Innovation, technology and the global knowledge economy: Challenges for future growth.

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Abstract

This paper discusses the role of knowledge, technology and innovation in economic growth within the context of the "Green roads to growth" project. It summarizes the current state of the art in this area, illustrates this with selected graphs and tables based on published statistics and raises issues for discussion. The main focus is on the big shift of our understanding of economic growth that has taken place in recent decades, exemplified by emergence of terms such as "the knowledge based economy", "the ICT revolution" and "innovation", which - although not an entirely new issue – did not get much attention a few decades ago. Particular emphasis is placed on reviewing the new micro-evidence on innovation and the knowledge-based economy that has emerged in recent years. However, since extensive micro-evidence on innovation and knowledge-based growth is available only for a limited number of developed economies, we also consider other types of indicators (that are available for a larger set of countries), and present a synthetic overview of the differences in performance across different parts of the globe. Finally we summarize the main trends and discuss the challenges posed by these for future growth, sustainability and policy.

(*) I am indebted to Martin Srholec for assistance in producing many of the empirical illustrations used in this paper and to Mario Pianta and Jørgen Rosted for useful comments and suggestions. Remaining errors and omissions are my own responsibility. Address for correspondence is jan.fagerberg@tik.uio.no (P.O. Box 1108 Blindern, N-0317 Oslo, Norway).

Introduction

It is difficult to find an issue that is more central to policy makers' agenda than how to achieve economic growth. Indeed, it is generally acknowledged that economic growth is seen as essential for the realization of important policy objectives, such as income, welfare (including the environment) and – last but not least - employment. The ability of a country to foster economic growth and, hence, realize other important policy objectives is what is often termed the "competitiveness" of a country (Fagerberg 1988, 1996, Fagerberg, Knell and Srholec 2004). Therefore it comes as no surprise when policy makers in the European Union want to make Europe the most competitive region in the global knowledge based economy (the Lisbon agenda). What this means is simply to get the European Union on a growth path that is consistent with the realization of important policy objectives.

Although this may sound simple enough experience tells us that getting there may not be just as simple. In fact, the EU has not come very far in realizing the ambitious goals of the Lisbon agenda, and concerns have been expressed on to what extent the political steps taken in order to do so are really appropriate. This reminds us of the important insight that any policy aimed at raising long-term growth has to be based on a thorough understanding of the factors behind growth and the concrete circumstances into which the policy is going to be implemented. In the next sections we discuss the first of these issues in a bit more detail. Focus will be on the big shift of our understanding of economic growth that has taken place in recent decades, exemplified by emergence of terms such as "the knowledge based economy" (which seems to be on everybody's lips these days), "the ICT revolution" and "innovation" (which - although not an entirely new issue – did not get much attention a few decades ago). Particular emphasis is placed on reviewing the new micro-evidence on innovation and the knowledge-based economy that has emerged in recent years and the conclusions that can be drawn from this on how knowledge based growth works at what the scope for policy may be.

However, extensive micro-evidence on innovation and knowledge-based growth is only available for a limited number of developed economies. To arrive at a more coherent picture of global dynamics we therefore broaden the scope to include other types of indicators that are available for a larger set of countries, and present a synthetic overview of the differences in performance across different parts of the globe. Finally we discuss the challenges posed by these current trends for future growth, including the issue of sustainability. As discussed already by the classical political economists two centuries ago, growth may be of two different kinds: A mere expansion of activity without a change in methods of production, or it may involve a change in the latter as well. While the former inevitably sooner or later will be constrained by limited natural resources, the latter may arguably escape the resource constraint – at least for the foreseeable future - by getting more out of less and changing the resource base. Indeed, without continuing technological and organizational change, growth will be impossible, because of the constraints posed by limited natural resources. Therefore innovation is key to sustainable growth and economic development on a global scale.[1]

[1] Innovation is also important for employment. The introduction of new products (product innovation) is commonly acknowledged to have a clear positive effect on employment. But it has been argued that process innovation, due to its cost-cutting nature, may also displace jobs. However, such differences (in employment effects) between different types of innovations, while distinguishable at the level of the individual firm or industry, tend to become more blurred at the level of the overall economy. In fact, many economists go so far as to argue that the savings in costs, following a process innovation in a single firm or industry, by necessity will generate additional income and demand in the economy at large, which will "compensate" for any initial

Perspectives on growth: From mechanization to knowledge [2]

Intuitively, most people easily accept the idea that knowledge and economic development is intimately related. However, this is not the way different levels of development used to be explained by economists. From the birth of the so-called “classical political economy” – a term invented by Karl Marx - two centuries ago, what economists have focused on when trying to explain differences in income or productivity is accumulated capital per worker. Similarly, differences in economic growth have been seen as reflecting different rates of capital accumulation. This perspective arguably reflects the important role played by “mechanization” as a mean for productivity advance during the so-called (first) industrial revolution, the period during which the frame of reference for much economic reasoning was formed. Closer to our own age Robert Solow adopted this perspective in his so-called “neoclassical growth theory” (Solow 1956). The theory predicted that, under otherwise similar circumstances, investments in poor countries (e.g. those with little capital) would be more profitable than in the richer ones, so that the former would be characterized by higher investment and faster economic growth than the latter. As a consequence of this logic, a narrowing of the development gap (so-called “convergence”) should be expected. Based on another argument borrowed from the classical political economists (reflecting their opposition towards mercantilist politics and feudal privileges), such convergence was by many economists deemed all the more probable; the less the state interfered with working of the “free” market. This gave birth to a particular approach to development policy, termed the “market friendly” approach associated, advocated by international agencies such as the IMF and the World Bank (see, for instance, World Bank 1993).

The prediction that global capitalist dynamics would be accompanied by a convergence in income and productivity between initially poor and rich countries was an attractive one in many respects. It represented a liberal and optimistic view on global economic development. As long as governments did not interfere excessively in the working of markets, and limited itself to certain basic tasks, a happy ending was expected to be within sight. However, it is rare to see a prediction that is so completely rejected by the evidence as this one is. In fact, the history of capitalism from the industrial revolution onwards is one of increasing differences in productivity and living conditions across different parts of the globe. According to one source, 250 years ago the difference in income or productivity per head between the richest and poorest country in the world was approximately 5:1, while more recently this difference has increased to 400:1 (Landes 1998). But in spite of this long run trend towards divergence in productivity and income, there are many examples of (initially) backward countries that – at different times – have managed to narrow the gap in productivity and income between themselves and the frontier countries, in other words, to “catch up”. Japan in the decades before and after the Second World War and the “Asian tigers” more recently are obvious examples.

This diversity in performance across countries on different levels of development is not limited long historical periods (centuries) but is even more characteristic today. As an illustration of this Figure 1 plots growth in GDP per capita (horizontal axis) versus its level (vertical axis) for a large sample of countries during the last quarter of a century. In this way

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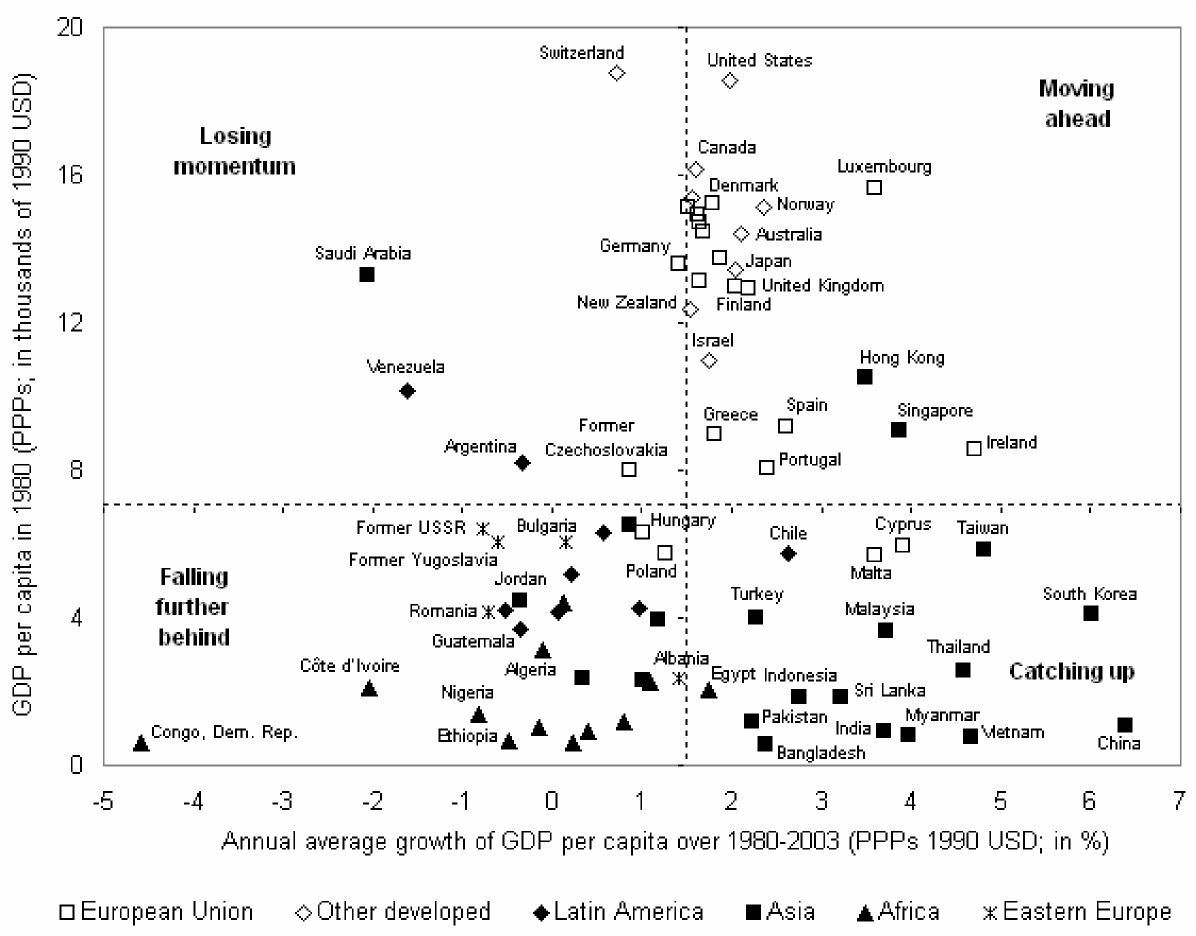
negative effects of a process innovation on overall employment. The issue remains highly controversial, and we will not discuss it in further depth here. For a good, up-todate overview of the literature on innovation and employment see Pianta (2004).

2 Some of the text in this section draws on my paper “Knowledge in space: What hope for the poor parts of the globe?, presented at a conference organized by EC, OECD and NSF-US on Advancing Knowledge and the Knowledge Economy in Washington January 10-11, 2005, forthcoming in D. Foray and B. Kahin.

four quadrants emerge. Up to the left you have initially rich countries that grow slowly ("losing momentum"), down to the right initially poor countries that grow fast (e.g. "catching up"). If the global economy is on a converging path, the great majority of countries will cluster in these two quadrants. But this is not the case, the majority of countries clearly belong to the remaining quadrants; up to the right initially rich countries that continue to move ahead of the others ("moving ahead") and down to the left poor countries that grow slowly ("falling behind"). As is evident from the graph the latter group consists to a large extent of African countries (joined by some Latin American and Asian ones and some former members of the USSR or its sphere of influence in Eastern Europe).

Figure 1: Convergence vs. divergence in GDP per capita over 1980-2003



Source: GGDC (2005).

Table 1 illustrates this tendency towards divergence in a more substantive fashion by reporting data for levels of growth in GDP per capita for major players in the global economy. It should be noted that the means reported in the table are population weighted to avoid an unwanted influence of small countries (which dominate in terms of mere numbers but not in terms of population or GDP) on the reported statistics. As is evident from the table the performance of low-income economies differs greatly. While China and some other Asian economies catch up at a rapid rate, countries in Eastern Europe and the CIS[3] and African countries hardly grow at all (fall behind). However, there are also signs of divergence between more advanced economies recently, with United States doing somewhat better in terms of GDP per capita growth than its counterparts in Europe. The latter difference, it might be noted, is even more striking in GDP growth since employment is developing more favourably in the United States than in the European union.

Table 1: GDP per capita by regions over 1980-2003 (in PPPs, population weighted)

	GDP per capita (in thousands of 1990 USD)			Average annual growth (in %)		
	1980	1990	2003	80-90	90-03	80-03
European Union (25)	11,994*	14,358	17,784	1.9*	1.7	1.8*
O/w EU-north	14,176	17,046	20,415	1.9	1.4	1.6
EU-south	11,048	13,849	17,350	2.3	1.7	2.0
EU-new members	6,386*	6,686	8,611	-0.3*	2.0	1.2*
United States	18,577	23,201	29,208	2.2	1.8	2.0
Japan	13,428	18,789	21,373	3.4	1.0	2.0
Asian Tigers	5,306	9,975	17,120	6.5	4.2	5.2
China	1,067	1,858	4,429	5.7	6.9	6.4
Asia (other developing countries)	1,510	1,924	2,834	2.5	3.0	2.8
Latin America	5,781	5,351	6,051	-0.8	1.0	0.2
East Europe and CIS	6,199	6,510	5,246	0.5	-1.6	-0.7
Africa	1,672	1,581	1,646	-0.6	0.3	-0.1
World	4,678	5,417	6,821	1.5	1.8	1.7

Note: *) Data is missing for Slovenia, Estonia, Latvia and Lithuania.
Source: GGDC (2005).

How to explain this diversity in patterns of development? Is it related to a superior ability to develop and/or exploit knowledge in the successful countries, as many perhaps would suspect? As noted in the introduction, theoretical work for a long time tended to ignore the role of knowledge in development (Fagerberg 1994). This was not only caused by the fact that economists' focus for historical reasons was elsewhere. It also had to do with a particular view on knowledge that came to dominate economics, that is knowledge as a so-called "public good" or a body of information, freely available to all interested, that can be used over and over again (without being depleted). Arguably, if this is what knowledge is about, it should be expected to benefit everybody all over the globe to the same extent, and hence cannot be invoked as an explanation of differences in growth performance. Hence, following the logic, the real reasons behind such differences must rest elsewhere. Moreover, if everybody benefits to the same extent, why should anybody care to provide it? For a long time many economists found this question so perplexing that they chose to ignore knowledge altogether (i.e., regard it as a factor that is alien to economic reasoning, or "exogenous" as it is conventionally expressed).

More recently economists such as Paul Romer put an end to this practice by suggesting that knowledge, in the above "public good" sense, is a by-product of investments that firms undertake in order to develop new products and services (Romer 1990). The reason why, following this view, firms find it profitable to do so is that intellectual property rights (patents etc.) give them sufficient protection to secure a healthy private return on their investments. Hence, following this approach, how intellectual property rights are catered for

[3] The Council of Independent States (CIS) consists of former Soviet Union member states.

(including legal and institutional aspects) may have a very important impact on the economy . The social returns are, at least on average,[4] assumed to be even higher, enhancing the pool of public, freely available knowledge, and spurring growth. If such pools of knowledge can be assumed to be "national" in character, models based on this perspective (so-called "new growth theory") might yield predictions consistent with the observed long-run tendency towards divergence in GDP per capita (with large countries - with large "national" knowledge stocks - in a particularly good position). However, such an assumption would be difficult to justify, given the perspective on knowledge underlying the approach (a body of information). Indeed, the logic of the argument clearly suggests that such freely available knowledge would not be bound to (geographical) context and hence should be expected to benefit all countries.

Should we accept that knowledge is not an important factor behind the vast differences in income across different parts of the globe? Or is there something fundamentally wrong with the way knowledge is conceived by the theoreticians? We put our bets on the latter. When Robert Solow and others started to model growth more than fifty years ago, there was not a lot of work available on knowledge and innovation in firms. However, during the last two decades we have seen a proliferation of work in thin area, with several big surveys, numerous case studies and a lot of interpretative work, and we now know a good deal more about how firms search for, develop and use new knowledge. Surprisingly, this new "knowledge on knowledge" does not seem to have been exploited much by the theoreticians in their attempts to construct models of knowledge based growth. Although innovation is now generally recognized as key to growth, formal models of growth, in particular, typically embody very abstract assumptions on how innovations are brought about, which arguably are not of much help for policymaking. Policy makers are therefore struggling with how to transform these new insights on growth into workable policies, and the European Union's Lisboa/Barcelona process may in fact serve an illustration of this.

Understanding innovation based dynamics: Conceptual framework and empirical evidence

During the last two decades innovation has increasingly become a central focus for policy makers. The reason for this is the central role innovation is assumed to play for income and employment growth (and quality of life more generally). It is increasingly recognized that high quality science and R&D is not sufficient for the realization of important social objectives. New ideas, important as they may be (with potentially far-reaching consequences), have little economic and social impact unless carried out into practice. This – carrying new ideas out into practice – is what innovation is about, and that is why it so important.

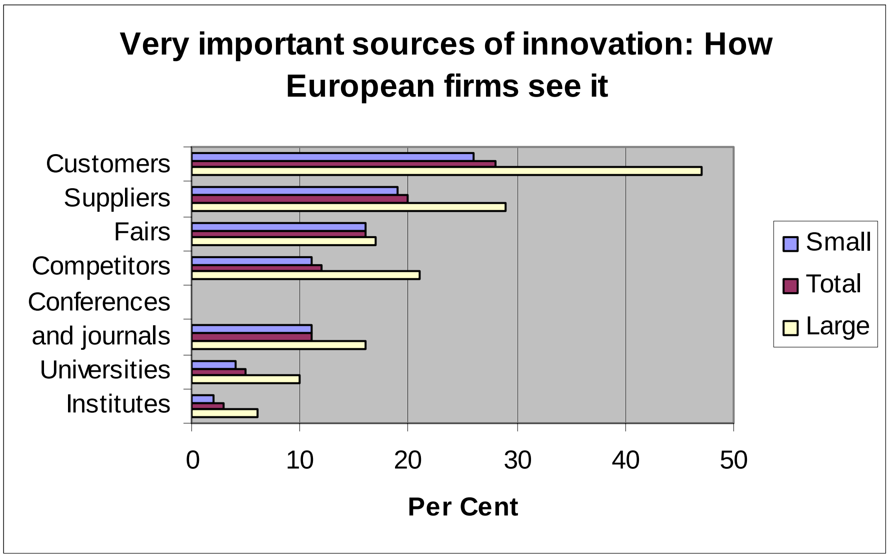
For a long time this seemingly innocent step – carrying new ideas out into practice – was not seen as very significant. The major focus, among policy makers and academics, was on the process prior to the first attempt of commercialisation of a new idea, e.g., science and research (within large public and private sector organizations). As long as investments in science and R&D were kept at a high level, it was assumed that the derived social and economic benefits would follow. This perspective on innovation - which later became known as "the linear model " (Kline and Rosenberg 1986) - has typically been used to legitimate large public investments in science and R&D. It continues to be an influential view,

[4] Since new technology displace old technology, and hence makes investments made in the latter obsolete, social returns may also in some cases be less than (the sum of) the private returns (see Aghion and Howitt 1998). We will not discuss this possibility further here,

particularly among policy makers. For instance, this type of reasoning concurs well with the recently announced EU policy of raising its expenditure of R&D to the 3% of GDP level.

However, although few would deny that science and R&D play important roles in long run economic social and change, the exact nature of these relationships has been subject to considerable controversy. Partly this had to do with the problems in identifying empirically the links between investments in science and R&D and the assumed economic benefits. Another source for raising new questions about innovation comes from a diverse body of empirical research on innovation processes in firms. Although some of it dates way back, this research has been especially vibrant in recent years, particularly in Europe (the so-called Community Innovation Survey – CIS). The CIS survey, now in its third version (Eurostat 2004), shows that, apart from internal sources, interaction with users is the most important source of innovation for firms followed by contacts with suppliers, participation at fairs/exhibitions and impulses from competitors (Figure 2). Contacts with the public R&D infrastructure (universities and research institutes) are generally considered to be of much lesser importance. Although there are some differences in results across countries and/or industries, the ranking of the various sources in terms of their importance is remarkably robust. The biggest difference is actually between firms of different sizes; large firms consistently value external sources of innovation more highly than do small firms.

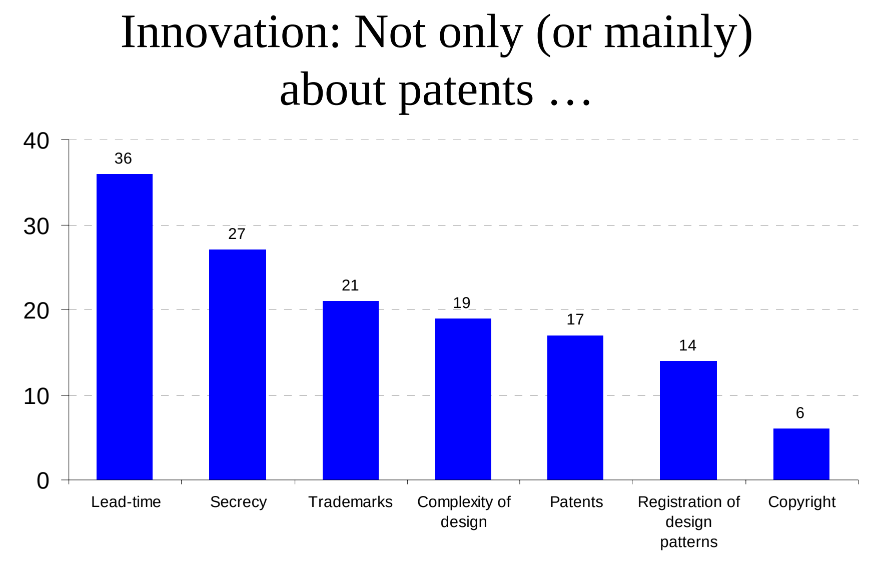
Figure 2. The Community Innovation Survey: Evaluation of external sources of information used in innovation



Source: Eurostat (2004)

This is not to say that universities do not have an important role to play in a knowledge based economy, but according to firms the most important impacts are of an indirect nature, such as through the supply of highly educated and skilled personnel. Admittedly, these findings may seem to be at odds with the widespread expectations among university administrators these days of substantial future incomes to universities from direct involvement in innovation activities (through intellectual property rights - IPRs). However, available evidence from the US, which spearheaded this movement, indicate that for most universities that have followed this trajectory, establishing an IPR system has in fact been a pure financial loss (Mowery 2004). Arguably, the type knowledge on which much recent discussion of this subject focuses, e.g., codified information that is patented and traded in markets (or not patented and hence provided for free), is only one among several types of economically relevant knowledge (albeit an important one). In fact, there is now a large body of research showing that firms generally do not regard patenting as the most important way to protect their knowledge (Foray 2004, Granstrand 2004, Figure 3 below). This does not imply that there may not be segments within certain sectors or industries that are different in these respects (the biotechnology industry is the prime example) but the general picture is a different one.

Figure 3. The Community Innovation Survey: How to appropriate the benefits innovation

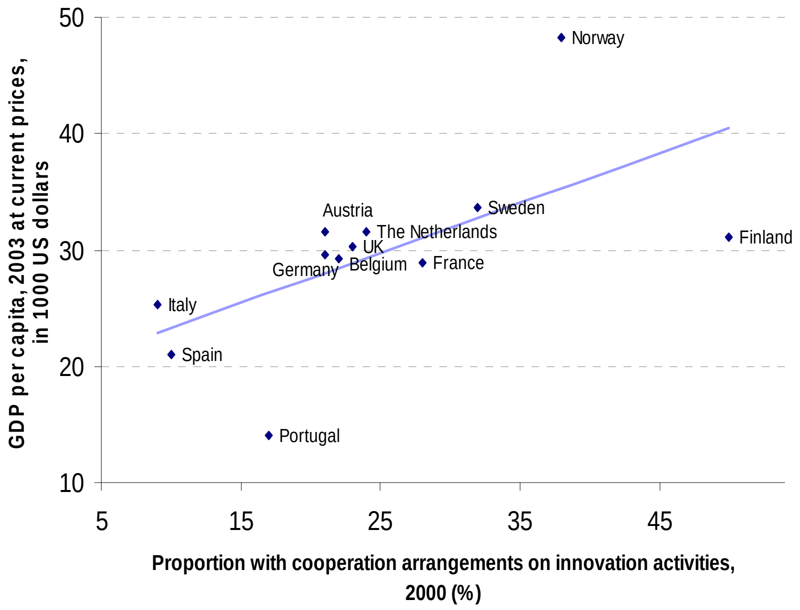


Source: Eurostat

The truth of the matter is that in most areas of knowledge, there is a long way from scientific discoveries to commercial exploitation. Lags of several decades or more are not uncommon (Rogers 1995, Fagerberg 2004). Technological activities of firms seldom take abstract scientific principles as point of departure and search for commercial applications (although that may happen). The general pattern is that of a perceived need among customers, a problem that needs to be solved, which generates a search for relevant knowledge. Research emphasizes that, in most cases, firms only have imperfect knowledge on the relevant options in front of them, and that they tend to be myopic, searching, internally at first, then in the neighbourhood of their existing competence/network (Nelson and Winter 1982, Dosi 1988, Cohen and Levinthal 1990, van der Ven et al. 1999). Consistent with this, as illustrated in Figure 2 above, the most highly valued external sources are typically customers and suppliers.

The finding that innovation does not only depend on firms' own (internal) efforts, but also on interaction (and knowledge sharing) with external actors, such as customers and suppliers, led during the 1990s to the formulation of a new approach ("systems of innovation", see Lundvall 1992 and Nelson 1993), which explicitly attempts to take the systemic (or recurring) character of such patterns of interactions more thoroughly into account. This system approach, in its various versions, has become popular among policy makers and analysts, among other things due to its flexible structure (which means that it can easily be adapted to different settings/issues) and the fact that it offers a handy framework for accumulating knowledge about the links between the public R&D infrastructure, policy initiatives/support schemes and firm behaviour. Although it has been argued that (perhaps because of this flexibility) the approach lacks precision when it comes to making statements on causality and providing policy advice (Fagerberg 2003, Edquist 2004), the correlation between the extent of innovation-cooperation and GDP per capita is very strong, indicating that innovation-cooperation pays off (Figure 4).

Figure 4: Innovation-cooperation pays off



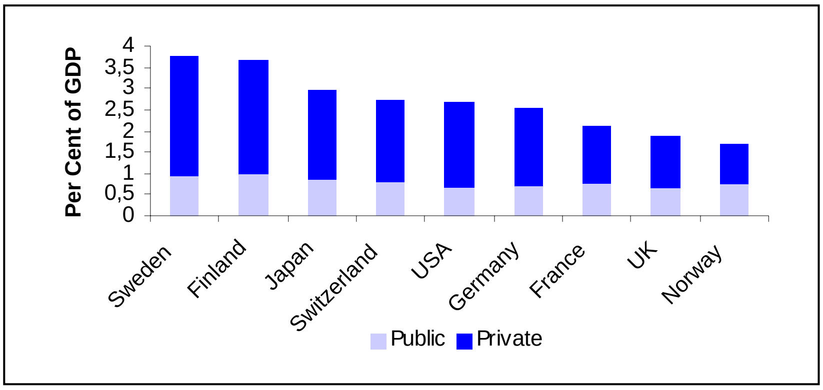
Source: Own calculations based on Trendchart Innovation Scoreboard 2 and Eurostat (2004)

What much recent work in this area boils down to is that some of the popular folklore surrounding the innovation phenomenon, focusing for instance on the construction of technologically very demanding devices, based on scientific breakthroughs, occurring in big laboratories with the help of very advanced and expensive equipment etc., may be a bit one-sided. Albeit some innovations are of this sort, many are not, including a lot of those that matter economically. In fact, innovation is not limited to certain so-called high-tech industries, but flourishes in other industries as well, not to speak of services (von Tunzelmann and Acha 2004, Miles 2004), although the factors that matter for innovation (and consequently the available policy options) may vary somewhat from one sector to another (Malerba 2004). Although some innovations may be spectacular technological breakthroughs, the bulk of innovation in modern societies consists of relatively small improvements and it is probably a safe bet that the cumulative impact of these is as great (or greater) than that of the more "radical" or "revolutionary" ones.

Moreover, a key lesson from modern innovation research is that not only technological innovations of the product and process type, which are what people often use to focus on, matter but that organizational innovations are very important as well. In fact, many of the most important innovations throughout history have been of the organizational kind such as, for instance, the new distribution system that accompanied the development of mass production in the US a century ago, or how Toyota and other Japanese companies reorganized the entire value chain in the car industry in the period following the end of the Second World War (Bruland and Mowery 2004, Fagerberg and Godinho 2004, Lam 2004). Although some organizational innovations have followed in the wake of technological breakthroughs, and have been shown to be of critical importance for the commercial exploitation of such advances, organizational innovation may also be an important impetus to growth in its own right (the Japanese experience in the car industry is arguably an example of this).

Thus we now have relatively extensive evidence from several countries, based on surveys of innovation activities of firms, that consistently shows that what generally matters most for successful innovation is not so much the link with basic science, big public laboratories or universities, or IPRs for that sake, but close interaction with users (demand), suppliers and competitors (Granstrand 2004, Smith 2004, von Hippel 2005). These lessons may raise important questions for policy. Arguably, in many cases the policy discourse tends to focus too much on the resources available for innovation, e.g., R&D, rather than innovation as such, which – if anything - should be the prime target for policy. For instance, a well-known concern among policy makers has been that of too little investments in R&D compared to other countries. But such comparisons tend to forget that these figures may reflect differences in specialization patterns, since R&D intensities differ a lot across industries, and countries for various reasons specialize (and distribute their R&D) differently across industries/sectors. In fact, there are much larger differences across countries in R&D efforts than in GDP per capita (which is what matters most in the end). Arguably, it is not obvious that it would be a good idea to regard the industrial structure of a country as obsolete, just because it is not high R&D. As pointed out by von Tunzelmann and Acha (2004), there may be a lot to gain economically from investing in innovation (including R&D) in industries with more modest R&D requirements. On the other hand, it is perfectly possible that there may be industries (or industrial segments) for which the prospects are far from promising, so that a gradual reorientation would be more than justified. However, to be able to deal with such issues in a constructive manner, a relatively detailed analysis of a country's innovation system – its strength, weaknesses as well the external challenges with which it will be confronted – would be required. Concentrating all the attention on a specific number – R&D as a percentage of GDP – may be of little help in this regard.

Figure 5. Cross-country differences in R&D: Private, not public



Source: Trendchart Innovation Scoreboard 2002

It is also important to keep in mind that differences in aggregate R&D intensities across developed economies are mostly due to differences in private, not public investments in R&D (which tend to be more equal across the developed world). Private investments in R&D, on the other hand, depend on a number of factors, such as for instance the strategic orientation of management, the costs, the perceived risk, the demand for new, innovative products or services and the extent to which R&D is deemed necessary to be able catering for this demand. Hence, innovation and R&D are jointly decided. If demand is failing or risk considered too high (which may in some cases amount to the same thing), innovation projects will be abandoned (or not started), and the same applies to the associated R&D investments.

Focusing exclusively on the amount of R&D investment, instead of innovation and the wider set of factors that influences it, may in fact not be so fruitful.

The global knowledge economy and the ICT revolution

In some sense growth has always been knowledge-based, so one might think that what we have witnessed is more a shift in perspective than in the way the global economy works. There is some truth in this statement but we shall argue that there is more to it than that. Since extensive micro-evidence on innovation and knowledge-based growth of the type considered above is available for a limited number of countries only, we will in this section broaden the scope to include other types of indicators, available for a larger set of countries, that in various ways reflect the roles that knowledge and innovation play in the economy. The first broadly available indicator that we will consider is patenting in the United States. There are a few things to note here. First, in contrast to what is often taken for granted, patents reflect invention not innovation. The great majority of inventions never reach the innovation stage, and many innovations are never patented. Hence, patenting is only a very partial measure of innovation, with a clear bias towards (potentially) valuable codifiable knowledge that is easy to copy/distribute and hence may depend on legal protection for its realization. Second, since patent systems differ across countries, comparative analyses are commonly restricted to patenting in one single country (due to its share size the US market is normally preferred).[5]

The patent data reported in Table 2 illustrate several important trends. The first is the rapid increase in patenting over time. This increase is especially evident for ICT patents, the number of which increased by a factor of five during the last quarter of a century (compared to a mere doubling for total patents). This clearly reflects the crucial role played by innovation and diffusion of ICTs during this period, as well as the important role played by patenting in the ICT industry. The second important trend is the almost total lack of patenting in the US market by developing country firms. This does, of course, not imply that such firms do not innovate at all but that in most cases the innovations they undertake are not patented (or patentable), as will be the case for many minor innovations. Among the developed countries, the US performance is of course impressive (but difficult to interpret given the lack of assured comprability). However, what is even more striking is the very rapid growth in Japanese patenting in the US market, with a level in 2004 on pair with the US performance (total patents) and clearly above the US for ICT patents. Patenting by the Asian Tigers (Korea, Taiwan, Singapore and Hong Kong) grew even faster, from an almost negligible level to a level well above the European average. Thus for what it is worth, the data seem to confirm the leading role played by US – and increasingly so – Japanese firms in the global knowledge economy, with European firms lagging considerably behind, recently overtaken by Asian

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5 It is generally acknowledged that the propensity of American residents to register inventions in their own national patent office (USPTO) is higher than that of non-residents, and that this creates an upward "home country bias" in the statistics (that needs to be corrected for to allow for international comparisons based on the USPTO data). Following Archibugi and Coco (2004) we adjust for this bias by taking into account information on US and Japanese patents registered at the European Patent Office (EPO). The assumption is that since Europe a foreign market both for American and Japanese inventors there should no bias in the propensity to patent for inventors from these countries in the European market (while data for European inventors in the European market will be biased of course). The formula used is the following (see Archibugi and Coco 2004, p. 633):

$$\textit{Adjusted US patents at the USPTO} = (JAP_{USA} * USA_{EPO})/ JAP_{EPO}$$

where JAP_{USA} represents patents granted to Japanese residents in the United States, while USA_{EPO} and JAP_{EPO} capture patents granted to American and Japanese residents at the EPO.

Tiger firms as well. This appears to confirm the widespread worry that Europe is not adapting well to the challenges posed by innovation-based growth (Fagerberg, Guerrieri and Verspagen 1999).

Table 2: Patents granted at the USPTO by regions (per million people)

	Total patents			ICT patents		
	1980	1990	2004	1980	1990	2004
European Union (25)	32.0	40.6	55.0	4.6	7.1	17.2
O/w EU-north	52.2	65.4	88.1	7.6	11.8	28.2
EU-south	7.7	12.2	15.9	1.1	1.6	3.6
EU-new members	2.5	2.0	2.0	0.2	0.2	0.4
United States	163.7	189.7	286.2	27.5	39.9	122.7
Japan	61.1	158.1	277.5	15.1	57.2	146.9
Asian Tigers	1.7	14.2	135.7	0.2	2.6	69.5
China	0.0	0.0	0.4	0.0	0.0	0.1
Asia (other developing countries)	0.0	0.0	0.2	0.0	0.0	0.1
Latin America	0.3	0.3	0.6	0.0	0.0	0.1
East Europe and CIS	1.6	0.7	0.7	0.2	0.1	0.2
Africa	0.2	0.2	0.1	0.0	0.0	0.0
World	14.0	17.2	26.0	2.4	4.0	11.3

Note: The “home country advantage” of United States in the USPTO patents is adjusted according to an estimation method proposed by Archibugi and Coco (2004, p. 633).
Source: OECD (2005a).

Does this picture withstand scrutiny? For this purpose we report in Table 3 data for three related indicators; R&D expenditure, production of scientific articles and ISO 9000 certifications in the last decade or so. Compared to patents R&D clearly is a broader indicator, reflecting efforts/capabilities of relevance for invention, innovation and absorption of technology/knowledge. Hence it may be seen as a reflection of what is commonly called “technological” or “absorptive” capacity, e.g., the ability to not only develop but also to identify, acquire and use new knowledge (Kim 1997, Cohen and Levinthal 1990). Consistent with this it has a much more egalitarian distribution across countries than patents. The rapid increase in Chinese R&D is especially noteworthy (Dahlman and Aubert 2001). But also Japan and the Asian tigers increase their R&D efforts significantly over the last decade. As in the case of patenting, the dominating R&D performers are the US, Japan and the Asian Tigers, but this time with Japan in a comfortable lead (as a percentage of GDP). Europe is, again, lagging behind the frontier. However, Europe is doing better in science (articles), on pair with Japan in fact, but still below the United States. Europe is also doing well on ISO 9000 certifications, especially in the South. Japan too is performing reasonably well on this dimension.

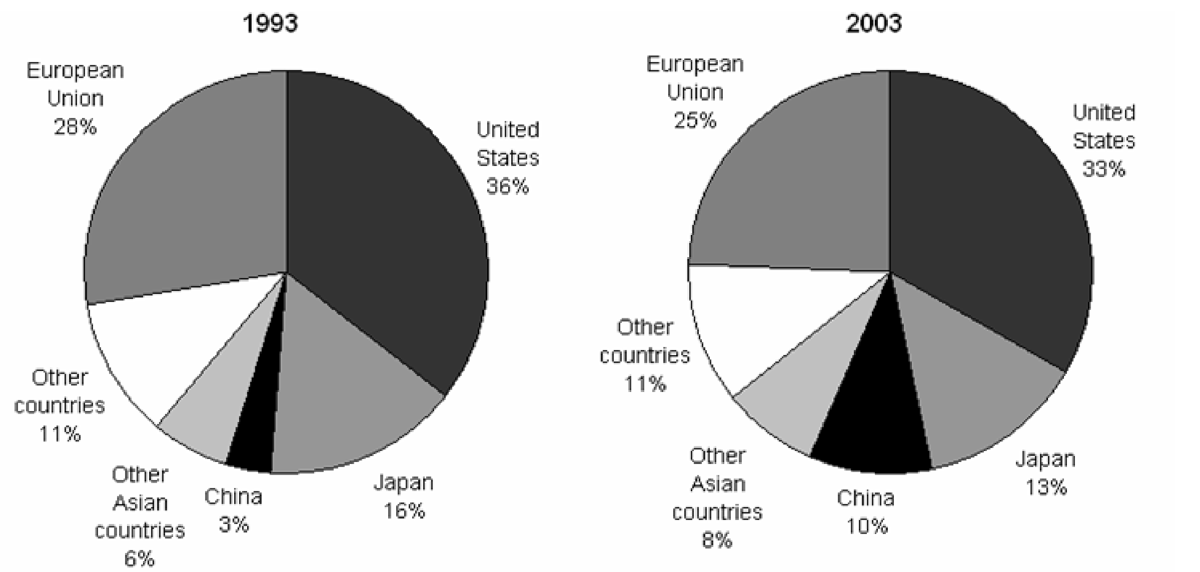
Table 3: Technological capabilities: Selected indicators

	R&D expenditure ¨ (% of GDP)		S&E articles (per million people)		ISO 9000 certifications (per million people)	
	1993	2003	1991	2001	1993	2003
European Union (25)	1.8	1.8	366	496	83	539
o/w EU-north	2.2	2.3	517	649	141	453
EU-south	1.0	1.1	201	362	11	860
EU-new members	0.9	0.8	115	181	1	322
United States	2.5	2.6	767	704	8	143
Japan	2.8	3.2	319	452	3	438
Asian Tigers	1.7	2.3	75	316	12	274
China	0.7	1.3	5	14	0	75
Asia (other developing countries)	0.5	0.6	7	9	0	14
Latin America	0.5	0.6	15	31	0	23
East Europe and CIS	0.9	1.1	5	66	0	37
Africa	0.5	0.5	9	7	1	5
World	1.7	1.8	90	106	8	91

Note: Data on R&D refer to the nearest year available to 1993 and 2003.
Source: OECD (2005b), RICYT (2005), NSF (2005), ISO (2004).

Hence the picture that suggests itself is one of a high performing US, a highly sophisticated and productive (but slow-growing) Japan and a number of other Asian economies rapidly catching up both technologically and economically. Europe on the other hand appears increasingly to stagnate and lag behind along most dimensions. It is important to note that the share size of some of these rapidly growing Asian economies is bound of to have an important impact on the global knowledge economy. As shown in Figure 6 below, today about one third of global R&D is done in Asia, about the same as in the USA and well ahead of the EU (one quarter). China alone stands for about one tenth of global R&D (and rapidly increasing).

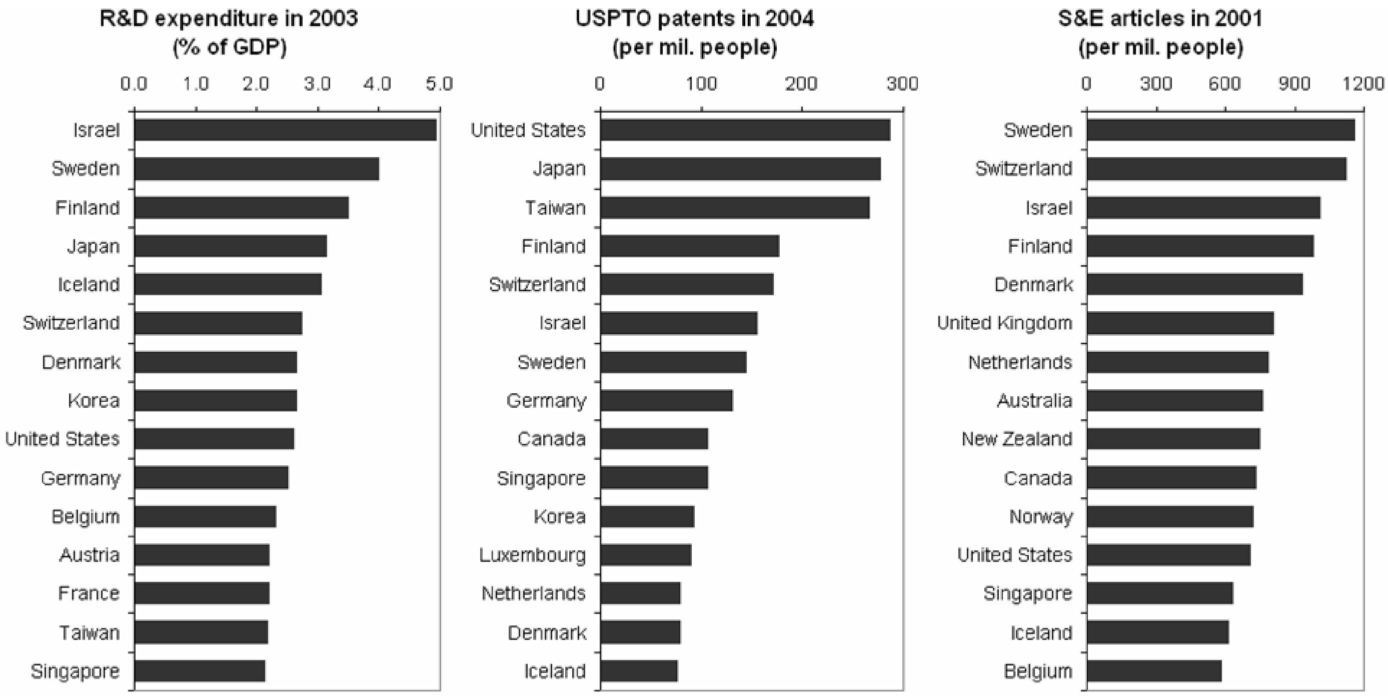
Figure 6: Concentration of R&D expenditure in the world economy (in PPPs)



Note: Data on R&D refer to the nearest year available to 1993 and 2003. The group of other Asian countries also includes Asian Tigers. Source: OECD (2005b).

However, Europe consists of many different countries, so to better account for this diversity we include in Figure 7 the fifteen highest-ranking countries along the four indicators considered above. It is interesting to note that the countries with the best performance generally are small countries, several of which are European. Four small countries in particular generally obtain a high rank; Finland, Israel, Sweden and Switzerland. This is particularly so for scientific publications and R&D. For patenting the US, Japan and Taiwan are the frontrunners but immediately followed by the above "gang of four". The ranking on ISO 9000 indicators tends to deviate a bit from the other indicators but two of these four small countries are among the four top performers in this case too. Hence the relatively mediocre rating for Europe on the indicators considered here is not the result of a uniform pattern. Primarily it reflects the performance of the larger European economies.

Figure 7: Top 15 countries by selected indicators of technological capabilities



Note: Data on R&D refer to the nearest year available to 1993 and 2003.
Source: OECD (2005ab), RICYT (2005), NSF (2005), ISO (2004).

Tables 4 and 5 contain information on another important aspect of technological capability, what is often termed “human capital”, e.g., the level of education of the population/labour force. As is evident from table 4, enrolment in secondary schooling has been high for most developed economies for a long time. Historically, enrolment rates have been much lower in the developing part of the word, but have recently started to rise there as well. However, despite this increase, enrolment in secondary education is still low in Africa and parts of Asia.

There are much larger differences in tertiary enrolment. The first thing to note is the very special position of the United States. If we go back 25 years, more than half of the relevant age group in the US was enrolled in tertiary education, compared to less than one quarter in Western Europe. Although the United States continues to be in the lead in this area, over time the differences between the US and other developed economies have been reduced, and the level of tertiary enrolment has increased in most countries. But tertiary enrolment continues to be at a very low level in many developing countries in Africa and Asia (including China).

Table 4: School enrolment by regions (gross enrolment ratios)

	Secondary schooling			Tertiary schooling		
	1980	1990	2002	1980	1990	2002
European Union	82	92	121	23	32	60
o/w EU-north	87	97	139	24	36	61
EU-south	75	90	106	23	33	60
EU-new members	83	84	103	18	21	56
United States	91	93	94	56	75	83
Japan	93	97	102	31	30	51
Asian Tigers	75	87	90	14	31	67
China	46	49	70	2	3	16
Asia (other developing countries)	31	42	56	6	8	14
Latin America	42	49	89	13	17	27
East Europe and CIS	95	92	93	37	42	54
Africa	21	29	37	4	5	9
World	49	55	70	13	16	26

Note: Averages weighted by country’s population.
Source: USAID (2004) and World Bank (2005).

The fact that US enrolment rates were so much higher than elsewhere a few decades ago transforms into a much higher share of population with completed tertiary education today (Table 5). This puts the United States in a unique position; around one third of its labour force has completed tertiary education, compared to around one sixth of the labour force in Japan and the Asian Tigers and one tenth of the labour force in the European Union. To the extent that contemporary technological progress is skill-biased (Acemoglu 2002, Pianta 2004), the unique position of the United States in this regard may explain some of the superior performance of the US economy when compared to other developed economies recently. However, in many developing economies the level of skills is still much lower. For instance, in China only one of every fifty members of the labour force (over 25 years of age) has completed tertiary education. This together with relatively low enrolment rates indicate that for China and other countries in a similar situation the skill-level of the labour force will continue to be low for many years ahead.

Table 5: Share of population with completed schooling (in %; age over 25)

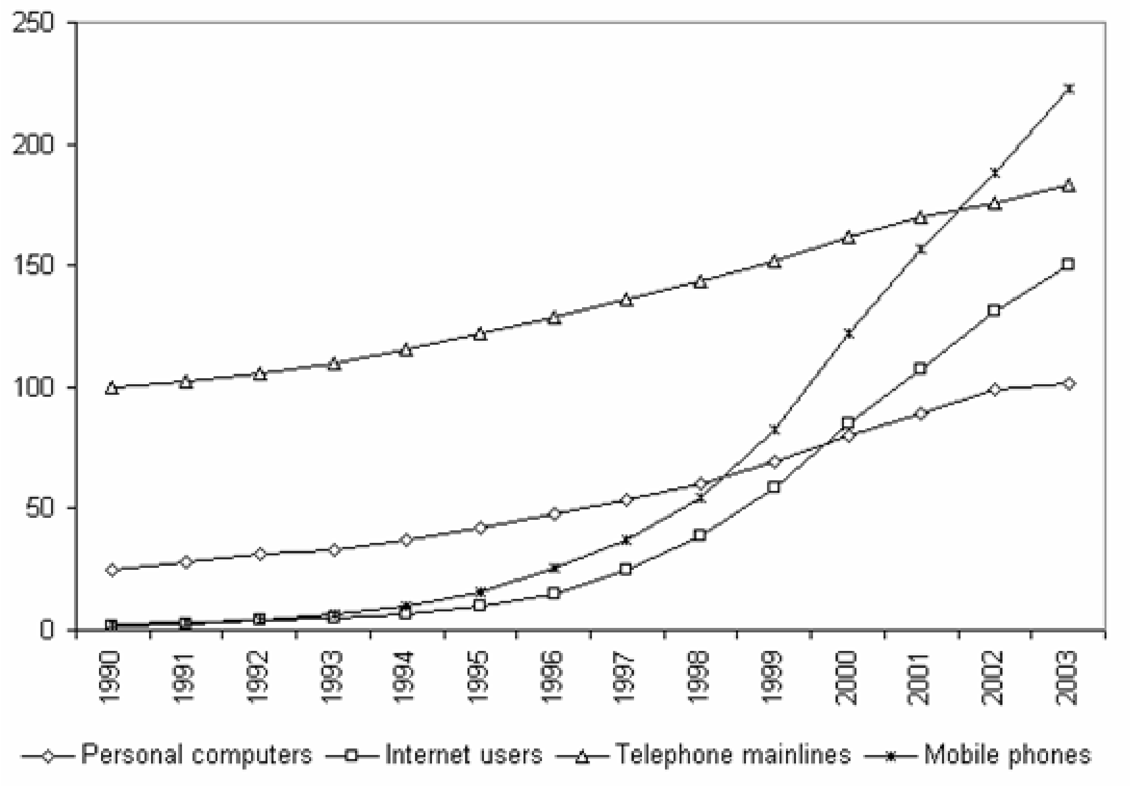
	Secondary schooling			Tertiary schooling		
	1980	1990	2000	1980	1990	2000
European Union	15	18	18	5	7	10
O/w EU-north	19	21	20	5	7	11
EU-south	9	12	13	3	5	9
EU-new members	12	17	18	5	7	10
United States	47	24	22	18	27	30
Japan	15	16	17	9	13	15
Asian Tigers	17	29	30	6	8	15
China	6	14	14	1	2	2
Asia (other developing countries)	5	7	8	2	3	4
Latin America	5	7	8	4	6	8
East Europe and CIS	n/a	n/a	n/a	n/a	n/a	n/a
Africa	2	4	7	1	2	3
World	9	11	12	3	5	6

Note: Average weighted by country's population.
Source: Barro and Lee (2000).

ICT is a much-heralded factor in economic growth, epitomized by the protagonists of the so-called "new economy" perspective on growth and development. Although the popularity of the concept "new economy" faded somewhat after the crash of the Internet bubble, the ICT revolution is a real phenomenon that should not be taken lightly. Not only has it created powerful new industries (and unbelievably rich industrial tycoons) but it has also revolutionized "how things are done" in many if not most areas of economic and social life. In fact the latter is what is meant by a technological revolution (Freeman and Louca 2001). Although the new industries that emerge are important drivers of growth in their own right, the major economic effects arguably come through the diffusion and application of ICTs throughout the economy and the continuing improvements that follow in the wake of these processes. Therefore, the extent to which a country manages to benefit from the ICT revolution will not primarily depend on its ability to develop into a competitive location for production and export of ICT products, which after all not every country can succeed in doing, but on the ability of the country to successfully diffuse and apply ICT technology throughout the economy. Thus, if one is interested in the relationship between ICT and economic growth, especially in a comparative perspective, it is very instructive to look at diffusion rates for major ICT products, which is the approach adopted here.

Figure 8 illustrates the ongoing character of the ICT revolution by comparing diffusion rates for an "old ICT" – mainline telephony – with three new technologies that emerge from the ICT revolution; PCs, the Internet and Mobile telephony. As is evident from the graph mainline telephony – which was invented more than a century ago – continue to diffuse at a relatively rapid rate. In the beginning of the 1990s there was one telephone per ten people in the world at large, in 2003 the density of mainline telephones had increased to one per six persons. One should perhaps have expected that the speed of diffusion, as indicated by the slope of the graph, would be much higher for the new ICTs, and this clearly applies for both mobile telephony and internet use (which have developed very rapidly from an almost negligible level ten years ago). In fact the spread of mobile telephony has now surpassed that of the older technology (mainlines) and Internet use is not far behind. But, interestingly, the diffusion of PCs, an arguably much more costly (and demanding) technology compared to, say, mobile telephony, has been much slower. Still there is less than one computer per ten persons in the world at large. This indicates that diffusion of ICTs still has a long way to go.

Figure 8: Diffusion of ICT technologies in the world economy (per 1,000 people)



Source: ITU (2005) and World Bank (2005).

Table 6: Indicators of ICT diffusion by regions in 2003 (per 1,000 people)

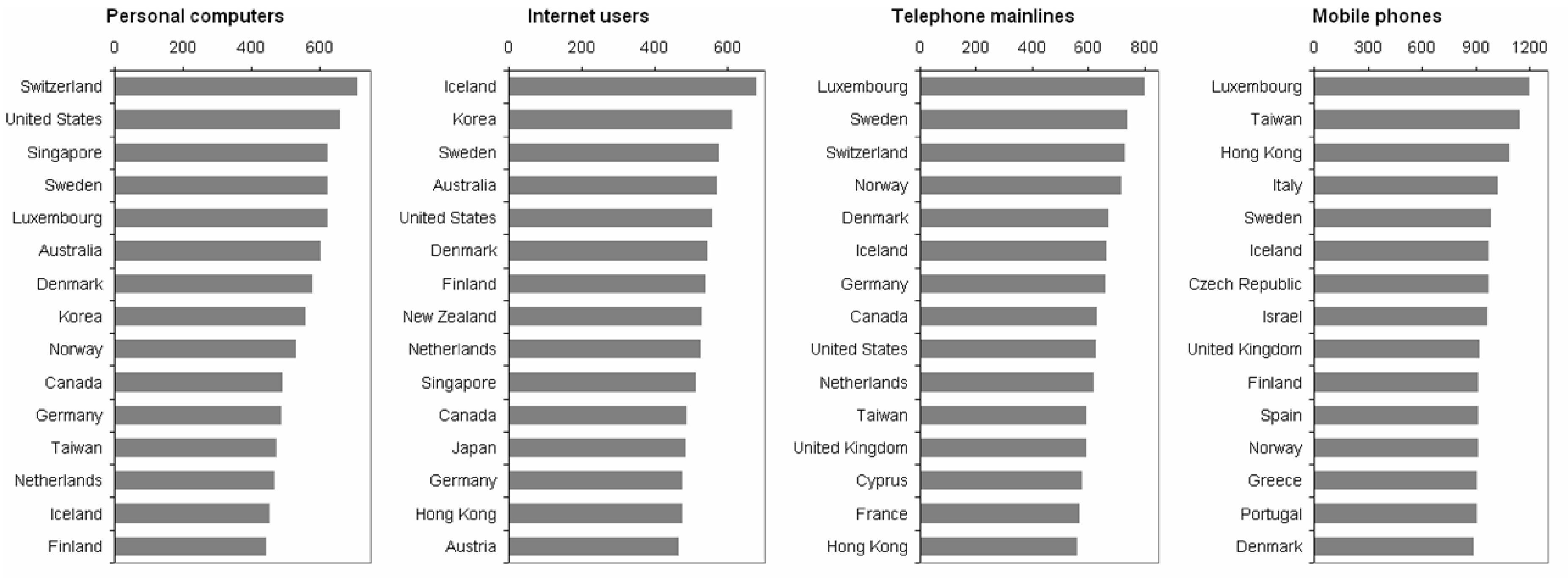
	Personal computers	Internet users	Telephone mainlines	Mobile phones
European Union	324	366	520	817
o/w EU-north	429	440	604	809
EU-south	197	274	458	960
EU-new members	161	258	325	614
United States	660	556	621	543
Japan	382	483	472	679
Asian Tigers	526	533	550	862
China	28	63	209	215
Asia (other developing countries)	17	32	59	75
Latin America	68	90	169	233
East Europe and CIS	69	53	216	199
Africa	14	15	29	60
World	101	113	186	228

Source: ITU (2005) and World Bank (2005).

Table 6 reproduces the same indicators for major countries and regions of the global economy for the most recent year available (2003). This shows that ICTs are very unevenly distributed across the global economy. Diffusion rates in Africa are only a small fraction of those in the developed part of the world. This applies to all ICTs but is most evident for PCs and the Internet. But as in other areas there are important differences within the developed world as well. In general the US is in the lead in the diffusion of new ICTs, especially PC and Internet technology, closely followed by the Asian Tigers and – at a certain distance – Japan and the European Union. However, the Europan Union is doing better than the US in the diffusion of mobile telephony, in which it is second only to the Asian Tigers. Interestingly, mobile telephony is the only major ICT technology that has caught on in the poorer part of the world. In Africa for instance, although still at a low level, there are four times as many mobile telephone users than PC or Internet users.

As with other types of statistics these overviews may mask important differences within the aggregates. We therefore plot in Figure 9 the indicators for the top fifteen countries along each of the four indicators considered above. It is interesting to note that although the United States is relatively high up on the list for diffusion of PC and Internet technology (but not mobile telephony) the position of the country is by no means exceptional. In fact it is joined as being among the world leaders in ICT use not only by the Asian Tigers (as might be expected from the evidence considered above) but also by a bunch of smaller European economies. In fact on every indicator in Figure 9 about one half of the top fifteen performers are small European countries such as, to mention some prominent examples, the Nordic countries, Luxembourg, the Netherlands and Switzerland. Hence, the relatively modest performance of the European Union as a whole in the diffusion of some core ICT technologies when compared to, say, the USA and some Asian economies, is primarily caused by developments in the larger member countries.

Figure 9: Top 15 countries by indicators of ICT diffusion in 2003 (per million people)



Source: ITU (2005) and World Bank (2005).

Another important aspect of the ICT revolution may be its relationship with knowledge (Foray 2004). According to some analysts the exact relationship between growth and knowledge has changed due to ICTs, making knowledge more footloose and hence challenging the competitive positions of well-established locations for economic activity in Europe and elsewhere, favouring poorer economies and giving a strong impetus to "convergence" in productivity and income in the global economy. This is an important issue for which "hard" evidence is hard to come by (and which we consequently will not venture into in great detail here, see Ernst, Fagerberg and Hildrum (2002) for an extended discussion). However, while it is true that knowledge codification has been on the increase for centuries, and that this continues at an accelerated rate in the present ICT era, much economically relevant knowledge is not of this form. For a firm to profit from knowledge, whether through exploitation of existing or creation of new knowledge, what is required is the ability to combine many different kinds of knowledge/capabilities, of which some may not be codified and have little to do with science or technology in the received sense. For instance, it has been shown that relevant skills in combination with the ability to undertake adequate organizational changes are of critical importance for being able to profit from new ICTs (Bresnahan, Brynjolfson and Hitt 2002). Hence, although the ICT revolution has affected economic growth in a major way, and is likely to continue to do so for a considerable period of time, it is in itself not likely lead to increased convergence in productivity and income across the globe. In fact, the effect may just as likely be the opposite one if current trends towards a very uneven distribution of ICTs globally (the "digitial divide") are not reversed.

Summing up the argument – implications for policy

This section will sum up some of the "stylized facts" that emerge from the analysis. Are there groups of countries emerging that position themselves quite differently with respect to the growth of the global knowledge-based economy? What are the possible implications of this with respect to growth and convergence? Are the policy initiatives that have been developed in Europe, such as those originating from the Lisbon/Barcelona summits, appropriate in this new situation? And what about the longer term (and the need for a transition to a sustainable growth path)?

However, let us first delve into what is implied by the term "knowledge based economy" and the extent to which it raises new challenges and opportunities for economic growth at the country level. In short, based on the evidence considered in this paper, can we affirmatively decide the extent to which there is something fundamentally new to "the knowledge economy" or if it – alternatively - is "old wine in new bottles"? If pressed on the subject I would say yes to the former and no to the latter. As pointed out previously knowledge has always been important for economic development but the way it operates today is new compared to situation, say, a century ago. This change is the combined effect of several important trends, some of which have gone on for a long time and some that are more recent. First it is the rise of innovation as an organized activity within firms. A century ago devoting resources to R&D and innovation was very rare. Today leading companies realize that without it they will not survive for long. This process of change started in Germany a century ago, continued in the US from the Second World War onwards (Nelson and Wright (1992) and has since spread to most of the globe. Hence as a global phenomenon it is fairly recent. The second important trend is the rise of what we may term a supportive R&D (or innovation) infrastructure – and a corresponding policy field - at the regional and/or national level, what is today commonly studied under the heading of "systems of innovation" (Edquist 2004). This is clearly a post-Second World War phenomenon (and in most countries much more recent than that). Third it is the massification of higher (tertiary) education, which started in the US after the Second World War and then spread to other developed countries. In most countries this is a very recent phenomenon, the full consequences of which have not yet been felt. And finally it is the ICT revolution, which has made it possible to create knowledge infrastructures that make it possible to search, combine and recombine knowledge and information much quicker and efficient than before. As is evident from the diffusion statistics surveyed above this process is still at an early stage.

The evidence considered in this paper clearly illustrates the dynamic character of the emerging knowledge based economy along all the four dimensions mentioned above; innovation, R&D infrastructure, higher education and ICT. The rapid growth of patenting worldwide, the catch-up in R&D expenditure as well as GDP per capita in several (previously poor) Asian economies, the massification of higher education and the rapid spread of new ICTs throughout the global economy all testify to the strength of this dynamics. However, this is not a process that benefits every country in the world to the some extent. On the contrary the available evidence seems to suggest that for some time now differences in GDP per capita between the dynamic (mostly rich) and less dynamic (mostly poor) parts of the world have been in increasing, and that this emerging divide is also mirrored in indicators of innovation, R&D infrastructure, higher education and ICT. However, this is not merely an increasing "north-south" divide, since some initially poor countries in Asia, China in particular, manage to catch-up. Moreover, there diverging tendencies at work within what we like to think of as the developed world, with in particular the European Union performing less well than, say, the United States and parts of Asia. These tendencies understandably worry policy-makers in the EU who have launched several policy initiatives to revitalize the growth and competitiveness of the European economy.

The chief policy goal that European policy makers have agreed on is to try to raise R&D investments towards the three percent of GDP target. However, although high R&D investment is an important indicator of a thriving knowledge-based economy, it does not follow that increasing R&D without changing anything else would necessarily change much. What is needed is a more holistic policy approach based on a solid understanding of the factors that induce (or hamper) R&D and innovation. Since interaction with users (and user competence) has been shown to be perhaps the most important factor behind successful innovation, one recommendation might be to explore the possibility for intervening on the demand side, which arguably should be within reach given that politicians actually control around half of GDP in many European countries (somewhat less in others but still a big chunk of overall demand). The challenge in that case would be how to transform the big spenders among the public sectors, such as education, health, communication, energy provision (in some countries) etc., into powerhouses for innovation. More generally, what would be needed is a transition to an experimental economy; in which experiments with new solutions/technologies would be the normal state of affairs, not the exception. Arguably, such an economy would generate more innovation, and higher R&D expenditure in the private sector. This would, however, also necessitate a tolerance among policy-makers and the general public for the failures that inevitably would accompany any transition to a more experimental policy framework.

Finally, what about the sustainability issue? Is the knowledge based dynamics (or innovation based growth) discussed here really sustainable in the long run? This is a challenging question and it is difficult (if not impossible) to answer it with any degree of "certainty". However, what can be said is that if there is a sustainable growth path for the global economy, it is probably this one. Economic growth in the traditional sense requires increased use of non-renewable resources and is therefore likely at some stage to be constrained by resource scarcity. Innovation – and knowledge based growth – is about mobilizing the knowledge, creativity and courage of the population to envisage new solutions that save resources and satisfy needs in new and better ways. Knowledge-based growth – what is sometimes termed “the innovation machine” - is a wonderful device to bring us closer to that aim. But firms and entrepreneurs need to be convinced that the new solutions they eventually come up with are likely to have a market, otherwise they will be reluctant to enter into the relevant search processes. Arguably, this is where politicians may have their main chance, e.g.; by providing motive, encouragement and direction to search processes that might otherwise have been prematurely abandoned (or never started). And a good place to start might well be with the public sector’s own needs (Fagerberg, Guerrieri and Verspagen 1999)!

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