



Workpackage 1

**Future Challenges for a
Knowledge-Based Economy**

Deliverable 1.2

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http://europa.eu.int/comm/research/index_en.cfm

http://europa.eu.int/comm/resarch/fp6/ssp/kei_en.htm

http://www.corids.lu/citizens/kick_off3.htm

<http://kei.puplicstatistics.net/>



¹ Substantial parts of this report are based on Arundel, Colecchia and Wyckoff, (2006).

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1. Introduction

The Lisbon strategy for Europe, developed in March 2000, stressed the need for Europe to become a more dynamic and competitive 'knowledge-based economy' (KBE). An evaluation in the fall of 2004 of European progress towards the Lisbon goals noted a general lack of progress (Kok, 2004). The Kok report also noted that the challenges to meeting the Lisbon goals are actually increasing over time, due to demographic change within Europe, increasing competition from China in high value-added goods and from India in services, and the continuing dominance of the United States in KBE sectors such as ICT and biotechnology. The authors point out that in the face of these challenges, Europe must 'radically improve its knowledge economy and underlying economic performance' (p 12).

Theories of the KBE, as reviewed in WP 1.1, are not fully capable of dealing with these and other structural changes that are occurring on a global level. There are five major structural changes that are relevant to knowledge-based economies:

1. Increasingly global production chains for goods and services, leading to changes in the location of comparative advantages.
2. The development of new centres of knowledge and innovative activities.
3. Demographic changes including increases in the average life span.
4. Changes in stocks and flows of skilled workers.
5. Technological shifts driven by new technology or environmental requirements.

These five major changes will alter the environment for innovation and competition over the next few decades and consequently the types of indicators that European policy makers and academics will need to be able to effectively evaluate and respond to future challenges. This report examines each of these five challenges for a knowledge-based economy and the types of indicators that will be required to track structural changes over time.

2. Global Production Chains

The first structural change consists of major shifts in the location of comparative advantage for the production of both manufactured goods and services, or the development of "Cross National Production Networks" (Zysman and Newman, 2004). China, the new 'workshop of the world', accounts for a growing share of manufactures. Over the short to medium term of up to 20 years, firms in developed countries are likely to respond to cost competition from India and China by increased off-shoring of production, including the production of high technology products such as ICT and aerospace equipment². Such shifts in the location of production have been made possible by ICT, innovation in organizational forms and logistics, and low transportation costs, leading to value chains that can be 'contracted out to independent producers wherever those companies are located in a global economy'. Under

² Pharmaceutical off-shoring is blocked by regulatory requirements, which is why low cost Puerto Rico, which is officially within the United States, is a global centre for pharmaceutical manufacturing.

these conditions, supply chain management and associated organizational innovations become an increasingly important factor in competition.

In addition to manufacturing, there has been an increase in global supply chains for services since the mid 1990s. India is developing strengths in services such as software development, clinical trials, and call centres. The OECD estimates that India was the sixth largest exporter of business services in 2002, close behind the Netherlands and France (van Welsum and Vickery, 2004a). Furthermore, the same OECD study estimates that a high percentage of total 2003 employment is susceptible to off shoring: 19.2% for the EU 15, 18.6% for Canada, and 18.1% for the United States. The estimate is based on occupations with the following characteristics for an 'off-shoring' potential: intensive use of ICT, output that can be traded or transmitted using ICT, high information or knowledge content, and work that does not necessarily require face-to-face contact. Of note, this would include a high proportion of the well-paid jobs in the KBE that are supposed to replace losses in manufacturing employment.

Zysman (2004) argues that globalisation has been partly driven by increasing modularisation of standard components. Under these conditions, innovative firms rely on cross-national production networks and create value from the efficient use of global supply chains. While it is clear that MNEs are important actors in the innovation process, their role is poorly understood, partly because the statistics collected by governments and agencies are usually limited to the national level and country to country comparisons. This can create incomplete data and unclear profiles on the activities of MNEs, including the location of their innovation investments around the world.

The development of global production is likely to have a major impact on innovative strategies by substantially increasing the value to firms of organizational and logistical innovations to manage complex and lengthy supply chains. This is one reason why the ability of firms to exploit value-added at every possible link in the production and distribution chain could become a key feature of a knowledge-based economy (Keita, 2004).

Organisational innovation of relevance to a KBE contains two components. The first consists of the organisation of the value-added chain, including production, distribution, and management. The second consists of new organisational forms of innovative activities themselves, such as how R&D is conducted, which is discussed in Section 3.

Structural changes in the location of comparative advantage do not automatically lead to gloom and doom scenarios for North American and European firms. Neither excessive hubris (as with the internet boom in the United States in the late 1990s) nor excessive pessimism (as with the strong belief in the late 1980s that European and American manufacturing firms would never be able to compete with Japan) are useful analytical perspectives. Instead, we need to think through the implications of structural change and

consequently the types of indicators that will be needed to inform policy options and private investment decisions.

The first crucial point about current structural change in the location of comparative advantage is that it won't last. Sooner or later, increasing productivity and wealth in India, China and other developing countries will result in currency realignments that will reduce the disparities in wages and incomes that drive off-shoring strategies based on seeking lower wage costs in manufacturing and the provision of services. An often forgotten point is that the advantages of distant, low-cost production are slim. Even a 10% increase in shipping costs can reduce the cost advantage of producing some goods in China to zero.

Due to a lack of official statistics, little is known about the extent and real impact of off-shoring. Further work is required to identify employment effects such as the following:

- What types of employment are affected (e.g. knowledge creation versus application)? For instance, what percentage of off-shored jobs are in low-skilled low-wage occupations such as clerical jobs and what percentage are higher skilled occupations such as those that require technical, scientific and engineering knowledge?
- Which occupations are most affected? This is a useful indicator given the differences in the skills composition of varying occupations (e.g. different skill levels and different fields of specialisation).
- What are the wage differentials for the same occupation between the source country and the off-shored location, plus rates of salary growth abroad?

3. The Changing Environment for Innovation Strategies

Neither outsourcing nor off-shoring are new – both have been underway for decades. However, a second development, which is of great interest to innovation policy over the short and medium term, is that India, China and other developing economies are likely to increasingly compete not only on the basis of low wages, but on innovation across a growing range of products and services. One consequence is that it could be increasingly difficult for high-wage countries to compete on the basis of 'continual innovation', as suggested by Paul Krugman (1979) twenty-five years ago, and by many of the current theories of the unique features of modern economies – at least not through a narrow view of innovation defined as new products and processes in high technology sectors.

New sources of data suggest that the innovative capabilities of low wage mega-countries such as India and China are probably increasing rapidly. A recent study by the OECD estimates that the number of researchers in China increased from 531,000 in 1999 to 811,000 in 2002 (Schaaper, 2004) and R&D data for China also shows a rapid increase after 1991, reaching 1.2% of GDP in 2004. Although both of these estimates contain a wide margin of error, due to the absence of a developed national statistical system in China, there

is little doubt that the number of researchers and PhD graduates, and the level of R&D investments are increasing in China and in India. Anecdotal evidence highlights an increase in the ability of both India and China to compete not only in low value-added sectors such as textiles, but also in knowledge intensive sectors such as software, capital goods and ICT manufacturing³. An analysis of USPTO data by Puga and Trefler (2007) shows a sharp rise after 1996 in the number of US owned patents with at least one inventor that is a resident of either China or India, indicating that American FDI or suppliers to American firms in these two countries are increasingly responsible for developing patentable innovations for their parent firm. This suggests that both China and India are capable of turning FDI into a mechanism for developing innovative capabilities, in contrast to Thailand and Mexico, where such co-patenting has either reached a plateau or declined.

The development of innovative capabilities in China and India could drive firms to develop R&D centres in these two countries. There are three main reasons for this. First, firms could move part of their R&D to China or India to take advantage of local pools of inexpensive but highly skilled labour. Second, firms can seek specialized expertise that is not available in their home country. This is the motivation of European pharmaceutical firms in the past decade for establishing R&D centres in the United States. Third, firms can establish R&D labs in foreign markets in order to adapt current products to local tastes or develop new products that meet local demand. An example is the establishment by many telecom equipment firms of R&D centres in China in order to develop products that are suited to the Chinese market. Nokia, for example, developed its 6108 mobile telephone in China because it wanted to optimize the ability of the telephone to text Chinese characters.⁴

Many MNEs already have experience in developing R&D centres outside of their domestic base, including major high-technology firms such as Ericsson, Nokia and Nortel. Almost half of Nokia's global R&D spending is outside Finland while Nortel Networks conducts R&D in more than 10 countries, including Australia, China, France, the UK and the US⁵.

The OECD estimate that about 20% of total jobs in the EU could be off-shored, including many of the 'knowledge jobs' of the future, should give pause for thought. This is already occurring in some sectors, such as the move of many software development tasks to India, or the establishment of research centres in China by major telecommunication and biotechnology firms. To date, we lack reliable statistics on both the extent to which innovation activities such as R&D are being globalized, and possibly more importantly, the innovation capabilities of the research centres that have been established by multinational firms in developing countries. For instance, we do not know if these centres are performing leading-edge research or largely adapting products to local markets. Of the three reasons for establishing R&D centres abroad, only the first can be construed as true off-shoring.

³ See Engardio P and Roberts D, 'The China Price', International Business Week, December 6, 2004.

⁴ Perhaps a fourth reason will need to be considered in the future — avoidance of national regulations that could limit research in certain areas (e.g. biotechnology research being done in foreign countries to avoid regulations at home).

⁵ See <http://www.nortelnetworks.com/corporate/technology/innovation/randd.html>.

One possibility, discussed by Zysman (2004), is that the competitive advantages provided by innovation should decline as an increasing share of firms base their competitive strategies on innovation. This effect can be driven both by an increasing awareness of innovation by firms based in developed countries and by an increase in the use of innovation by firms based in developing countries. In each case, greater competition could reduce the ability of innovative activities to provide the excess rents that drive profits and investment. This could produce a paradox whereby policy efforts to encourage more creative innovation, as with the 3% R&D intensity goal for Europe, result in declines to the private returns from innovation. However, three factors could mitigate the reduction in profits from increasing competition over innovation.

The first factor concerns the location and costs of innovation activities. Zysman (2004) notes that although R&D was originally essential to product differentiation, the provision of R&D is becoming a commodity that can be purchased from universities, start ups and spin-offs, or from cheaper R&D centres in developing countries. This perspective partially ignores several characteristics of knowledge that make it difficult to commodify or contract out innovative activities, such as the potential loss of core knowledge to competitors, difficulties in writing contracts under uncertainty, and the need for in-house absorptive capabilities to apply the results of R&D. Nevertheless, these constraints could be less severe in some sectors. For instance, pharmaceutical firms can contract out R&D services for clinical trials while firms in the office equipment sector can obtain the results of R&D 'embodied' in components. In both of these sectors, large firms can succeed by becoming technology integrators rather than doing most development work in-house. Examples include Dell in ICT or several of the large pharmaceutical firms whose expertise lies more in marketing than in product development.

The second factor that follows from an increase in the share of firms that compete on the basis of innovation is that firms can aggressively manage intellectual property in order to profit from their investments in innovation. This could be one reason for the increase in patenting observed during the 1990s. Market differentiation strategies based on design, trademarks and branding could also become increasingly important⁶. An example is the computer firm Apple, which is aggressively using design, patents and branding to appropriate its investments in innovation.

Third, firms can introduce strategies to improve the efficiency of innovation, such as the number of new innovations that are developed per unit of R&D spending. The organisation of innovation itself is changing. As the range of technologies required for innovation has expanded, innovation has become more complex, while information technologies have driven down the cost of experimentation. Factors linked to globalisation have reduced the

⁶ In affluent societies, design is an increasingly important method of product differentiation that is useful across all sectors. A dependence of brands also creates risks, as when a brand is associated with irresponsible environmental production or exploitation of workers. Conversely, brands can be used to advertise socially responsible environmental and employment practices.

cost of research collaboration and the cost of outsourcing key components. In response to both developments, firms have become more specialised, relying on co-operation among participants in different fields of expertise. This strategy can reduce uncertainty, share costs and knowledge, and bring innovative products and services more quickly to the market.

The reorganisation of innovation can improve the productivity of innovation: increasing outputs per unit costs. This is one explanation why firms have decreased the role of stand-alone central labs and increased their use of linkages such as networks, alliances and formal and informal relations. The development of such linkages could be producing basic structural changes that improve research productivity and allow innovation systems to adapt to new conditions. The much-cited innovative cluster of Silicon Valley is the most visible expression of strong innovation dynamics that can emerge from the evolution of linkages between dominant innovative firms (e.g. Fairchild), government funding agencies (e.g. DARPA), the geographical interaction of young firms, an outward-oriented university system, new forms of intermediaries like venture capitalists and “angels,” and the formation of strategic partnerships between firms manifested in alliances, patent licensing, and patent pools. Indicators to track and understand these dynamics are important for forging policy that supports this experimentation while retaining a competitive environment.

The efficacy of these three counter strategies to improve the profitability of innovation depends on favourable technological opportunities, or the R&D and engineering costs of developing new innovations versus the expected earnings from these innovations. There are no reliable data for technological opportunity, but the opportunities are believed to be highest during the early years of a new technology, lowest during its mid life, and to increase as the technology matures. Essentially, the view is that new discoveries become increasingly difficult and consequently costly. The rapid increase in the cost of developing new drugs in the pharmaceutical sector is a possible example of a steep decline in technological opportunities. Biotechnology was supposed to reinvigorate the sector by opening up new fields for profitable innovation, but so far this has not led to a decline in drug development costs, suggesting that biotechnology still remains in its infancy.

4. Demographic Change and Demand

The third major structural change is a demographic increase in the average age in many developed countries. There are two concerns for a KBE, neither of which broaches the issue of pensions or whether or not a shrinking labour force can support a growing non-active population⁷. The first is the effect of demographic changes on the market demand for

⁷ The argument is often alarmist and depends, for its solution on a higher birth or immigration rate. Within Europe, a large untapped reservoir is to increase the labour force participation rate (the percentage of the working age population that is employed), as recognized by ECOFIN (2005). The labour force participation rate can never reach 100% due to individuals in education, family care, or with disabilities, but the highest observed rates for 2004 of 75.7% in Denmark and 82.3% in Iceland give an indication of how much unused labour is available, compared to the EU average participation rate of 63.3% (Eurostat, SBS, 2005).

innovative products. The second, discussed in Section 5, concerns the supply of highly skilled individuals.

Research consistently shows that the adoption rates for innovative consumer products and services, such as mobile telephones and internet access, is inversely proportional to age and positively correlated with income. As an example, in 2000, 90% of Italian between the age of 15 and 24 had a mobile phone, compared to only 30% of Italians over the age of 55 (EURESCOM, 2001). In Denmark in 2004, internet access rates are close to or above 90% for all age classes below 60, but decline to 54% for individuals over 60 years of age (StatBank Denmark, 2005).

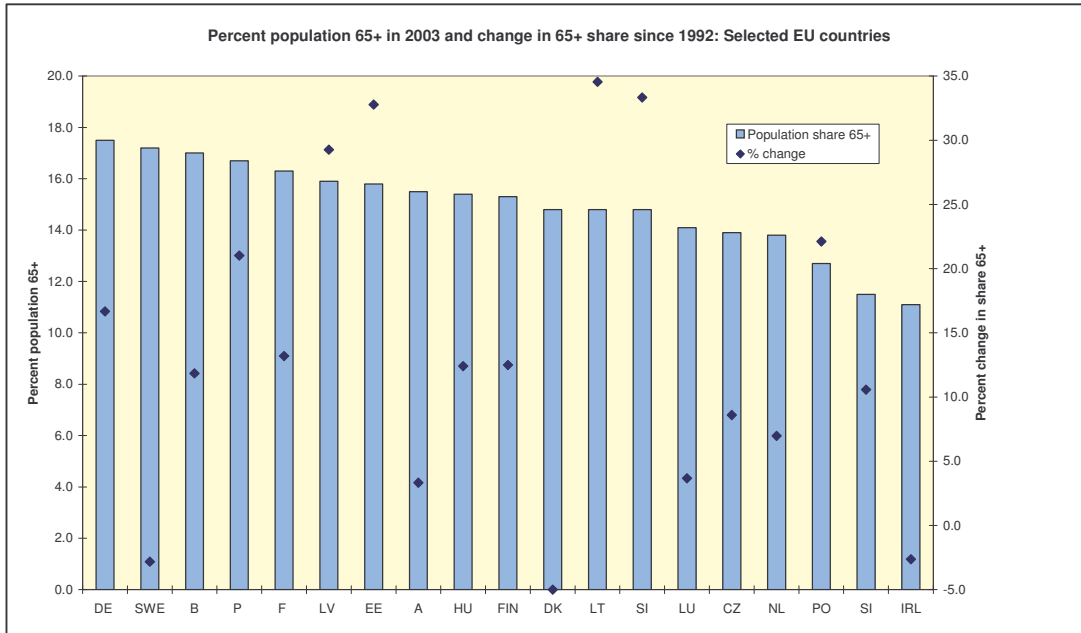
Demographic change leading to large increase in the population share of older age cohorts could reduce aggregate domestic demand for innovative goods and services. As an example, the low internet access rate among the Danish elderly would prevent the Danish government from providing many services for this age group over the internet, even though internet provision could significantly reduce costs. Secondly, in so far as a sophisticated domestic market plays a role in national innovative capabilities, an aging population with low levels of interest in innovation could reduce the innovative capabilities of the home market⁸. Both factors could lead firms based in countries with aging populations to seek both markets and research facilities in more youthful countries. This phenomenon is not restricted to developed countries. China's one child policy will leave a similar legacy in the future, with a rapid increase in the average age of China's population.

As shown in Figure 1, demographic ageing currently affects some of the most innovative European countries (Germany and Sweden) more than some of the least innovative economies (Poland and Slovakia). Conversely, the share of the population over 65 declined in three countries (Sweden, Denmark and Ireland), all of which are above the EU average for innovative capabilities, whereas the share increased by over 25% in several of the EU's least innovative countries (Latvia, Estonia, and Lithuania)⁹. This indicates that demographic patterns are neither fixed nor simplistically related to national innovative capabilities.

⁸ This is one of the four main points of Porter's diamond for national innovative capability. However, there is little empirical evidence to support the role of sophisticated domestic consumers, aside from a few case studies that suffer from a selection bias, such as an example by Beise (2001) for the telecom sector.

⁹ National innovative capability is based on the Summary Innovation Index of European Innovation Scoreboard.

Figure 1

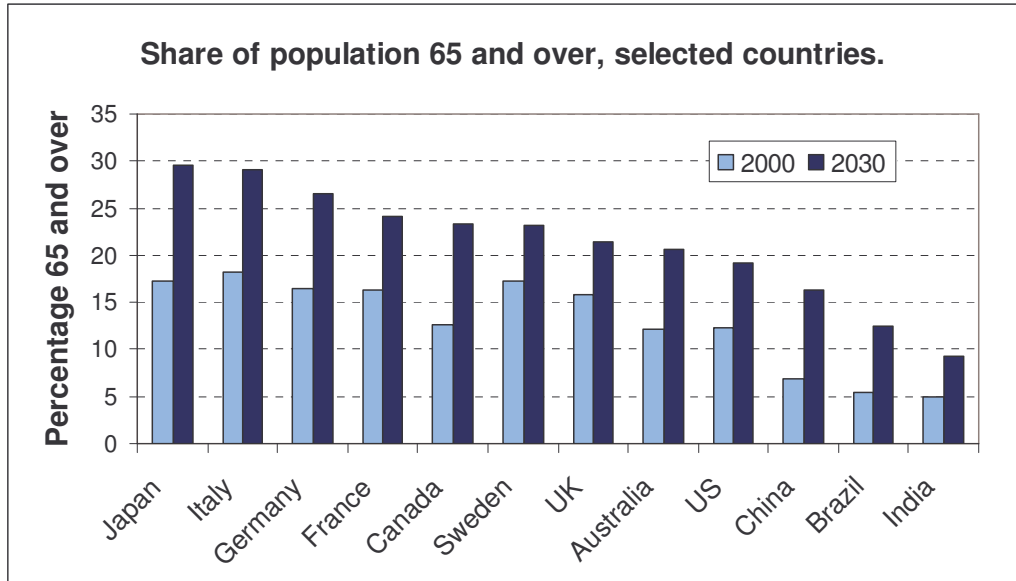


Source: MERIT/Eurostat

Figure 2 shows the share of the population aged 65 years and over in 2000 and projections for this age cohort in 2030 for selected countries. As the figure shows, in 2030, Japan and Italy are facing about one in three of its population aged 65 and over, Germany more than one quarter and countries like France, Canada, Sweden and the UK at least one in five. Projections for India are that in year 2030 still fewer than one tenth of the population will be aged 65 and older.

Another development that could be affected by changing demographics is user-centred innovation. Advances in computer hardware and software make it possible to outsource custom design to users (via innovation toolkits), while the ability of individual users to combine and coordinate their innovation-related efforts is improved by new communication media such as the internet (von Hippel, 2005). Although the concept of user-centred demand has been established through case examples, the actual economic importance of user-centred demand in either lowering innovation costs for firms or influencing the direction of innovation is unknown. Furthermore, user-centred innovation covers an enormous range of inputs, from consumers that pick and choose among existing components when purchasing a computer via the internet, to substantial technical feedback on needs that are currently unmet. In so far as user-centred innovation occurs through the internet, the low internet access rates among older age cohorts could be a concern. Conversely, the internet permits firms to get useful feedback from customers around the world as easily as they can obtain feedback from their domestic customers.

Figure 2



Source: Ministry of Internal Affairs and Communications, Statistics Bureau, Japan (2005).

Consumer demand can constitute an important incentive or constraint in shaping the innovative activity carried out by private firms, but at the same time it defines the range of new technological solutions and products which can be successfully brought to the market. Data on the value that innovation generates for customers is needed. With a possible increase in user-centered innovation, the location where innovation takes place changes. This requires integrating customer requirements and ideas through organisational innovation. For example most of the gains for firms' productivity come from the linkages of business processes via information technology. Customer-related processes are integrated with sales and with delivery, with inventory management (part of the production process) and so forth. Examples are Dell's built-to-order distribution system (customers customize their products) or Wal-Mart's supply chain (information on products through barcodes are transmitted to suppliers who are directly responsible for inventory management). Attention needs to be given to the role of suppliers, customers and interactions with customers. This means developing indicators of innovation processes that look at how customers and suppliers are interacting by using new technologies. One possibility is to introduce new questions in innovation surveys or in surveys of ICT usage.

5. The Supply of Human Capital

At the heart of a KBE are people who use, develop and adapt innovations and technology. As demand for this cadre of talent increases and as innovative networks increasingly cross borders, this segment of the labour force has become increasingly global. Key ports of entry for this flow are universities, with Florida (2005) referring to students as the 'canaries for

the global competition for talent'. The United States, Australia, the United Kingdom and Switzerland are able to attract foreign students to their universities who in many cases stay on and become researchers or otherwise add to the domestic pool of talent.

The immigration of hundreds of thousands of highly-skilled individuals was essential to the success of the United States' ICT and software sectors (AEA, 2005). This was based both on a large input of tertiary students who then remained in the United States after completing an advanced degree and on a visa system that favored the highly skilled. In 2002, for example, the US awarded 24,558 S&E doctorates from US universities, of which 5,234 were earned by non-US citizens on temporary visas. Among these, 75% had definite plans to remain in the United States and only 25% planned to leave – largely for Canada, the UK, Germany, France and Japan (see Burrelli, 2004). Although there are programmes to encourage exchange, relatively few US-born doctorate recipients from US universities plan to go abroad. In the second half of the 1990s, foreign workers filled more than one quarter of the ICT job vacancies in the US, which increased 'knowledge-intensive' employment in the US and helped to keep wage costs down in a sector that accounted for almost 30% of net employment gains in the latter half of the 1990s. The data on H-1B visas in the US show that IT firms were the key users of the visa programme for short-term workers¹⁰.

The pattern during the 1990s consisted of a net inflow of the highly skilled into the United States, both from developed and developing countries. In some supplier countries to the United States, such as Canada, the loss of university graduates was partially compensated by inflows from developing countries, resulting in a global circulation of human capital.

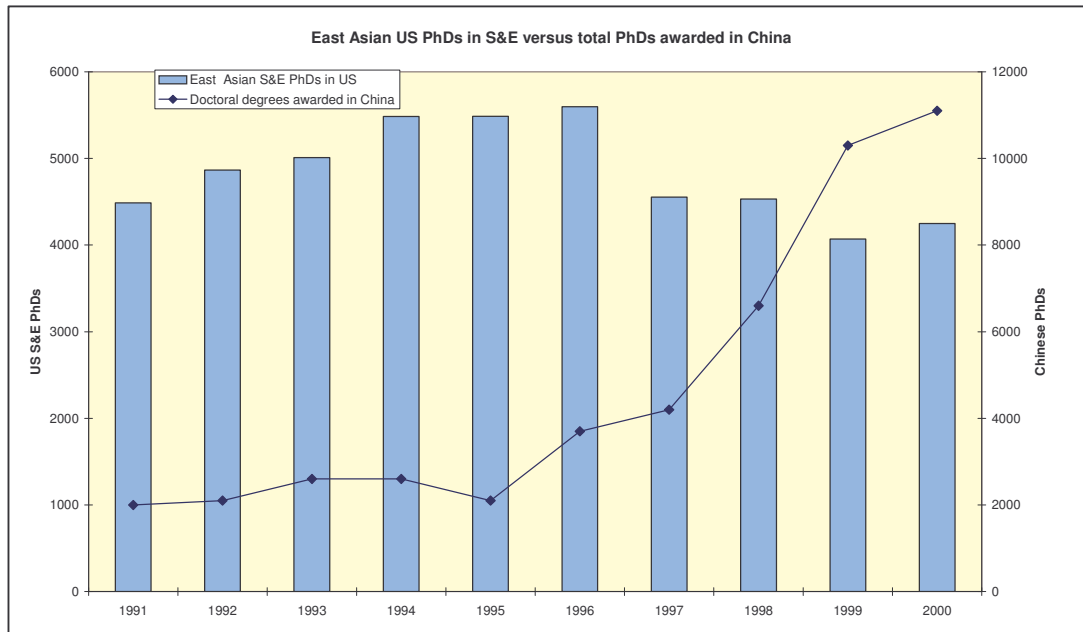
However, the developed countries, particularly the United States, face a potential decline in the global inflow of skilled workers, as a consequence of increasing economic opportunities at home for the highly skilled. This could have substantial impacts on the innovative capabilities of developed countries.

Part of the current growth and jobs strategy for Europe depends on copying the American success in attracting highly skilled immigrants (EC, 2005). This could be poor timing, since the ability of developed countries to attract and compete for students in the global market could already be declining and this decline could either speed up, or force up wages. As shown in Figure 3, the supply of PhD candidates to the United States from the major source region of East Asia (mostly China), peaked in 1996. The number of American science and engineering PhDs from East Asia declined by 24% between 1996 and 2000, well before the additional visa restrictions in the United States after 2001. At the same time, the number of PhDs produced by China took off in 1996, and educational opportunities have further increased in China with the establishment of Chinese branches of Western universities. It is likely that the two trends are linked, with the decline in the flow of PhD students to the US

¹⁰ In addition, the US obtains many of its innovative entrepreneurs from immigrants. According to the US Census, the foreign-born show higher percentages of entrepreneurs compared to US-born.

from East Asia due to increasing educational opportunities at home. These declines have also intensified recently, possibly in response to stricter visa requirements after 2001, with a 22% decline between 2003 and 2004 in foreign graduate applications to American Universities to physical science programmes, a 24% decline for life sciences, and a 36% decline for engineering (CGS, 2004). The number of GMAT applications to the United States from non-US residents also declined by 25.6%, from 68,063 in October 2001 to 50,629 in October 2004¹¹.

Figure 3



Source: Table 2 & Figure 8, Wyckhoff and Schaaper, 2005.

The decline in foreign student applications to study in the United States could benefit Europe, if foreign students turn to Europe for university placement. In contrast, Europe could also be feeling the effects of an increase in educational opportunities in ‘donor’ countries. For example, in the UK, the number of university applications for the fall of 2005 by students outside of the European Union fell by 5.3%.¹² These changes suggest that Europe could find it increasingly difficult to rely on immigration for skilled workers.

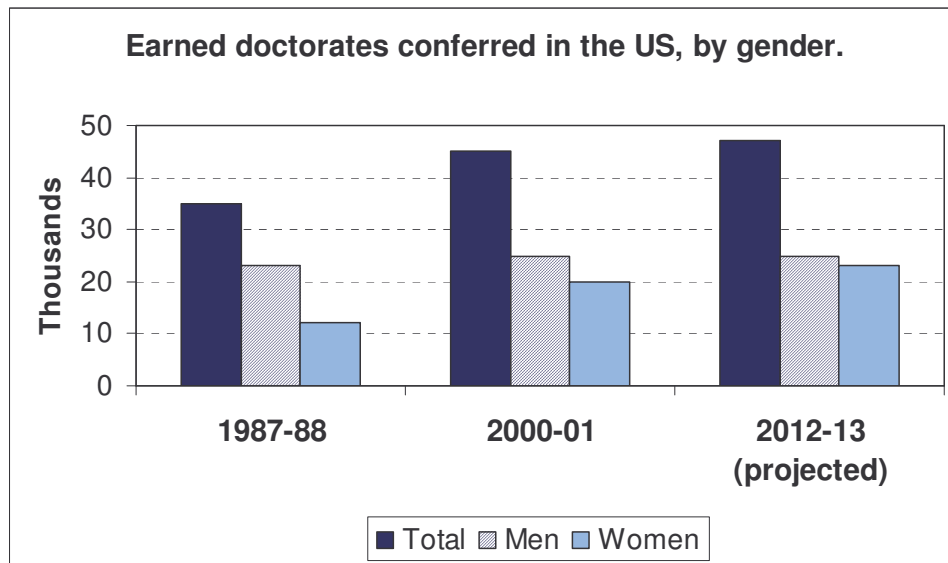
An alternative is to increase the indigenous supply of tertiary students and new doctorates from under-exploited segments of the population, including women or older age cohorts. As an example, projections for the United States show the number of Bachelor degrees rising by 21% overall between 2000-2001 and 2012-2013 with most of the growth driven

¹¹ See www.gmac.com/gmac/TheGMAT/Tools/YearToDateGMATVolume.htm.

¹² See UCAS (<http://www.ucas.ac.uk/new/press/news170205/index.html>).

by women: for women the projected rise in the number of Bachelor degrees is 25% and for men, 16%. At the doctorate degree level, the middle range projections shows an increase of only 5% between 2000-2001 and 2012-2013 and there is actually a decrease in number of doctorates estimated for men of 0.1%, whereas for women there is an increase of 12%. Figure 4 shows the estimated trend for the number of doctorates in the United States by sex (includes both US-born and foreign-born students).

Figure 4



Note: the projections are in the middle range. Source: NCES.

The quantitative goals of the Lisbon and Barcelona summits to improve R&D intensities will require better data on the pipeline that produces indigenous researchers and on success with attracting high skilled immigrants. This includes better indicators on the demographics of skills by age and gender and among immigrant and non-immigrant populations. One goal is to reverse the current declining interest in science among students that has been observed in many European countries (Finland is a notable exception) and in the supply of highly skilled individuals. This will be of crucial importance if growing opportunities for the highly skilled in the ‘donor’ countries (India and China, etc) reduce the ability of developed countries to source talent from abroad. An increase in the indigenous supply of scientists and engineers could depend on greater success in attracting large under-represented groups, such as women, to pursue science and engineering careers. This might also be necessary to overcome the decline in the supply of students due to low birth rates over the past decades in developed countries. Furthermore, the need for highly skilled individuals could partly be met through lifelong learning.

5.1 What types of skills?

The OECD is currently coordinating a new survey on the careers of doctorate holders (CDH). This information will help to inform policies to address the need for skilled individuals as part of the Lisbon and Barcelona summits. Yet it remains an open empirical question how many doctorates are necessary for efficient innovation, compared to other skilled individuals with technical training or a Bachelor or Master's level degree. How does the contribution vary across the fields of science and how does this vary across different sectors? For example, a large number of doctorates could be a good predictor of innovative success in biotechnology, but indicators on the fields of specialisation that are brought together would be needed. The need for information on the field of specialisation is particularly relevant in areas like biotechnology where measurement by the traditional classifications is difficult (e.g. some data sets provide a breakdown for doctorates in biotechnology whereas others include biotechnology within a larger discipline). Then there is the example of the aerospace sector where there may be relatively fewer doctorates and a greater mix of master's and bachelor level qualified engineers along with technically trained personnel (e.g. technologists and technicians). Better indicators on doctorates are certainly needed, but so are other indicators on the demand for (e.g. occupation, sector) and the effectiveness of researchers with other qualifications¹³.

Currently, data on human resources are based either on the identification of knowledge-intensive occupations, or, more commonly, by level of education. Occupational data are often unreliable because an occupational category can combine low and high skilled tasks. Using the level of educational attainment also has several limitations: the definition is limited to formal education and excludes workers' knowledge and life-long learning, and educational attainment does not necessarily capture all formal training because it is typically limited to the highest qualification. A more dynamic view of skills would be useful. One way to expand our knowledge is to explore the activities of knowledge workers. For example, what activities (occupations) are open for particular training (e.g. occupations of engineers)? Stephan (1999) makes the case for measuring knowledge flows from academia to industry. Likewise, how do the activities of knowledge workers (as defined by education) vary among low, medium and high-technology intensive sectors?

Shifts in knowledge intensity are taking place across a range of sectors. Canadian data suggests that knowledge intensity is pervasive and affects all aspects of the Canadian economy. Surprisingly, the largest increase in knowledge intensity was in the logging and forestry industry, followed by wholesale trade. Data for Canada show demand for highly skilled human capital occurs across all sectors and not just within the traditional 'high-tech'

¹³ Two relevant official policy documents for Canada (Achieving Excellence by Industry Canada and Knowledge Matters by HRD) do not specify if the need for more skills is specifically for doctorates or for other qualifications. The documents only provide a target for a 5% annual increase in Masters degrees and PhDs from Canadian universities.

and education sectors (Beckstead and Vinodrai, 2003). Indicators for the demand for and deployment of human resources across all industries are required.

The main problem facing policy development is the limited number and quality of human resource indicators. Traditional S&E indicators, such as the number of R&D personnel per 1,000 employees, are only of limited use. There is a need for better indicators on both the stocks and flows of knowledge workers (OECD 1996) and by the type of skill or level of education. Innovation is not dependent only on tertiary education, for example. In the case of skilled trades, the population is greying rapidly and this is exacerbated by the belief that the KBE is all about high technology and advanced education degrees. How will a chemist conduct research without a supply of custom-designed glassware once all the glassblowers have gone? Technicians and technologists are part of research teams. Skilled trades are an essential part of the network of S&E researchers, and part of the engineering and production teams that are essential to the diffusion of new technology.

5.2 Mobility

The European policy community, as shown in a diverse number of policy documents, firmly believes that there is a need for greater mobility among the highly skilled. The discussion is usually in terms of mobility between public science and private industry and across national borders, but the concept of mobility also extends to flows of skilled employees from one firm to another.

There are two economic justifications for greater mobility. First, the movement of highly skilled personnel can act as a powerful ‘vector for sharing knowledge’ and as an ‘instrument of information and technology transfer’. International mobility, especially within Europe, is assumed to be a positive factor that promotes scientific excellence and which benefits both training and careers (Harfi, 2004). Second, both the supply and demand for specialized, highly-skilled labour can be very small within a single country. This can lead to mismatches in supply and demand, resulting in either a failure to fully use the skills of scientists and engineers, or the abandonment of promising research projects, due a lack of human resources. Encouraging mobility, through reducing barriers to the movement of the highly skilled within Europe, can help improve the match between the supply and demand of human capital.

The first justification for mobility depends on how ideas and knowledge best flow between different centres of development. The stress on personal mobility (defined as a move of six months or more) assumes that such mobility provides unique advantages that are not available through other channels for the flow of information, such as reading publications and patents, attending conferences, or short term mobility to work on carefully defined projects. The theoretical justification for personal mobility is based on the distinction between tacit and codified knowledge, with tacit knowledge requiring personal contact for transmission, although it does not necessarily require face-to-face contact.

In the age of the internet and cheap travel, when does a permanent move of over six months, versus using the internet or short-term transfers to work on projects, provide distinct advantages, particularly for the flow of tacit knowledge? Similar questions apply to mobility between the public research sector and the private sector. Under what conditions is the effective exchange of ideas or innovative capability best promoted by long-term informal contacts or by long-term shifts in researchers from one sector to the other? So far, we do not know how much mobility is a good thing – there must be an upper limit¹⁴, nor do we know enough about the most effective forms of mobility – temporary, long-term, or networking via the internet (virtual labour mobility (Teferra, 2000)), or the comparative value of other channels for exchanging ideas and knowledge.

The second justification for mobility depends on the size of the labour market and the opportunities for productive research. The very low level of international mobility from the United States, with only about 3% of American citizens with new PhDs intending or deciding to work abroad, suggests that the American economy is large enough to provide ample opportunities for its own highly-skilled individuals, although there is substantial mobility of American doctorates within the United States¹⁵. The low percentage of American PhDs that consider going abroad also shows that the highly-skilled do not necessarily want to move abroad, given sufficient opportunities at home.

In the European context, the mobility of European citizens needs to be separated into two components: flows within the EU and outflow to countries outside the EU. European policy favours intra-EU mobility. This is partly because many Europeans who go abroad (mostly to the US) have no intention of returning and bringing back useful knowledge that could benefit the European economy. We also lack empirical data that might show that useful knowledge is returning to Europe via networking. There is evidence that the French and German-born return from the US, but there is no evidence on what this means for the EU. Are these persons returning with fresh ideas and at a time of high contributing potential, or are they returning at the end of their career?

One possible result is a net loss to some European countries, particularly those with generous education systems that are effectively subsidizing the US work force. However, the labour market justification for greater mobility applies as equally on the global scale as it does on the EU scale. It is possible that many of the highly skilled ICT scientists that left Europe for Silicon Valley would have languished in Europe through a lack of opportunities,

¹⁴ The models of Haupt and Janeba (2004) for mobility and Cowan and Jonard (2004) for networking find that the optimum level of each is well below the maximum possible. Wickramasekara (2003) suggests that returnees from developed to developing countries need to have 10 to 15 years experience abroad to provide benefits to their home country, but this is partly based on the time needed to acquire entrepreneurial and networking skills.

¹⁵ The 2000 Censuses in many OECD countries provide indicators on the percentage of expatriates and immigrants in each country with tertiary skills, but no information is available specifically for doctorate holders (Dumont and LeMaitre, 2004). The 1999 SED shows that this doctoral cohort is highly mobile even before their first permanent job, with 71.1% completing their doctorate in a state other than their first tertiary institution, and only 11% completing all of their education in the state of their birth.

or through a failure to work with other leading scientists in one of the world's leading innovation hotspots. The ability of Silicon Valley to attract the best from around the world is likely to be one of the causes of the stream of innovations that it has produced. In this theoretical example, the knowledge of the skilled European researchers in Silicon Valley *would have* returned to Europe, albeit in embodied form contained in ICT hardware and software.

6. Technological Shifts

The fifth structural change is very difficult to predict, but consists of major technological shifts. These shifts could occur through the development of new generic technologies such as biotechnology or nanotechnology, in response to rapidly increasing demand for food, mineral, fibre, and energy resources, or from environmental imperatives to counteract unsustainable exploitation of the world's resources (MA, 2005). Whatever the cause, technological shifts can increase demand for investment in research and the skills to use new technology.

While worries about limits to economically affordable petroleum resources have existed for some time, the growing demand from China and India could rapidly increase both prices and depletion rates. Perhaps more significant is the better understanding of how the consumption of carbon-based fuels are changing our climate. Both trends are open to criticism, but when the two trends are combined, it becomes clear that science and technology in the not-to-distant future will need to move forward on several fronts: develop alternative, economically competitive sources of energy, improve the efficiency with which energy is used, and develop methods for sequestering carbon contained in fossil fuels. This will require innovation in the resource sectors and in how energy is used across all sectors of modern economies.

Biotechnology is widely viewed as an emerging generic technology, although both the breadth and depth of its economic impacts are likely to be far less than those of ICT (Arundel, 2003). Nevertheless, the application of biotechnology to agriculture and industry could have major economic effects and hopefully substantial social and environmental benefits. Obtaining these benefits will require a long-term research strategy, which may increasingly take place in developing countries such as Brazil, China and India, rather than in the original biotechnology leaders of the United States and Europe.

Shifts in technology can also result from changes in public support for research. This is occurring in the United States, with an increase in public support for life sciences, including biotechnology, and a decline in support for technology fields (engineering, physical sciences, mathematics and computer science). The share of total Federal R&D funding in the United States for technology declined from 48% in 1981 to 32% in 2003, while funding for life sciences increased from 36% to 54% of the total. This shift in priorities is

controversial, partly due to the long lag times before health sciences R&D results in commercial products (AEA, 2005).

The future growth of all types of economic activity (including the entertainment industries) will require materials and energy. One country that recognizes this basic fact as a strategic necessity is China. Whereas developed countries are investing heavily in innovation, China is investing large amounts of money in the exploitation and purchase of natural resources worldwide. During a two-week trip in South America in December 2004, China announced investments and other expenditures in South American countries to purchase natural resources worth 100 billion dollars. A few countries such as Norway are doing extremely well out of natural resources and this is likely to continue in the future, with growing resource scarcity producing handsome rents.

7. Indicator Needs

These five major structural changes are not the only relevant trends that will influence the development of a European knowledge-based economy. Other possible factors that could influence a knowledge economy for better or for worse include cultural changes, where secular individualism might increasingly conflict with religious conservatism, as in the United States¹⁶. Systems of governance could shift towards self-regulation and network management (co-determination). Some of the trends towards globalization create political opposition that could alter current trends, or consumer actions might influence some outcomes, such as the slow food movement that support buying locally produced products instead of prepared food products sourced through global production chains. Major political upheaval in rapidly developing countries such as China or India could have substantial impacts on global value chains and the location of innovation activities. However, with the caveat that it is impossible to accurately predict the future, we suspect that the five changes outlined above will continue to affect Europe, although new trends could also develop.

These five main structural changes will influence the types of indicators that are required over the short and medium-term future to track the knowledge-based economy. Some of these indicators are already available and discussed in WP1.1. There are several categories of indicators that are lacking and will be required:

- Organizational innovation and logistics, including value-added chains
- Globalization of innovation activities
- Demand for innovative products
- The global circulation of human resources, including different types of skills

¹⁶ It has been widely pointed out that in the 2004 election in the United States, the most innovative states tended to vote Democrat, while the least innovative states voted Republican. In so far as tolerance and secularism are causes of a creative innovative environment, as argued by Richard Florida (2002), the increasing political power of religious conservatism in the United States might have a negative effect on American innovation. Over the next decade, we might be witness a natural laboratory for Richard Florida's ideas. Richard Florida (2005) has picked up on this theme in his recent book, *The Flight of the Creative Class*.

- New technologies, material and energy efficiencies

Table 1 maps the indicator requirements to track future challenges against the five main characteristics and drivers of a KBE. Indicators that are already available in a fairly consistent manner and over time are highlighted in green. Indicators that are only available from one-off studies, or sporadically, are marked in blue, while indicators that do not appear to be available at this time are in red.

Table 1. Indicator requirements for future challenges by the characteristics of a KBE.

Challenges	KBE characteristics				
	Production & diffusion of ICT	Skilled human resources	Knowledge production: R&D & creativity	Entrepreneurship & creative destruction	Structural & organisational change
Global production chains		<i>Employment effects of delocalisation of production by occupation type</i>	Prevalence of market differentiation strategies using industrial design and trademarks	<i>Spin-offs and new subsidy creation abroad by domestic firms</i>	<i>Use of consumer-supplier integrated production chains</i> Percent of firms by sector that have moved some production off shore (either directly or via contracting out)
Innovation strategies			Expenditures on R&D abroad <i>Capabilities of foreign R&D centres owned by MNES</i> Innovation collaboration outside the EU (CIS)		<i>Technological opportunities</i>
Demographic change		Numbers of new entrants into S&E fields of study Re-skilling/life long learning by age cohorts		Demand for innovative products by age cohorts (Eurobarometer) Technology use rates by age cohorts: i.e. for internet	Employment participation rate by age and sex
Human capital	Transfer of embodied knowledge to Europe from Europeans working abroad	Immigration and emigration of scientific, engineering and technically skilled, by age and gender Interest in science among young age cohorts by gender <i>International mobility indicators for the skilled</i>	Effectiveness of different methods of transmitting knowledge (PACE) <i>Mobility between public science and industry</i> <i>Educational attainment levels for innovation by sector</i>		
Emerging technology		Availability of skilled workers in emerging fields	Measures of growth of emerging areas: patents, bibliometrics, etc.	New firm establishment rates in developing fields	<i>Technological opportunities in emerging fields</i>

Key: **Bold** = indicators available; Normal font = One-off indicators available or data should be available for constructing an indicator; *Italics* = No indicators available or data sources unknown. Blank cells indicate that there are no current data needs, or the relationship is not relevant.

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