? Does tele-working represent a positive development for families allowing for more flexibility, or does tele-working mean office work is now officially brought home and the line between work and family life is increasingly blurred?

3. Solutions for missing indicators[23]

As noted in Section 2, many indicators of relevance to measuring and understanding the knowledge economy are simply unavailable. The problem is most acute in the areas of human resources, knowledge transfer and the relationship between innovation and entrepreneurship.[24]

New indicators can be developed by combining existing data in new ways, from reanalyzing existing data, or from conducting new surveys. The latter are expensive and increase response burdens to the managers of firms. This section provides examples of each of these three methods, although there is overlap between them. Four in-depth studies were conducted for this project. Table 1 lists the studies and the methods used.

Table 1. Project studies addressing missing indicators

KBE topic	Authors	Method
1. Human resources	Hansen et al, 2006	Combining data
2. Knowledge production & diffusion	Arundel & Bordoy, 2006	New survey
3. Organisational innovation	Arundel et al, 2007	Combining data; reanalyzing existing data
4. Innovation & entrepreneurship	Arundel, 2007	Reanalysing existing data

3.1 Human resources

The relevant study by Hansen et al (2006) evaluated the link between human resources and performance, as well as implications for indicator development.

Slow growth of high- and medium-high technology industries has been associated with weak science and technology linkages that can be explained, in part, by a lack of a strong scientific base.[25] Industries are operating in a knowledge economy, an economy in which one of the main challenges for measurement and indicator development is to consider knowledge capital and develop linkages to the more traditional science and technology indicators.

Although indicators of scientific performance include some measures of human capital (e.g. degree in S&T, labour force level of educational attainment, R&D personnel (FTEs and headcount), S&T occupation, etc.), measures of scientific and technical performance continue to focus on a core group of indicators, and within this group R&D expenditures and R&D intensity are key. Indicators on human capital are analyzed but they are not linked to other indicators that are used to analyze scientific performance.

In the study that is the basis for this sub-section (Hansen et al., 2006), links between R&D expenditures and other S&T indicators and human capital are examined. The successful 'linking' of scientific performance to science disciplines will provide the possibility to link to

[23] Section 3 is based on papers presented to the international Blue Sky II conference in Ottawa, September 25-27, 2006: "What indicator for Science, Technology and Innovation Policies in the 21st Century?".
[24] Other lacking indicators are related to economic and social outputs: environmental innovation, public sector innovation and globalization. These are not, however, covered in this section.
[25] From the Terms of Reference for *S&T Linkage Indicators*, European Commission, 2004.

other S&T indicators such as R&D expenditures and human capital indicators such as the flows of graduates and the mobility of researchers.[26]

High- and medium-high technology (HMHT) intensive manufacturing industries are important contributors to economic growth. In the EU high technology (HT) intensive manufacturing industries, HRST accounted for 52% of total employment in 2005; in the medium technology (MT) intensive manufacturing industries, HRST accounted for 39% of total employment.[27] For each of the EU countries, HT intensive manufacturing industries have the highest concentration of researchers as measured by share of R&D personnel.

Does education contribute to HT technological performance? The link between R&D expenditures and PhDs in S&T and productivity were analysed by Hansen et al. (2006). According to the results, it appears that although money certainly matters, people really matter when it comes to HT technological performance. Although the correlation between R&D expenditures and HT productivity is not necessarily low, the correlation between education (PhDs in S&T) and HT productivity is significant.

Does educational strength (as measured by PhDs in S&T) contribute to HT technological performance? Although clearly technological performance hinges on the combination of money (R&D expenditures) and people, people are important and not to be excluded from measurement of HMHT performance. Results from Hansen et al. (2006) suggest a distinctive and considerable impact of educational strength on technological performance.

Does educational strength (as measured by PhDs in S&E) contribute to technological performance in general? In Hansen et al. (2006) analysis was carried out on HT, MHT, MLT and LT industries for seven countries over six time periods. The findings suggest a positive relationship between PhDs and technological output, and this is not limited to HT industries — this applies across all industries.

The results of this preliminary exploration of the scientific base of HMHT manufacturing industries show that existing data and indicators can be used to develop new indicators for human capital and scientific and technological performance. The results also suggest that more attention needs to be paid to human capital and education for performance and R&D expenditures and other performance indicators need to expand scope to consider human capital and education indicators. The high correlations found between human capital, in this case limited to PhDs awarded in S&E, and technological performance as measured by patents, suggest a need to expand indicators to consider the link to human capital and scientific and technological performance. Box 1 captures the main results from the study.

[26] Concordance tables to link scientific and technology fields and industries developed by INCENTIM, CWTS, OECD, and EC, have been used.
[27] Eurostat, *Statistics in Focus*, 13/2006.

Box 1. Preliminary results of the study by Hansen et al., 2006:

- The focus on 'money' is too narrow. Money matters but human capital matters and perhaps more in some cases. The early results of this work show significant correlations suggesting human capital contribute to technological performance (as one might expect) BUT variations in PhD strength seems to be more important than variations in R&D expenditures. Moreover, testing on other industries (MLT and LT) produce similar results.
- It may not be appropriate for policy to continue to focus on researchers and S&T workers in terms of the more traditional supply/demand models; there needs to be a focus turned to the role of human capital with regards to the scientific base of industries and the relationship to scientific and technological performance. There needs to be efforts to bring human capital into mainstream measures of performance.
- The time frame to improve scientific and technological performance may be longer than anticipated. Although money is a factor (e.g. increasing R&D investment), human capital is linked to productivity. This means investing in education and waiting three to four years after the PhDs graduate to see measurable impact on technological productivity.
- Policy needs to support measurement and indicator development on human capital for integration with other innovation and economic performance measures.

3.2 Knowledge creation and diffusion

The relevant study by Arundel and Bordoy (2006) evaluated possible indicators for the transfer of knowledge from public research sector organisations (PROs) (universities and research organisations) to the private sector, and discussed some of the issues involved. The study proposes both conducting new surveys in EU member states where no data are collected on the knowledge transfer activities of PROs and improving the comparability of results where such studies are conducted, as in the UK and Denmark.

Indicators from a survey of Knowledge Transfer Offices

Six indicators can be obtained from surveys of KTOs such as the ASTP, Proton, and UK (HEFCE and UNICO) surveys. Three are leading indicators and three are indicators of the uptake of public sector knowledge by the private sector (see Table 2).

Table 2. KTO indicators

Leading indicators	Uptake or use indicators
Invention disclosures	Licenses executed
Priority patent applications	Start-ups established
Patent grants (technically unique)	License revenue earned

The KTO indicators require a comparable denominator. This can be either per 1000 research staff or per million Euros or US dollars, in purchasing power equivalents, for R&D. Further work is needed to determine which is the better choice, and if there are other public data sources (as in the Netherlands) for either research staff or research expenditures. There are two additional issues. First, should all research expenditures be included, or only expenditures in science and computing? Second, research activities can occur several years before a patent application is made or a license executed. Should the denominator average research expenditure over a longer time period, such as the preceding three years?

The leading indicators are measures of future possible uptake of public sector knowledge, while the uptake indicators measure current use. A license will not be executed unless a firm plans to use or further develop the knowledge. License revenue is a proxy for the expected value of the knowledge to firms.

A seventh possible indicator is the number of research collaborations, but we are concerned that this might be more unreliable. The KTO may be unaware of a large number of informal agreements.

High quality, representative KTO indicators could be obtained from a survey of approximately 1500 European universities and research institutes. Compared to the size of Innobarometer (approximately 4,500 firms) or to the Community Innovation Survey (over 100,000 firms), this would be a comparatively small, inexpensive, and manageable survey.

The major need here is for better data on the success of start-ups, since it is not the number that of start-ups that is important over the medium to long term but the ability of start-ups to grow and earn revenues, or be taken over by larger established firms.

Secondary KTO indicators

From a policy perspective, the knowledge produced by publicly funded institutions should benefit the domestic economy and it should be efficient. Three additional indicators are relevant here, as shown in Table 3.

Table 3. Secondary KTO indicators

Indicator	Function
Percent of licenses to firms located within the country	Measure of national benefit
Percent of patent portfolio that has ever been licensed	Efficiency
Percent of licenses on an exclusive basis	Efficiency & public interest

The first indicator measures national benefit. The criteria should not be based on ownership of the licensee but on location. A license to a domestic subsidiary of an international firm will still provide benefits to the national economy.

The first efficiency indicator measures the efficiency of the KTO to only patent inventions with commercial potential. As patenting is expensive, particularly in Europe, high licensing rates are desirable. It will take time for a KTO to build up sufficient experience with both licensing and patenting, so this indicator needs to be tracked over time.

The second efficiency indicator measures the usefulness of IP to encourage firms to develop knowledge produced by public research. The main argument for patenting and other forms of IP protection is that firms will not invest in developing an invention produced by the public research sector unless they have an exclusive right to the knowledge. Knowledge or university inventions than can be licensed on a non-exclusive basis, for instance to multiple firms, do not need to be protected by IP. In fact, IP protection (assuming no infringement) could delay or inhibit the commercial application of this knowledge. This knowledge could have been more efficiently disseminated through open publication. The only justification for non exclusive licenses is to earn income for public sector institutes. Whether or not this is a suitable reason will depend on national goals for knowledge transfer, but most public research organisations can only fund a few percent or less of total research expenditures from licensing income. The possible gain in income could be less than the public benefit from open dissemination of the knowledge.

Indicators from other sources

KTO indicators, by themselves, can give a misleading picture to policy analysts of knowledge transfer from the public research sector to firms. They cannot capture the full range of such knowledge flows, which include firms learning about the outputs of the public research sector from reading the scientific literature, talking to public research staff at conferences, or from a range of informal meetings and discussions. Using KTO indicators alone, particularly the leading indicators, can send the wrong signals to public research institutes to simply produce more patents and invention disclosures.

Alternative indicators can be constructed from the CIS or from including questions in one-off surveys such as Innobarometer. Three possible indicators are included in Table 4.

Table 4. Indicators of informal knowledge transfer

Indicator	Source
Percent of firms that give a 'moderate' or 'high' importance to public research (universities or research institutions) as a source of knowledge for innovation	CIS
Percent of firms that report collaborating with domestic universities or research institutions for innovation	CIS
Percent of firms that use 'open science' methods (reading publications, informal contacts, attending academic conferences, personnel exchanges) to obtain knowledge from universities or research institutions	One off surveys

The indicators of informal knowledge transfer can be disaggregated by firm size and sector of activity. For example, it will be useful for policy to know the types of firms that most benefit from public science.

Composite indicators

If a composite indicator for public research to private sector knowledge transfer is constructed, the weight for each indicator should be lower for the leading indicators than for the uptake indicators. Informal knowledge transfer indicators should count for a minimum of 33% of the total weight of the composite indicator and leading indicators for no more than 25%.

3.3 Innovation and entrepreneurship

This section looks at some new ways of combining existing CIS indicators on how firms innovate to achieve more policy relevant innovation indicators.

R&D and patents are excellent indicators of firm investment in developing innovations in-house through creative activities, particularly in manufacturing, but they are insufficient for capturing innovation as a process of diffusion, the development of distributed knowledge bases that are an essential feature of the knowledge economy (Smith, 2002; 2005), the continual increase in the economic importance of the service sectors, and many informal innovative activities. The latter could be particularly important as over two-thirds of scientists and engineers in the private sector are not employed as researchers (Bell, 2006).

However, the results of a series of in-depth interviews by UNU-MERIT with European policy analysts and a review of major European white papers on innovation shows that the European policy community still relies on long-established indicators for R&D and patents.[28] The CIS collects data that could be used to fill some of the gaps in our knowledge of innovation, but unfortunately the CIS has not been fully exploited for this purpose. The main cause is a continued focus on a science-push or linear model of innovation, which has resulted in a lack of demand on the part of policy makers for a wider range of CIS indicators, and a lack of supply from academics and national statistical offices of them.

According to the interviews by UNU-MERIT, the main types of new indicators that the interviewees would like to have concern the process of commercialization and collaborative activities involving innovation. Although innovation through the diffusion of technology and related skills is still currently of marginal interest to the policy community, increased interest in the role of demand in innovation could lead to greater interest in diffusion indicators. A gradual shift in Europe from supply-side support for the creation of new ideas to a concerted effort to ensure that these ideas find their way to firms that can apply them to their new products, processes and services can be seen.[29] This is also reflected in the interviews mentioned above.

Arundel (2007) gives a few examples of new policy-relevant indicators that could be constructed using CIS data. These new indicators include an output measure with improved international comparability, an indicator for knowledge diffusion, and a set of indicators for how firms innovate. The goal is to improve the impact of the CIS by improving the relevance of CIS indicators for policy.

Currently, almost all publicly available CIS indicators are simple frequency indicators based on one CIS survey question, such as the percentage of firms that applied for at least one patent or the percentage of SMEs that reported collaborating on innovation. Complex indicators based on the responses to more than one question are rare. However, complex indicators can be much more revealing of firm strategies than simple indicators and consequently could be of great value to the policy community. The new complex indicators - of relevance to markets, knowledge diffusion, and innovative capabilities – given as examples in Arundel (2006), are obtained from analyzing the micro-aggregated CIS-3 data that was released by Eurostat in July 2006.[30] The results of analyzing these indicators illustrate what could be done with new ways of using the CIS to construct indicators.[31] Table 5 gives an overview of three of such indicators.

An indicator based on sales from innovative products is a policy relevant measure. The downside to using an indicator solely based on the share of new-to-market product sales (a single-question-based CIS indicator) is that firms can have high shares from new-to-market products, but be mainly active in domestic markets, introducing innovations already available on other markets. This indicator is therefore misleading. On the other hand, the combined

[28] According to the TrendChart/ PRO INNO Europe website (http://ec.europa.eu/enterprise/innovation/index_en.htm), non-R&D innovation programs probably account for less than 5% of all government support for innovation. The new EU member states and especially SMEs are the main targets of such current non-R&D innovation policy actions.

[29] See e.g. the Aho report (CEC, 2006) or the proposed Competitiveness and Innovation Framework Program (CIP) (CEC, 2005).

[30] A major drawback is that the dataset only contains results for two highly developed countries, Belgium and Iceland, and for 10 less innovative EU member states – an illustration of the problem of access to micro-level CIS data.

[31] These indicators could also be constructed in the future using CIS-4 data, since the relevant information is also obtained by the CIS-4 questionnaire.

indicator (1), given in Table 5, gives a much better idea of innovative firms introducing innovations to the international markets, while also improving international comparability.[32]

Table 5. Suggestions for new CIS-based indicators

Indicator	Combination of CIS-3 questions used
1) Share of total product sales from new-to-market innovations by firms active in international markets	Share of total product sales from new-to-market innovations, *and* Firms' main market (local, national, international)
2) Firms involved in active knowledge diffusion*	Positive response to one or more of the following: Product innovations developed mainly in cooperation with other enterprises or institutions, *or* Process innovations developed mainly in cooperation with other enterprises or institutions, *or* One or more cooperation agreements on innovation with other firms or institutions
3) Characteristics of innovative firms, including four categories: A) Creative non-collaborative innovators; B) Creative collaborative innovators; C) Informal collaborative innovators D) Informal non-collaborative innovators	Firms involved in active knowledge diffusion (as defined above) Formal in-house creative activities measured by firms either: Performing R&D, *and/or* Applying for at least one patent

* Firms involved in active knowledge diffusion primarily obtain their innovations through collaboration with other firms or institutions.

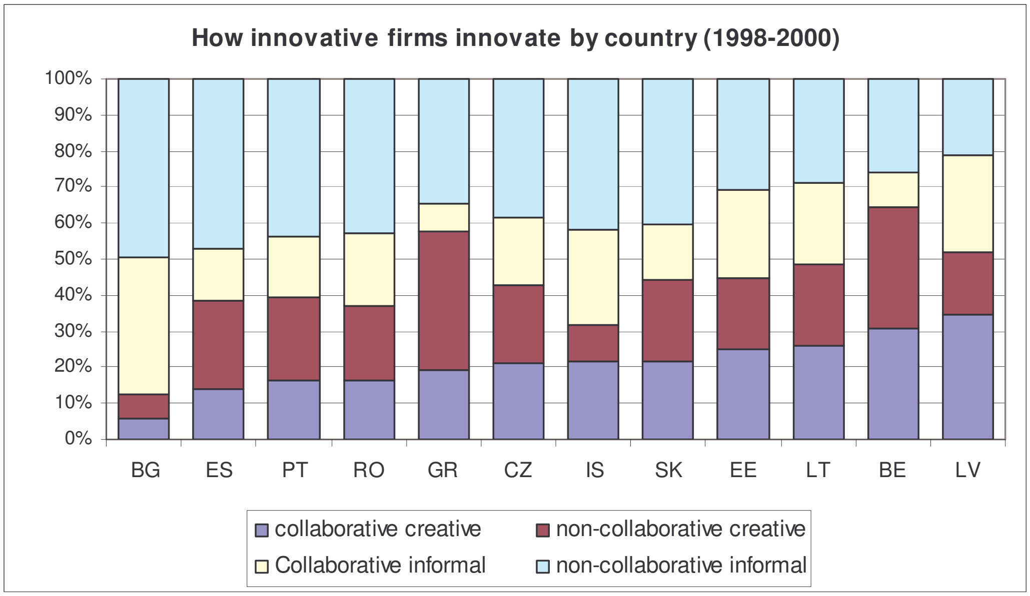
Diffusion based innovation is an essential and important aspect of innovation. Using the concept of active knowledge diffusion (see indicator (2) in Table 4) separates firms involved in active knowledge diffusion from those involved in non-interactive knowledge diffusion, in which firms only obtain external knowledge through open sources, or through purchasing technology. In the former case, firms will invariably need to interact with other firms or institutions and sometimes collaborate on their innovation projects. In the latter case, almost all innovative activity occurs in-house.

Finally, the characteristics of innovators vary a great deal. Focusing on the aspects of collaboration/non-collaboration and formal/informal innovation (see indicator (3) in Table 4), important to policy makers according to the UNU-MERIT interviews, improves policy relevance. Combining these aspects also assigns each firm to only one category, thus removing the problem of the CIS definition of the 'innovative firm', which makes it difficult to tell a technology adopter from a firm with extensive in-house R&D projects. Figure 1 shows that there are large differences in how firms innovate by country. Information on the

[32] Analysis in Arundel (2006) highlights the differences between using only the first indicator or the combination of the two: in the former case Spain is the leading innovative country, whereas in the latter case Spain shifts to the worst performer, while Belgium takes the lead. The group of countries in the study is limited to a sub-section of the EU-25.

distribution of how firms innovate should help policy analysts to better understand national innovative capabilities and to develop appropriate policy actions that can shift firm capabilities to greater collaboration and inventiveness. As shown by the analysis in Arundel (2006), both of these characteristics are associated with a higher incidence of activity on international markets, product innovation, and combined product and process innovation.

Figure 1



Source: CIS-3 micro-aggregated data referring to innovative activities in 1998-2000.

These three examples of new types of indicators that could be created using the CIS data are in response to the suggestions from the policy analysts interviewed by UNU-MERIT. However, this is an ad-hoc and incomplete method of identifying the types of indicators that would help the policy community. The CIS was designed to provide data on many types of innovative activities and consequently should be a key source of useful data for the European policy community. Research to develop indicators, descriptive analysis, and econometric analysis needs to revisit some of the issues that led to the development of the CIS in the first place.

3.4 Organisational innovation

Arundel et al. (2007) explore the relationship between innovation and the organization of the work of firm employees. The results support the view that how firms innovate is linked to the way work is organised to promote learning and problem-solving.

The study creates four basic categories of work organization from the variables in the original data from the Third Working Conditions survey:[33]

- Discretionary learning: high levels of autonomy in work, combined with high levels of learning, problem-solving and task complexity;
- Lean production: low levels of employee discretion in setting work pace and methods, high levels of job rotation and team work, high use of quality norms and employee responsibility for quality control;

[33] Conducted by the European Foundation for the Improvement of Living and Working Conditions.

- Taylorism: opposite of the first category, with low discretion and low level of learning and problem-solving; high use of teams, job rotation and quality norms; and
- Traditional organisation: monotonous work, low levels of learning and task complexity, with few constraints on the work rate; working methods are usually informal and non-codified.

Arundel et al. (2007) also use four mutually exclusive innovation modes that capture different methods of innovating, and a fifth category of non-innovators by using CIS-3 data.[34] The classification method uses two main criteria: the level of novelty of the firm's innovations, and the creative effort that the firm expends on in-house innovative activities. The four innovation modes are as follows:

- Strategic innovators: For these firms, creative in-house innovative activities form an important part of the firm's strategy. All firms have introduced a product or process innovation that they developed at least partly in-house, perform R&D on a continuous basis, introduced a new-to-market innovation, and are active in national or international markets. These firms are the most likely source of innovations that are later adopted or imitated by other firms.
- Intermittent innovators: All of these firms develop innovations at least in part in-house and all have developed a new for the market innovation. But, they are less likely than the strategic innovators to have developed important innovations that diffuse to other firms, either because they are only active on local or regional markets, or because they only undertake innovative activities intermittently, say when required by the introduction of new product line.
- Technology modifiers: These firms primarily innovate through modifying technology developed by other firms or institutions. None of them perform R&D on either an occasional or continuous basis. Many firms that are essentially process innovators that innovate through in-house production engineering will fall within this group.
- Technology adopters: These firms do not develop innovations in-house, with all innovations acquired from external sources. An example is the purchase of new production machinery.

Next, Arundel et al. (2007) combine these two dimensions on work organization on the one hand, and on innovation mode on the other. One of the main results is that there is a positive correlation between discretionary learning and the frequency of the two innovation modes for which the levels of novelty and creative in-house effort are the highest, the strategic and intermittent modes, while there is a negative correlation between discretionary learning and the frequency of non-innovators. Furthermore, the strongest positive correlation is between strategic innovators and discretionary learning. Finally, the results show a negative correlation between the frequency of the lean forms of organization and the frequency of the three innovation modes which depend on in-house creative effort for innovation, and a positive correlation with the frequency of adopters and non-innovators

The results support the view that there are systemic links between the way work is typically organized in a nation and the distribution of different innovation modes. Specifically, the study finds that in nations where work is organised to support high levels of discretion in solving complex problems firms tend to be more active in terms of endogenous innovation, i.e. innovation developed, at least to some degree, in house. In countries where learning and problem-solving on the job are more constrained, and little discretion is left to the employee,

[34] These modes originate from Arundel and Hollanders (2005).

firms tend to engage in a supplier-dominated innovation strategy. Their technological renewal reflects, almost exclusively, absorption of innovations developed elsewhere. These results challenge some of the established ideas and they raise new questions about the link between work organisation, learning and innovation.

The next step in more adequately addressing the relationship between organisation and innovation is to obtain complementary firm-level data on both innovation modes and organisational forms. The results from Arundel et al. (2007) provide a few tentative hypotheses that are consistent with the evidence and which could be explored when better data are available. One option is to develop better indicators of organisational innovation in future CIS surveys, as proposed by the third revision of the Oslo Manual in 2005. The CIS could respond to some of the limitations inherent in relying on the employee-level data of the European Survey on Working Conditions by supplying establishment-level data providing information on the way knowledge flows and knowledge sharing are organised within firms and how they relate to other aspects of corporate strategy.

4. Conclusions

This report has summarized the state-of-the-art in developing novel indicators from existing statistics, developed solutions to missing indicators, identified indicators that may need to change over time, and developed methods for monitoring progress towards policy goals in a knowledge-based economy.

Section 2 explains the differences between incomplete, unsatisfactory and missing indicators, and evaluated unsatisfactory and missing indicator areas for the main characteristics of a KBE, as well as the main outcomes. Annex A provides some examples of indicators in need of development.

Section 3 explores possible solutions for missing indicators for four key components of a KBE:

- Human resources: Linking aspects of HRST (PhDs in S&E) to scientific performance (R&D expenditures and patents), provides new evidence of the importance of human resources to innovation.
- Knowledge production and diffusion: Twelve possible indicators for the transfer of knowledge from public research sector institutions to the private sector are suggested. These indicators can be obtained either from surveys of Knowledge Transfer Offices, from the CIS, or from one-off surveys.
- Innovation and entrepreneurship: Three examples of complex CIS-based indicators are explored (share of innovative product sales of internationally active firms, involvement in active knowledge diffusion, and characteristics of firm innovation).
- Organisational innovation: The link between work organisation and innovation modes is investigated further through combining aggregated data from two major surveys.

These results show that the problem with many unsatisfactory or missing indicators can be overcome by imaginative use of data linking or reanalysis of existing data. In other cases, policy needs will not be met without new surveys or other data gathering exercises.

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Annex - Incomplete, unsatisfactory and missing indicators

Annex Table 1. Incomplete Indicators.

Indicator	EU-25 series ✗ missing ✓ complete	EU-15 series ✗ missing ✓ complete	Selected countries or selected years in the time series ✗ missing ✓ complete
Production and diffusion of ICTs			
Economic Impact of ICT sector			
ICT expenditure expressed as a share of GDP, 2000 to 2004.	✗	✗	✗ for selected countries ✗ for selected years
Number of patent applications to the EPO in ICT patent classes (priority year) per million population, 1981 to 2002.	✓	✓	✗ for selected years
Number of patents granted at the USPTO in ICT patent classes (priority year) per million population, 1981 to 1999.	✓	✓	✗ for selected years
Internet use by firms			
Businesses receiving orders over the Internet, 2003 to 2005.	✗	✓	✗ for selected years
Percent of individuals making use of the Internet by age, 2003 to 2005.	✗	✓	✗ for selected years
Broadband penetration rate (number of broadband lines per 100 population), 2002 to 2005	✗	✓	✗ for selected countries ✗ for selected years
Government ICT Production and diffusion of ICTs			
Percentage of individuals using the Internet for interacting with public authorities broken down by purpose, 2000 to 2005.	✗	✗	✗ for selected years
Human resources, skills and creativity			
General Education Indicators			
Science and technology graduates - Tertiary graduates in science and technology per 1000 of population aged 20-29, 1993 to 2004.	✗	✗	✗ for selected years
HRST education indicators			
Total HRST as a percentage of total employment by age cohort, 1993 to 2004.	✗	✗	✗ for selected countries ✗ for selected years
Skills			
Hours in CVT courses per 1000 hours worked (all enterprises), by NACE, 1999.	✓	✓	✓
Participation in life-long learning per working age population (25-64), 1994 to 2005.	✗	✗	✗ for selected years
Mobility			
Annual data on job-to-job mobility of highly qualified personnel (employed HRST) aged 25-64 at the national level by gender, 1994 to 2004.	✗	✗	✗ for selected countries ✗ for selected years

	EU-25 series ✗ missing ✓ complete	EU-15 series ✗ missing ✓ complete	Selected countries or selected years in the time series ✗ missing ✓ complete
Knowledge production and diffusion			
R&D family			
GERD expenditure as a share of GDP, 1981 to 2005.	✗	✗	✗ for selected countries ✗ for selected years
GERD per capita population (current PPP$), 1981 to 2005.	✗	✗	✗ for selected countries ✗ for selected years
Estimated civil GERD as a percentage of GDP, 1981 to 2005.	✗	✗	✗ for selected countries ✗ for selected years
GOVERD and HERD as a percentage of GDP, 1981 to 2005.	✗	✗	✗ for selected years
BERD as a percentage of GDP, 1981 to 2004.	✗	✗	✗ for selected years
BERD as a percentage of value added in industry, 1981 to 2004.	✗	✗	✗ for selected years
Patents			
EPO patent applications, 1977 to 2004.	✗	✗	✗ for selected years
EPO high tech patent applications by priority year per million population, 1977 to 2004.	✗	✗	✗ for selected years
USPTO high tech patent grants per million population, 1977 to 2004.	✗	✗	✗ for selected years
USPTO high tech patent grants per million population, 1977 to 2004.	✗	✗	✗ for selected years
Triadic patent families by priority year per million population, 1981 to 2005.	✗	✗	✗ for selected years
Bibliometrics			
Knowledge flows			
Share of all firms reporting public research as a high value information source, 2000.	✗	✗	✓
Share of all firms reporting public research as a cooperation partner, 2000.	✗	✗	✗ for selected countries
Share of SMEs collaborating on innovation, 2000.	✗	✗	✗ for selected countries
Total investment in intangibles			
Innovation, Entrepreneurship and creative destruction			
Entrepreurship			
Firm entries - real enterprise births of year n, as a percentage of the population of active enterprises of year n, 1997 to 2003.	✗	✗	✗ for selected countries ✗ for selected years
Firm exits, 1997 to 2003.	✗	✗	✗ for selected countries ✗ for selected years
Demand for innovative products			
GFCF as a percentage of GDP, 2003 to 2005.	✓	✓	✗ for selected countries ✗ for selected years
Firm level technology absorption,	✗	✗	✓

	EU-25 series ✗ missing ✓ complete	EU-15 series ✗ missing ✓ complete	Selected countries or selected years in the time series ✗ missing ✓ complete
Financing of innovation			
Market innovation outputs			
Share of firms introducing new to market products, 2000.	✗	✗	✗ for selected countries
Share of total sales from new to market products, 1998 to 2004.	✗	✗	✗ for selected countries ✗ for selected years
Share of firms introducing new to firm products, 1998 to 2004.	✗	✗	✗ for selected countries ✗ for selected years
Share of total sales from new to firm products, 2000.	✗	✗	✗ for selected countries
Community design registrations per million population, 2002 to 2004.	✓	✓	✗ for selected countries ✗ for selected years
Organisational indicators			
Percent of SMEs reporting non technological change, 2000.	✗	✗	✗ for selected countries
Economic outputs			
Income			
GDP per capita in PPS, 1995 to 2007	✓	✓	✓
Real GDP growth rate, 1995 to 2007.	✗	✗	✗ for selected years
Productivity			
Labour productivity per hour worked	✓	✓	✗ for selected years
Gross fixed capital formation – current prices – millions of euro – as a percentage of GDP, 2001 to 2005.	✓	✓	✗ for selected years
Employment			
Total employment growth, 1992 to 2004.	✗	✗	✗ for selected years
Total employment rate, 1992 to 2004.	✗	✗	✗ for selected years
Environment			
Energy intensity of the economy, 1991 to 2003.	✗	✗	✗ for selected years
Employment and economic welfare			
Employment rate of older workers, 1992 to 2002.	✗	✗	✗ for selected years
Long term unemployment rate, 1992 to 2002.	✗	✗	✗ for selected years
Inequality of income distribution, 1995 to 2004.	✗	✗	✗ for selected years
Quality of life indicators			

	EU-25 series × missing ✓ complete	EU-15 series × missing ✓ complete	Selected countries or selected years in the time series × missing ✓ complete
Internationalisation			
Trade			
High tech exports as a share of total exports, 1990 to 2004.	×	×	× for selected countries × for selected years
Direct inward investment flows as percent of GDP, 1993 to 2004.	×	✓	× for selected countries × for selected years
Knowledge production and diffusion of knowledge			
R&D spending of affiliates as a share of total BERD, 1982 to 2005.	×	×	× for selected countries × for selected years
Share of R&D funded from abroad, 1981 to 2005.			
Economic structure			
FDI intensity, 1993 to 2004.	×	×	× for selected years
Human resources			
Number of foreign students (non-EU) in tertiary education ISCED 5 as a percentage of tertiary education ISCED 5, 1998 to 2003.	×	×	× for selected countries × for selected years
Number of foreign students (EU) in tertiary education ISCED 5 as a percentage of all tertiary education, ISCED 5, 1998 to 2003.	×	×	× for selected countries × for selected years

Annex Table 2. Identification of key unsatisfactory indicators

Indicator group	Key missing indicators
Production and diffusion of ICT	Non-formal versus formal qualifications
Human resources, skills and creativity	▶ General education: ▪ non-traditional learning ▶ HRST: ▪ employment outcomes of graduates (e.g. occupation, sector) ▪ in-house training ▪ multi-tasking of researchers (e.g. activities and skills needed) ▶ Mobility: ▪ firm to firm
Knowledge production and diffusion	▶ R&D: ▪ public sector expenditures by field insufficient (e.g. do not provide for estimate for key generic technologies); ▪ business sector R&D (e.g. product-based approach); ▪ global R&D expenditures. ▶ Patents: ▪ not all innovations captured in patent data; ▪ lack of economic value for some patents. ▶ Knowledge flows: ▪ industry-science relations (e.g. impact on firm growth, employment growth); ▪ existing indicators limited to 'formal' knowledge exchange – ignore role of public science (e.g. missing publication and dissemination of academics' knowledge)

Innovation, entrepreneurship and creative destruction	► Entrepreneurship indicators: ▪ measures of entrepreneurship within existing firms — ability to discriminate between entrepreneurship oriented to an innovative business strategy or one without (e.g. corner store); ► Demand for innovative products: ▪ indicators for demand for innovations; ▪ indicators for regional, domestic, international demand (e.g. responding to local, national or international demand). ► Financing of innovation: ▪ total venture capital indicator does not provide for effect at various stages (e.g. start-up, availability during growth stages).
Economic indicators	GDP measures that value leisure time, income distributions, and negative externalities.
Globalisation	► human resources indicators: ▪ number and type (e.g. specialization) of foreign-born HRST, broken down by level (e.g. technical, bachelor, PhD); ▪ source of foreign-born HRST (country of origin, country of degree); ▪ sector of employment of foreign-born HRST (e.g. public or private sector demand); ▪ occupation of foreign-born HRST (e.g. public or private sector; e.g. basic or applied research); ▪ socio-economic characteristics need to be collected for all indicators in particular gender and age (e.g. demographic pressure on supply; women and science policy); ▪ scholarships/financial support for foreign students vs nationals; indicators on satisfaction with international posting. ► Improved measures of globalised R&D,

Annex Table 3. Identification of key missing indicators

Indicator group	Key missing indicators
Production and diffusion of ICT	► Economic impact of ICT sector: ▪ share of firms with portals (by NACE)
Human resources, skills and creativity	► General education indicators: ▪ non-traditional certification; ▪ e-skills. ▪ creative capacity of the population (e.g. pre-graduation) ► Skill indicators: ▪ non-traditional training systems (e.g. firm level; profession level); ▪ ICT skills for ICT producer versus ICT user industries; ▪ life-long learning — training and upskilling by occupation, by education (e.g. upskilling variance by level of formal qualification and field and economic activity). ► Creativity indicators: ▪ skills for adopting new technologies skills mix within occupations (e.g. occupation ≠ skills); ▪ skills composition of research teams (e.g. formal qualifications (level and field), non-formal (e.g. professional training). ► Mobility: ▪ sector: duration, frequency ▪ occupation: duration, frequency.
Knowledge production and diffusion	► Knowledge flows: ▪ indicators on type of knowledge obtained from industry-university collaboration ▪ role of knowledge diffusion in innovation development.

Innovation, entrepreneurship and creative destruction	► Entrepreneurship: ▪ measures of entrepreneurship within existing firms — rate of formation of new spin-off firms; ▪ measures of entrepreneurship within existing firms — rate of introduction of new products. ▪ indicators on availability or quality of managers (e.g. needed for commercialization). ► Demand for innovative products: ▪ government adoption of technology ► Financing of innovation: ▪ indicators for pre-seed, seed, and business angels. ► Organisational indicators: ▪ indicators on share of employees affected by organizational innovation; impact on employee duties and activities (e.g. increase or drop in responsibilities, skill needs); ▪ organizational innovation in the public sector.
Economic indicators	► Employment: ▪ IT and ICT employment for ICT producer versus ICT user industries ► Quality of life: ▪ confidence indicators (e.g. ability to prosper in the KBE — national, personal); ▪ ranking of individual response to change (e.g. go beyond a 'happiness' scale type indicator).
Internationalisation	► Knowledge production and diffusion of knowledge: ▪ diasporas (e.g. number, frequency ► Human resources: ▪ factors driving ERA HRST abroad; ▪ factors drawing foreign HRST to ERA