Investing in Knowledge: On the Trade-Off between R&D, ICT, Skills and Migration*

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Abstract

This paper deals with the complementarity between skills and knowledge by investigating particularly tacit knowledge flows between countries and regions. The main findings are threefold. First, there seems to exist a trade-off between acquiring knowledge through performing and putting effort in R&D and through investing into access to the public knowledge basin. Secondly, migration of high-skilled labour from South to North appears, as a result of the introduction and rapid evolution of ICT, no longer a dominant trend. Finally, the observed trade-off goes hand in hand with the accumulation and formation of tacit knowledge.

Keywords: Brain Access; Growth; Knowledge

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1. Introduction

Many authors in the field of science and technology (S&T) (e.g. David and Foray, 1995, Lundvall, 1992, Patel and Vega, 1999, Soete and Ter Weel, 1999 and Zander, 1999) have recently observed that the S&T system is shifting towards a more complex socially distributed structure of knowledge production activities, involving particularly a great diversity of organizations having an explicit goal of producing knowledge, i.e. learning entities. The previous system was much more based on a simple dichotomy between on the one hand learning and knowledge generating activities, such as research and development (R&D) laboratories and research activities carried out in universities, and on the other hand activities of production and consumption. The partial disappearance of this dichotomy has brought about a proliferation of new knowledge and research producing activities, which are less readily observable but nevertheless essential to sustain innovative activities in a global environment.

From this perspective, there has been a growing recognition of the importance of the international movement of tacit knowledge, in general, and high-skilled labour, in particular, to these new knowledge applying, creating and using places (e.g. Gassmann and Von Zedtwitz, 1999 and Grandstrand, 1999 with respect to the internationalization of R&D). Contemporary production processes rely increasingly on the acquisition and deployment of these high-skilled workers. Often, specific kinds of tacit knowledge are not available domestically and/or locally and are therefore “imported” from abroad. Burton and Wang (1999) e.g. report that as of April 1995, about fifteen percent of working US scientists and seventeen precent of working US engineers were non-native born. These figures do exceed the ten percent of the total US employed population born abroad. At the same time, they confirm the impression that the US is able to attract high-skilled labour from abroad benefiting directly from the effort put in education by other countries.[1] That this imported labour can become a significant factor in production is illustrated in Table 1. This table shows the number of non-US born scientists and engineers (S&E) in 1995. It appears that particularly in the natural sciences and engineering type of

[1] This “brain gain” is of course at the expense of the mostly publicly funded educational systems in the rest of the world - cf. Mahroum (1998).

occupations non-US born workers are over-represented.

Table 1. US S&E by occupation and percent non-native born in 1995

Occupation	Total (x 1.000)	Non-native born (percentage)
Total S&E	3,186	15
Scientists	1,625	14
of which		
Computer scientists	641	12
Mathematical scientists	87	16
Life scientists	305	16
Chemical and physical scientists	274	17
Social scientists	318	9
Engineers	1,560	17

Source: Burton and Wang (1999)

The importance for economic growth of the (average) level of tacit knowledge and human capital in an economy has led many to presume that a systematic “brain drain” or outflow of high-skilled labour may be detrimental to a country’s development; and might even lead to a situation in which countries face themselves stuck in poverty traps. The importance of the development of human capital to enhance economic growth has been explored and examined by many scholars both theoretically (e.g. Lucas, 1988, Azariadis and Drazen, 1990, Glomm and Ravikumar, 1992 and Aghion and Howitt, 1998) and empirically (e.g. Mankiw et al., 1992, Barro and Lee, 1994, Benhabib and Spiegel, 1994 and Hollanders and Ziesemer, 1999). All these approaches have concluded that differences in human capital accumulation and formation are to a certain extent able to explain cross-country growth differentials. Hence, the drain of human capital to other countries, such as the US, has, according to these studies, the effect of a slowdown of economic growth and development in countries suffering from a systematic outflow of high-skilled labour, while at the same time increasing the human capital endowment of the gaining countries.

Mountford (1997), however, shows that under certain circumstances a brain drain may increase the productivity of countries suffering from a brain drain. He discusses two ways in which a brain drain can have beneficial effects on economic development. First, he shows how the possibility of an outflow of high-skilled labour to a higher wage country raises the domestic return to education. This leads, according to Mountford, to an increase in human capital formation, which under certain conditions, might well outweigh the negative effect of the brain drain itself. Secondly, he shows that a brain drain can change the dynamics of educational class formation which results in the development and participation of a particular under-educated class. In this approach an optimal level of brain drain can be identified which weighs the benefits of this drain, due to increased incentives to induce human capital formation, with the costs of the skill depletion as a result of a brain drain. Stark et al. (1997) obtain similar results and conclude that, notwithstanding the outflow of high-skilled labour, a country can end up with a higher average level of human capital per worker. On the policy side, Miyagiwa (1991) shows that conventional policies designed to stop brain drain may succeed only in retaining those who are medium-skilled, while the high-skilled “specialists” continue to emigrate. This failure to keep S&E, or high-skilled labour in general, within a country raises both important questions and challenges with regard to the design of educational systems and S&T policies.

An important development which has non-negligible effects on migration and the problem of brain drain has, however, not been considered in the literature so far: the application and rapid worldwide availability of new information and communication technologies (ICT), which might tend to reduce the international migration of the high-skilled workforce. Modern satellite and fibre-optic communication lines, faxes and e-mail systems are able to set up communication lines between individuals and organizations in almost instant touch. A recent OECD study (OECD, 1998a) concluded that it would be surprising if these facilities, which increasingly enhance and become more comprehensive, do not make some inroads into at least the growth of mobility among high-skilled labour. At present, however, there is little research into the trade-off between the application of new technology for transferring knowledge and migration.[2]

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[2] E.g. *Research Policy* dedicates a 1999 volume to the internationalization of R&D without considering migration issues in relationship with the growing importance of ICT. Noisi (1999) notes in the introduction only that an increasing number of multinationals are moving R&D abroad and that learning is a key element in the development

This paper's aim is to fill this gap and provide a relationship in the new economic environment between the application and implementation of ICT as a global network, which enhances the flow of knowledge, and the migration of high-skilled labour. In doing so, it will be shown that high-skilled labour does not necessarily have to migrate physically to places where its marginal productivity is maximized, but that some kind of virtual presence might be sufficient to apply the specific knowledge required in a particular situation at stake. This observation has of course strong effects on newly industrializing countries because it highlights that by investing in access to this global network these countries not only might have new opportunities to converge more rapidly to the standard of living of the developed world, the emigration of their high-skilled workforce is also likely to slowdown. It is shown in this paper that the following stylized facts can be deducted from the analysis of the framework build in the next section:

1. There seems to exist a trade-off between acquiring knowledge through performing and putting effort in R&D and through investing into access to the public knowledge basin;
2. Migration of high-skilled labour from "South" to "North" appears, as a result of the introduction and rapid evolution of ICT, no longer a dominant trend; and
3. The observed trade-off goes hand in hand with the accumulation and formation of tacit knowledge.

Theories to explain the migration of high-skilled labour have only recently begun to get to grips with the processes underlying these phenomena. Although the literature on the international movements of high-skilled labour is not very extensive, Salt (1997) reports that a number of themes have been developing: migration associated with the activities of multinational companies (e.g. Rauch, 1991); brain "movement" (brain drain and returns to education); the emergence of an international skill market, which is part of a large public knowledge basin and serves to some extent as a large external labour market consisting of specialists; and finally, the

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of the internationalization of R&D. It should however be noted that other literature, e.g. Hollanders et al. (1999) dedicate a large part of their report to migration issues. In addition, Mansell and Wehn (1998) discuss in their book possibilities for newly industrializing countries to converge to the developed countries in terms of growth rates and economic welfare. They even come up and deal extensively with the construction of a knowledge indicator. However, migration issues are mostly omitted in their comprehensive analysis.

migration of students and researchers. What is at stake in this paper is the investigation of migration in association with the existence of a kind of publicly accessible knowledge basin created by the presence and growing importance of new elaborate ICT networks.

The plan of the paper is as follows. First, an analytical framework is build from which several contemporary trends can be observed and from which the three above mentioned stylized facts are drawn. These are the subject of empirical investigation in section 3. The last section deals with possible policy conclusions.

2. Access to Knowledge versus R&D expenditures

There is little doubt that the way to apply and use a particular technology is fully part of that specific technology, i.e. human skills and tacit knowledge are essential complementary assets to implement, maintain, adapt to and use new physically embodied technologies and codified knowledge. From this perspective, as noted recently in a growth model by Redding (1996) and Acemoglu (1998) in terms of a capital-skill complementary framework, tacit and codified knowledge can be regarded as two different aspects of knowledge accumulation and creation.[3]

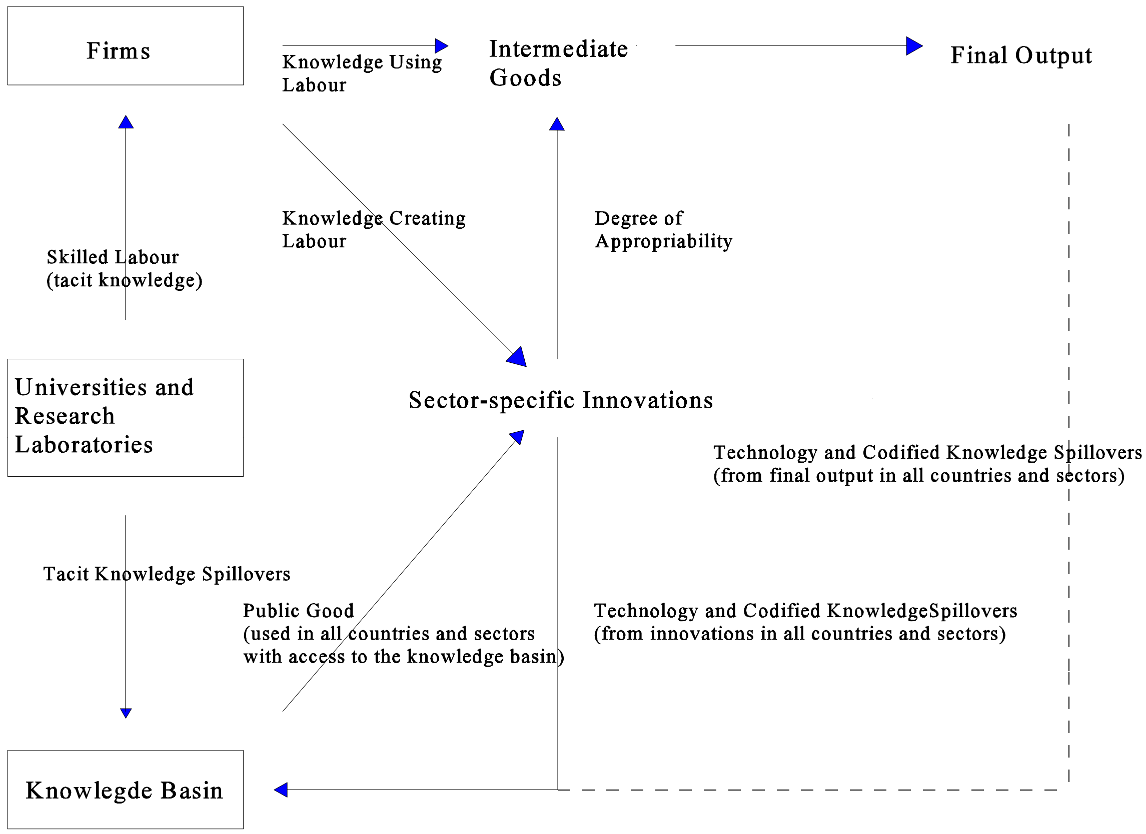
Figure 1 gives a basic schematic representation of economic activities in such an environment. This figure shows that a firm can possibly split its labour force into a knowledge creating department and a knowledge using division. In the knowledge creating department, workers are employed to invent new products and or technology standards, while workers in the knowledge using part of the company produce some specific intermediate goods, that are used to create the final output of the particular firm. This output might either be a physical product or non-physical output in the form of codified knowledge.

In this framework sector-specific innovations are induced and occur because of the effort of the firm's knowledge creating department on the one hand, and public knowledge from the publicly accessible basin on the other. Once a firm has invented a new product or technology standard and applies it in the production process, it depends on the degree of appropriability whether or not the knowledge created in the innovation process spills over to the public knowledge basin. In some cases all the firm's benefits from the innovation spill over to the public knowledge basin. It is therefore that such a firm has no incentive to innovate, once it is at the leading-edge of the particular market; in other words, the degree of appropriability is (almost) zero. In other circumstances, the degree of appropriability can be fairly high. Large firms are often better able to patent their innovations, and their innovations take much time and large effort to duplicate and or imitate. Hence, direct knowledge spillovers to the public knowledge basin are not to be

[3] This observation has also been investigated in historical perspective by Goldin and Katz (1998), and was already initiated by an early contribution of Griliches (1969).

expected from these firms to the extent they are observed in the first case.

Figure 1. A schematic representation of a knowledge creating and using economy



Source: Adapted from Aghion and Howitt (1998) and Soete and Ter Weel (1999)

Public knowledge is also enhanced by research performed at universities and other research institutes. Their output in the form of codified knowledge is often published in scientific journals and books or transmitted by channels such as conferences. The transmission of scientific work has undoubtedly become much easier due to ICT; e.g. a research paper of the National Bureau of Economic Research (NBER) can now be downloaded from the Internet in a few seconds, whereas it took a few years ago several weeks for such a paper to reach another continent. In addition, globalization and improved communication, due to ICT, may have contributed to an increase in the size of professional networks, e.g. computer networks have reduced the need for researchers to be physically in one place. The OECD (1998a) observes that consequently, a new form of scientific work has emerged, which provides access to colleagues in the same or related (academic) research fields and to equipment, software and databases that are traditionally part of laboratory organizations, without regard to geography. As a consequence, several forms of "telework" have emerged. Table 2 shows in this regard a significant change in remote collaboration in the US and France, particularly at the international level. This collaboration enlarges the overall knowledge stock in the economy and induces the international diffusion of knowledge created in these joint projects.

Table 2. Publications with international collaborators as a percentage of total publications in the United States and France

Field	**United States**			**France**		
	1981	1986	1991	1982	1990	1995
Total	8.8	7.5	11.0	19.9	22.9	21.6
Mathematics	8.8	13.4	17.1	45.5	50.9	40.0
Physics	8.5	10.5	16.1	36.0	37.3	43.3
Biology	4.8	6.5	10.0	19.5	24.5	21.3
Med. Res.	..	..	..	8.6	11.0	10.9
Chemistry	4.7	6.1	9.1	22.3	27.3	20.1
Earth Scs.	..	..	..	32.6	34.1	39.7
Engineering	..	..	..	25.1	28.0	30.6

Source: OECD (1998a)

At the same time, tacit knowledge, incorporated in e.g. S&E, is also created in universities. By means of education, the labour force becomes more productive because individuals obtain a higher level of skills which increases their marginal product. The skills of these educated S&E can be applied in both the knowledge using division (mostly engineers) and the knowledge creating department (mostly scientists) of a firm. Employing skilled individuals leads to higher levels of innovative activities in the knowledge creating department, on the one hand, and higher levels of production in the knowledge using division, on the other. Of course, these skilled individuals can also be employed at the universities themselves. Employing them at universities leads to a direct positive effect on the stock of public knowledge in terms of Figure 1, while employing skilled individuals at firms or in the business sector leads to possible indirect effects on the stock of public knowledge through the effort put in innovative activities at the firm level.

The framework put forward here clearly highlights the arguments stressing the importance for economic growth of both codified and tacit knowledge creation and usage, and the appropriability of the acquired knowledge following the efforts put in the research process. The main problems put forward by this model are first the means to perform research in order to develop both tacit and codified knowledge. Secondly, and more importantly for the purpose of the present analysis, this framework provides an argument to acquire knowledge through access to the publicly availability of knowledge in the virtual basin. This basin mainly consists of codified knowledge measured by the number of articles, patents, licences and copyrights. However, there is also a tacit component involved which can be measured by e.g. the global availability of S&E and the increased possibilities for learning. This ability to access the world's knowledge basin is likely to have a positive influence on economic growth and factor productivity in countries with development gaps relative to the world's advanced economies. Finally, adequate access to the knowledge basin enhances the level of development in countries or regions that do not produce this knowledge, by means of domestic R&D efforts. This observation stresses the opportunity for newly industrializing countries to profit from the knowledge spillovers from the world's leading countries. It also points to a new trade-off created by this increased access, in that countries have the opportunity to either explore and invest in knowledge themselves or invest in improvement of access to the world's knowledge basin by means of investing in ICT. This in turn opens up additional opportunities for newly industrializing countries to catch up with the developed economies, by investing in e.g. telecommunication, computers, modems and networks (Internet) to acquire better access to codified knowledge.

The existence, rapid development and increasing importance of this trade-off, due to the worldwide unfolding of ICT, challenges the traditional arguments put forward by proponents of R&D-based growth models, e.g. Grossman and Helpman (1991), because it now appears to become feasible for a country to make a cost-benefit analysis whether to invest in R&D or in access to the public knowledge basin.

However, if a country decides not to perform R&D itself and once the access to the knowledge basin is obtained, the knowledge subtracted from the basin has to be articulated and communicated in order to be productively applied in the production process. This cannot be achieved without appropriate skills, and organizational and institutional structures. Of course, skills are needed to unravel the knowledge obtained via access and organizations and institutions need to be set up in such a manner that the newly acquired production factor can be applied in an efficient way in the production process. Hence, tacit knowledge incorporated in human beings and organizations, to be able to appropriately use codified knowledge, has to be present. This observation is in line with the notion of capital-skill complementarity but can now be modified into a knowledge-skill complementarity setting, whereby the capital used is codified knowledge and the skills needed to use this codified knowledge have to be extracted from the tacit knowledge stock in a particular country, by means of improved opportunities to educate, in order to fully profit from the appropriated codified knowledge.[4]

There exists an elaborate body of literature on the nature of "tacit" capabilities. As Abramovitz (1986) noted, a certain level of (social) capabilities has to be present and explored in a country in order to be able to develop. This means that there has to be a certain level of skills and organizational design in a country to apply codified knowledge into the production process. Tacit knowledge can be obtained either by sending students abroad to acquire skills or by attracting S&E from advanced countries (tacit knowledge spillovers in terms of Figure 1). Particularly the first option has been a major factor in the development of newly industrializing countries because original inhabitants of a country who study and obtain a certain skill level, have stronger ties with their home country and are more willing to work back home than S&E "imported" from abroad. This foreign-educated high-skilled labour, then, has to teach the next generation how to develop production processes and networks further.

[4] See Bruinshoofd et al. (1999) for an empirical investigation of knowledge-skill complementarity in the Netherlands.

Newly industrializing countries may face a possible drawback of stimulating this process of sending students abroad to obtain a higher level of skills in the form of brain waste. Brain waste describes the de-skilling that occurs when high-skilled labour migrates back into forms of employment not requiring the application of the skills and experience applied in the former job and or studies. According to Bernstein and Shuval (1996), in their study of former Russian physicians migrating to Israel, there is clear evidence of this process, especially where standard of living gradients are steep.

On the other hand, opportunities arise through brain exchange as already indicated in Table 2. The essence of this concept is that those foreign-educated students who move back to their home country take on a job in locations where they can burgeon into firms and institutions that offer them jobs that broadly correspond with their acquired skills, qualifications and connections in the developed countries. Brain exchange, therefore, implies a two-way flow of expertise between origin and destination and to possibilities to collaborate in research projects and scientific work in general. Brain exchanges in some form are characteristic of all economies, and are one component in the complex of flows of knowledge between countries. At present, most of these knowledge flows are between countries with the same level of development, but once newly industrializing countries have opportunities to efficiently apply their high-skilled foreign-educated labour, they have entrance to the public knowledge basin. In this manner there are opportunities for newly industrializing countries to enhance their relative position.[5]

Hence, for access to codified knowledge to be successful, it has to go hand in hand with the development of tacit knowledge. This complementarity will in turn lead to higher productivity levels which can further boost access and development. The main arguments deducted from the framework put forward in this section can be summarized as follows.

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[5] Evidence from Japan indeed suggests that there seems to be a positive relationship between flows of skilled labour and technology (investment). It turns out that most of the Japanese foreign direct investment is in Indonesia (24.3%) and Hong Kong (20.7%), while these countries are also containing most Japanese expatriates, 11.2% and 18.9%, respectively. This would indicate that the capital exported to other countries in the form of codified knowledge has to be accompanied by tacit knowledge in the form of high-skilled labour (OECD, 1998a).

1. There seems to exist a trade-off between acquiring knowledge through performing and putting effort in R&D and through investing into access to the public knowledge basin. This trade-off gives newly industrializing countries a new opportunity to catch up with the developed world;
2. Migration of high-skilled labour to places where the marginal product of this labour is maximized is, as a result of the introduction and rapid evolution of ICT, which enhances communication, (brain) exchange of knowledge and information and collaboration among S&E, and which can consequently be regarded as a kind of virtual migration, no longer a detriment trend; and
3. The trade-off has to go hand in hand with the accumulation and formation of tacit knowledge, which means investment in skills, and these skills can be acquired by either sending students abroad or by stimulating virtual migration; in short: brain exchange.

In the next section the trade-off as described above and access issues to the public knowledge basin are discussed empirically by considering investment in skills and access to electronic networks and means of ICT.

3. The Empirics of Knowledge-Skill Complementarity

In the previous part it was shown that both the dimension and character of the production process have altered dramatically over the last decades. Knowledge has become a good, in the economic sense of its meaning, and has to be regarded as a key factor in achieving future prosperity. As will be shown here, one way of acquiring knowledge is to send students abroad to get e.g. a PhD. Another necessary condition to increase economic development seems to be access to networks. In the end, both access to the public knowledge basin, as defined in Figure 1 and analysed in the previous section, and skills are complementary assets.

3.1. Migration of students to acquire skills

Surprisingly few studies exist of the processes and trends of migration of students and other academics from newly industrializing countries to developed countries.[6] This section explores some data and tries to identify patterns and processes of migration of students. Table 3 provides an overview of foreign students in 21 OECD countries for the latest year available. From this table it can be observed that more than one-third of all foreign students in these OECD countries is studying in the US, while over seventy percent of all foreign students is located in the four 'leading' countries, i.e. France (13.9%), Germany (11.9%), the UK (10.4%) and the US (37.1%). Asia has, as could be expected, been the largest sending region, accounting for 555,219 students (or 45.3%) of the total number in selected OECD countries. Decomposing these data learns that 115,871(or 20.8% of the Asian total) students are from China, 69,736 (or 12.5% of the Asian total) are from Korea, 62,321 (or 11.2% of the Asian total) students are from Japan, with significant numbers coming from India, Indonesia, Hong Kong, Korea, and Malaysia. The large numbers of foreign students abroad from these Asian countries (despite their relatively large size) not only point to the underlying demographics, but also to the active policy pursued in these countries to acquire foreign skills and tacit knowledge, and eventually to be able to access the world knowledge basin more efficiently.

6 See Salt (1997) for an overview.

Table 3. Number of foreign students enrolled in 21 OECD countries by continent of origin

	Year	Total	Africa	North Am.	South Am.	Asia	Europe	Oceania	Former USSR
Total		1,224,611	146,248	85,240	42,599	555,219	331,981	13,199	1,110
AUS	1993	42,415	828	1,101	76	31,409	1,353	0	0
AUT	1995	25,175	1,014	662	319	4,738	18,087	0	64
BEL	1994	35,236	11,120	469	790	2,965	18,990	0	0
CAN	1994	35,451	5,842	4,580	933	17,029	6,175	29	0
DNK	1995	8,313	155	311	95	1,344	3,139	0	37
FIN	1995	2,566	317	160	40	789	1,195	0	0
FRA	1994	170,574	73,688	5,772	4,162	19,612	35,775	175	0
GER	1994	146,126	12,361	6,026	3,874	57,513	63,710	251	0
GRC	1992	1,513	244	66	6	997	184	0	0
IRL	1994	5,177	200	882	7	663	3,382	0	1
ITA	1995	24,014	2,495	815	1,002	4,098	14,686	574	111
JPN	1994	50,801	449	1,520	683	46,635	1,073	318	116
NLD	1993	11,389	1,142	411	1,488	2,913	5,313	43	49
NZL	1996	5,883	96	242	37	3,262	306	38	0
NOR	1995	11,158	1,093	761	313	3,536	3,819	0	57
ESP	1993	12,578	1,732	1,354	3,454	994	4,973	11	23
SWE	1994	13,600	422	630	431	2,739	7,306	0	90
CHE	1994	25,307	1,369	752	842	1,818	18,345	38	0
TUR	1995	14,998	648	30	2	11,248	2,991	54	0
UK	1994	128,550	10,189	10,095	1,749	50,041	54,646	1,220	85
US	1996	453,787	20,844	48,601	22,296	290,876	66,461	42,02	477

AUS: Australia, AUT: Austria, BEL: Belgium, CAN: Canada, DNK: Denmark, FIN: Finland, FRA: France, GER: Germany, GRC: Greece, IRL: Ireland, ITA: Italy, JPN: Japan, NLD: Netherlands, NZL: New Zealand, NOR: Norway, ESP: Spain, SWE: Sweden, CHE: Switzerland, TUR: Turkey, UK: United Kingdom, US: United States

Source: UNESCO (1998)

Another interesting conclusion which can be drawn from this table is the fact that region of origin plays an important role, e.g. of the 50,801 foreign students in Japan 46,635 (or 91.7%) are from other Asian countries, while in Austria, Belgium and Switzerland most students are from Europe, 71.8%, 53.9% and 72.5% respectively. Looking beyond this table at country-level evidence another interesting observation can be made. It turns out that the majority of African students in the UK, France and Belgium originate from the host countries' ex-colonies, e.g. over twenty-five percent of foreign students in France are from its former colony Algeria, while the same figure applies to Morocco, highlighting probably also the language barriers in educational systems.

In general three observations with respect to these figures can be made. First, it seems that regional aspects play a significant role, i.e. over 90% of students studying in Japan are from Asia and over twenty-five percent of foreign students in France, Germany and the UK are from Europe. Secondly, over seventy percent of all students studying abroad are located in the traditionally four most advanced countries, i.e. France, Germany, the UK and the US. Finally, former colonial ties can explain large flows of students from specific countries.

Particularly the second observation underlines the stylized facts of the previous section in so far as it illustrates that migration of high-skilled labour is directed towards regions or countries where its marginal product is maximized. Particularly the inflow of students to the world's leading countries underpins this phenomenon and gives countries from which the students originally are opportunities to establish a connection with the developed countries to acquire skilled labour and as a result tacit knowledge. The developed world, on the other hand, profits from the work these students perform and the results they obtain during their studies and research.

3.2. Access to the public knowledge basin

Access to the world's knowledge basin can be established by investing in modern means of communication. In this regard, recent investments in the deployment of fibre-optic cable might be an indication of the recognition of the importance of communication to acquire knowledge. Such communication infrastructure allows for new fast means of communication by providing e-mail, Internet access, telephone, telefax etc. Table 4 shows the deployment of fibre-optic cable throughout some OECD countries in the early 1990s. The table illustrates how within three years the increase in the use of fibre-optic cable has dramatically increased, particularly in the newly industrializing OECD countries like the Czech Republic (701.0%), Portugal (196.3%), Greece (60.0%) and Mexico (42.8%).

Table 4. Deployment of fibre-optic cable in the OECD area

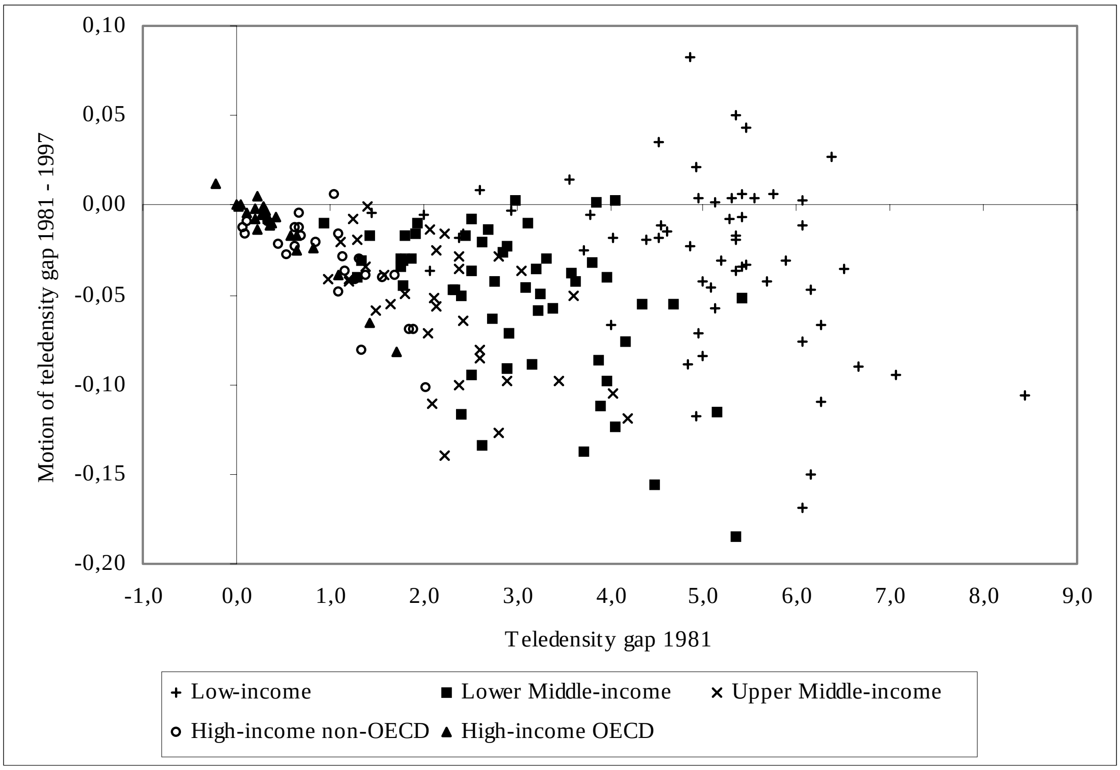
Country	1993	1995	CAGR[1] (%)	Measure
Austria	45,298	92,320	42.8	Fibre km
Belgium	4,6550	..	..	..
Canada	3,696,775	..	6.9[2]	..
Czech Republic	1,408	90,336	701.0	Fibre km
Denmark	9,300	..	10.8[2]	Km
Finland	164,024	425,955	61.1	Fibre km
France	34,000	..	..	..
Germany	68,400	86,000	12.1	..
Greece	2,745	7,025	60.0	Cable km
Iceland	156	315	42.1	Km
Ireland	8,600	11,200	14.1	Fibre km
Italy	1,333,000	1,964,000	21.4	Fibre km
Japan	168,300	..	26.3[2]	Km
Mexico	8,701	21,610	57.6	..
Netherlands	12,000	..	..	..
Norway	11,400	13,800	10.0	Cable km
Portugal	15,280	134,128	196.3	Km
Spain	24,857	36,041	20.4	..
Sweden	25,000	..	..	..
Switzerland	214,051	..	..	..
Turkey	20,700	28,300	16.9	Km
United Kingdom	2,300,000	2,800,000	10.3	Km
United States	7,545,539	10,714,811	19.2	Fibre miles

..: Not available, [1] Compound Average Growth Rate, [2] CAGR 1993-1994

Source: OECD (1997)

Since data on a larger set of (newly industrializing) countries on advanced communication methods are non-existent, main telephone lines per 100 inhabitants are used as a proxy for a country's state of ICT development or teledensity - cf. Mansell and Wehn (1998) and Hollanders et al. (1999). Although imperfect, using these data as a proxy for the development and possible application of ICT, this can give a picture of the opportunities for some countries to develop more rapidly than others. Using the World Bank (1998) classification of countries from poor to rich, five classes can be distinguished: low-income, lower-middle income, upper-middle income, high-income non-OECD and high-income OECD countries.[7] Figure 2 shows the relative teledensity gap with the US in 1981 and the motion of this gap from 1981 to 1997, the latest year from which data are available. This figure illustrates that most countries are below the horizontal axis, which indicates that they are converging relative to the US. Most OECD countries seem to experience the same pattern of the application of teledensity as the US, while the upper-middle income and high-income non-OECD countries face the most rapid convergence. Investigating the lower-middle income countries learns that these countries also convergence, although in a less strong manner than the higher income groups. The diverse pattern observed for the low-income countries indicates that some of these countries catch up with the US, while others strongly diverge.

Figure 2. Motion of the teledensity gap 1981-1997

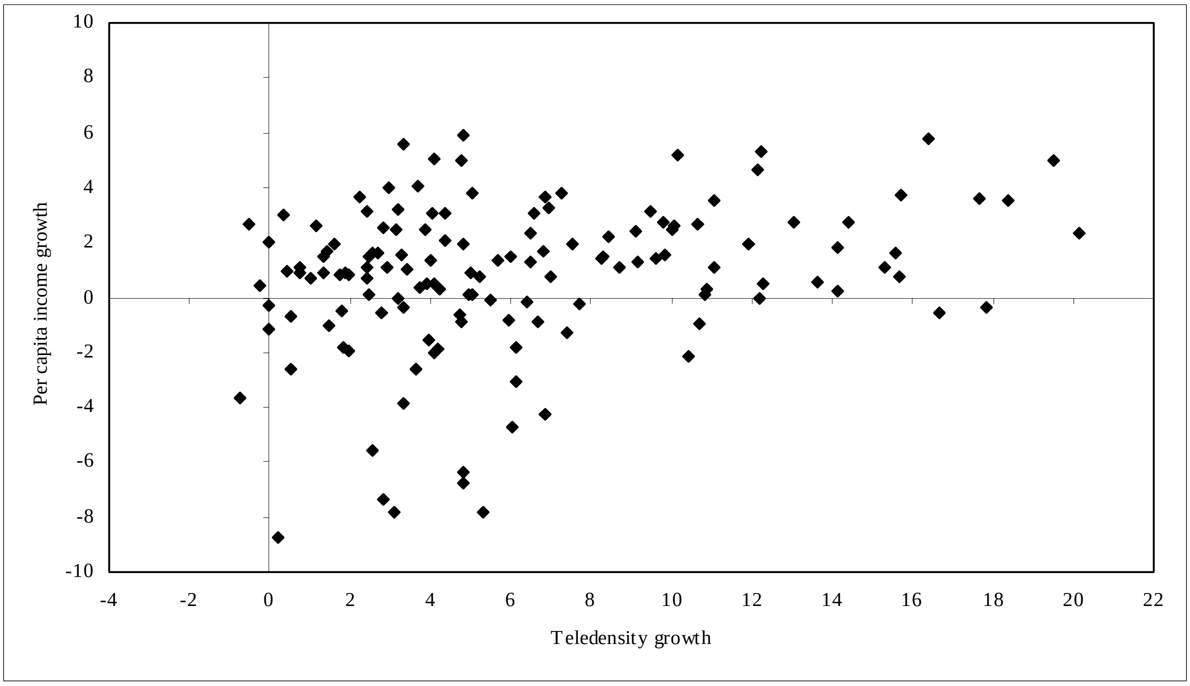


Source: Compiled from ITU (1999)

[7] Annex 1 provides a list of the countries included in the several groups.

This general pattern of convergence in terms of teledensity towards the world leading countries illustrates the importance of access to the public knowledge basin. In this respect Figure 3 shows a general positive relationship between GDP per capita growth and the growth of teledensity for a set of 211 countries in the period 1991-1997. The results point towards growth based on access to knowledge in the broadest sense of its meaning. However, the set of countries can be split into two categories: countries observing annual teledensity growth rates of less than about eight percent and countries experiencing annual growth rates of more than eight percent. When this observation is taken into account one can establish that the former group of countries shows no relationship between wealth and access, while the latter shows a positive relationship. This indicates that there is a certain threshold in investing in access and reaping the fruits of these investments. Therefore, again referring to the contribution by Abramovitz (1986) but now in a "dynamic" framework, there has to be a certain level of development to establish a sufficiently large growth of teledensity. This growth then leads to higher growth rates of income.

Figure 3. Relationship between teledensity growth and GDP per capita growth 1991-1997



Source: Compiled from ITU (1999) and World Bank (1998)

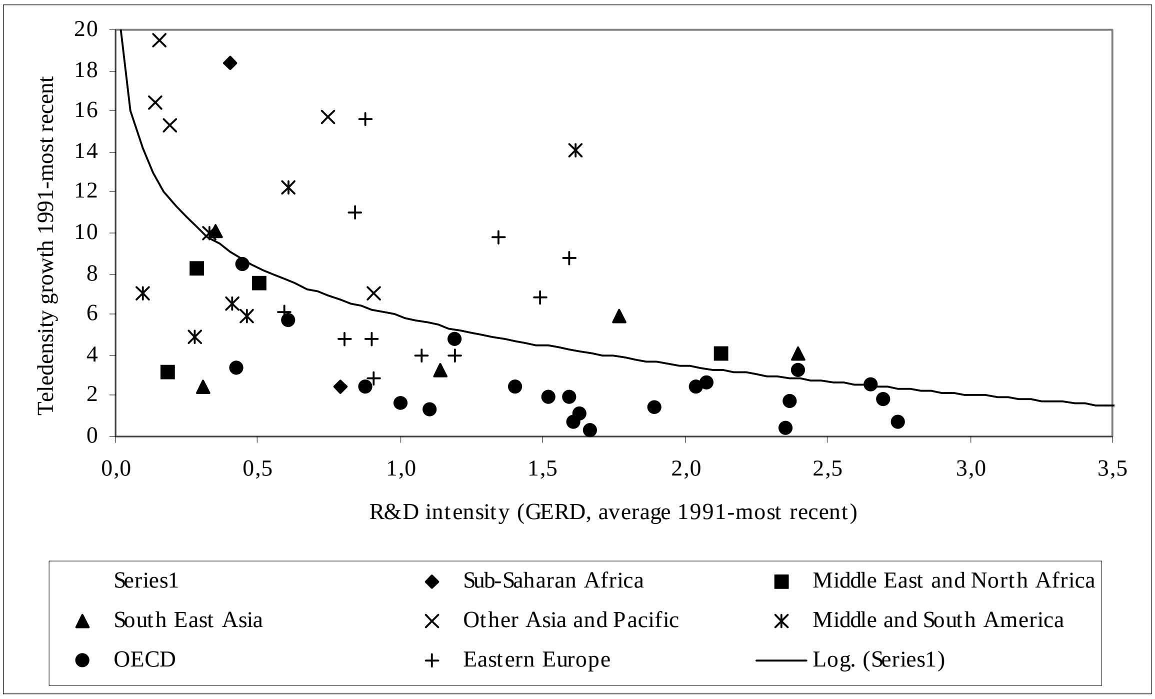
The general findings of this section are therefore first that the rapid development of the application of advanced means of communication indicates the importance of access to knowledge, defined here in terms of Figure 1 as the public knowledge basin. Secondly, teledensity growth is rapid and most countries seem to converge to the US, indicating that the world as a whole becomes more and more a global village where virtual presence in all regions can be established and migration is not by definition necessary to obtain knowledge. This virtual presence is likely to induce the performance of most countries, since a positive relationship can be obtained between the growth of income and the growth of teledensity.

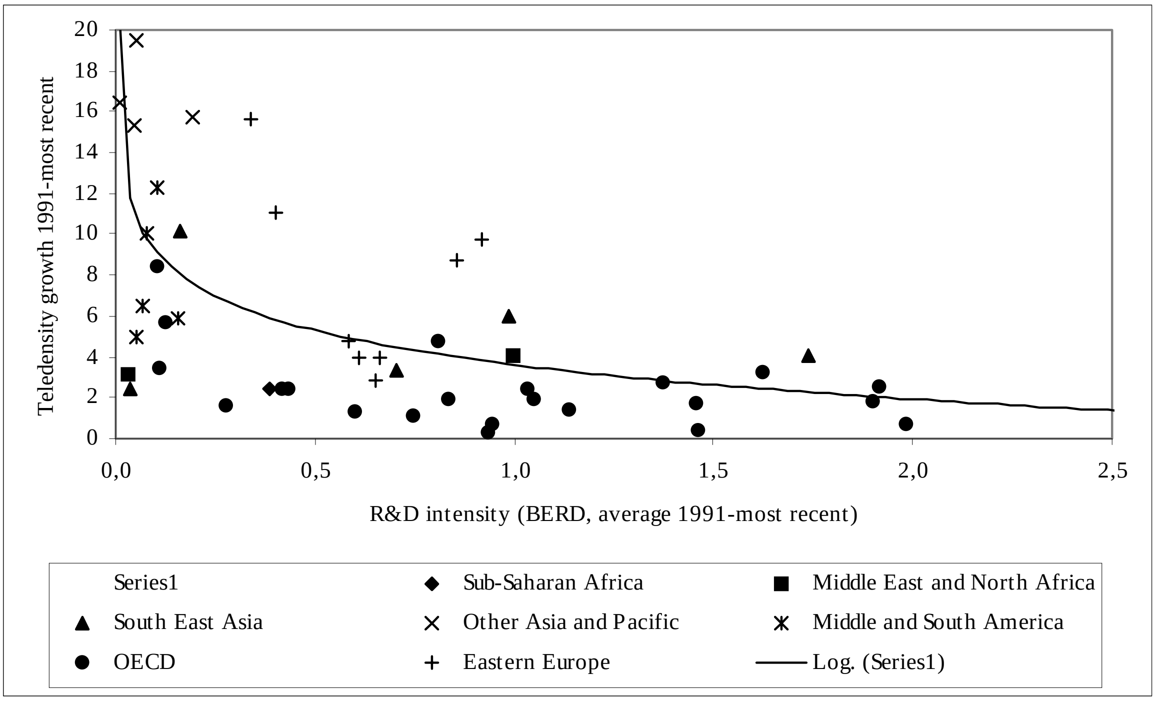
3.3. The trade-off between R&D and access to the public knowledge basin

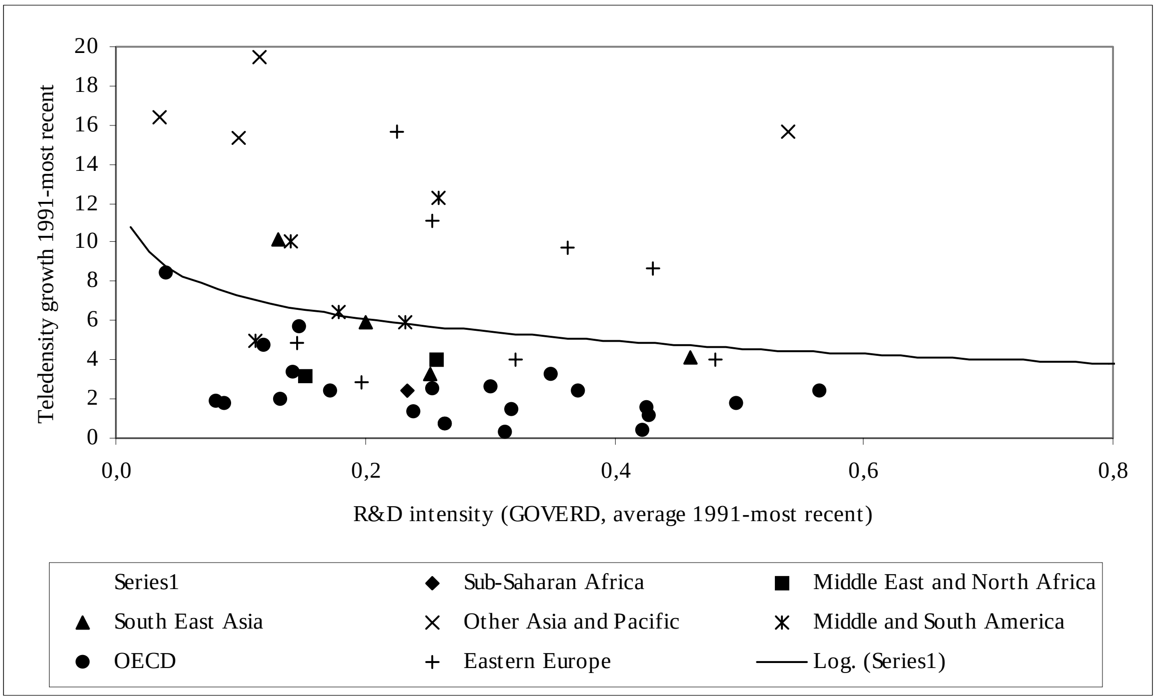
Above it was shown that students migrate particularly to the world's richest countries to acquire skills and tacit knowledge. In addition, there seems to be a positive relationship between effort put in setting up networks (teledensity growth) and wealth accumulation (GDP per capita growth). Combining these two findings gives an opportunity to examine the suggested trade-off which states that expenditures and effort put into the traditional R&D process can be substituted with investment in ICT to obtain access to the public knowledge basin. To stress this relationship examine in Figure 4a-d. In these figures the following four measures of R&D expenditures are used to compute R&D intensities for several countries for which data are currently available: gross domestic expenditures on R&D (GERD), business enterprise intramural expenditures on R&D (BERD), government intramural expenditures on R&D (GOVERD), and higher education intramural expenditures on R&D (HERD), respectively. In these four figures the following division is made: Sub-Saharan African, Middle East and North African, South East Asian, Other Asian and Pacific, Middle and South American, OECD, and Eastern European countries.

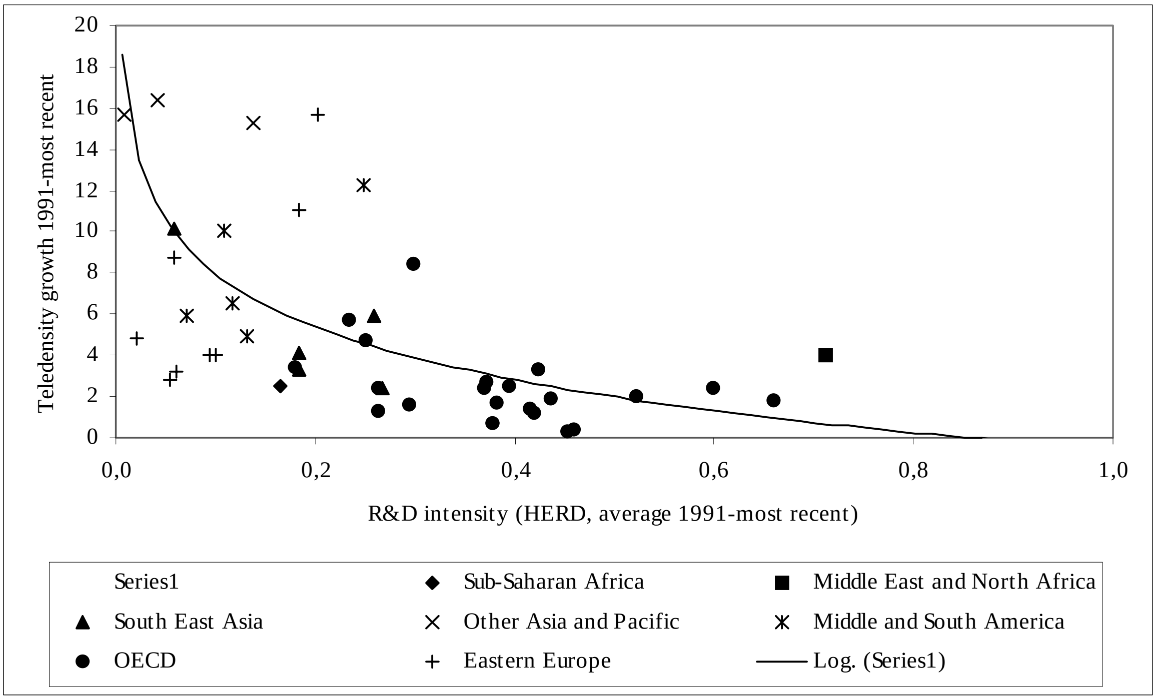
The results of examining these figures is that for all types of R&D there seems to be a trade-off between effort put into performing R&D "inhouse" and trying to establish a connection with the public knowledge basin by means of expanding the application of ICT. Particularly, the rapidly newly industrializing Asian countries seem to benefit from access instead of performing research themselves. This might be another explanation why these countries appear to develop so fast, without performing "fundamental" research - cf. Freeman (1987).

Figure 4a-d. R&D intensity and teledensity growth, 1991-1997









Source: Compiled from OECD (1998b) and ITU (1999)

4. Policy Conclusions

The importance given to knowledge for economic growth and welfare, in the light of the analysis laid out in this paper can be highlighted as follows.

First, knowledge accumulation can increasingly become analysed like the accumulation of any other capital good, as shown in Figure 1. However, there are some fundamental differences with traditional material capital goods. First, and foremost, the production of knowledge will not take the form of a physical piece of equipment, but becomes embedded in some specific blueprint form or in human beings and organisations; the tacit part. In each of these cases there will be positive externalities: the knowledge embodied in blueprints, people or organisations cannot be fully appropriated, as was shown in the analysis following Figure 1. With little cost to the knowledge creator it might flow away to other firms or to the public knowledge stock. Of course there are costs in acquiring knowledge. On the one hand, establishing a research department working on innovative projects is certainly not cheap, while on the other hand, investing in higher education and skills is expensive as well. This provides a rationale for policies to focus on the importance of investment in knowledge accumulation, both codified and tacit.

Secondly, the growing consensus on the importance of knowledge for industrial competitiveness is also closely related to the emergence of new ICT, which have resulted in a dramatic decline in the price of information processing; in a technological driven digital convergence between communication and computer technology; and last, but not least, a rapid growth in international electronic networking, as is shown in the analysis above. ICT allow for the codification of information and knowledge. As a consequence, ICT make codified knowledge more accessible to all sectors and agents in the economy linked to information networks or with the knowledge how to access such networks. While local capabilities to use or have the competence to access such codified knowledge will vary widely, the access potential is there. ICT, in other words, brings to the forefront the potential for catching-up. Most importantly, it results in a trade-off between “inhouse” R&D and access to the specific knowledge required.

Thirdly, the perception of the nature of migration has changed significantly over the last decade.

Broadly speaking, migration is observed less in terms of physical presence, and more in terms of the ability to exploit systematically the benefits and new opportunities of virtual presence. This new feature implies to some extent more use of a worldwide technological base allowing development of the newly industrializing countries without the danger of brain drain. The globalization of tacit knowledge induced by new ICT moves the spectrum from brain drain to brain exchange with the result that mutually beneficial use of knowledge is profitable for both newly industrializing and developed countries.

The recognition of the importance of this new broader notion of knowledge accumulation is challenging the traditionally segmented "market failure" policy approach to S&T support. It stresses the importance of investment in ICT infrastructure as allowing for access to the public knowledge basin and investment in tacit skills as allowing for a more efficient use of such a worldwide knowledge basin. At the same time, it brings to the forefront the explicit choices between these different types of S&T policies.

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Annex 1

High-income OECD countries

Australia, Austria, Belgium, Canada, Denmark, Finland, France, Germany, Greece, Ireland, Italy, Japan, Korea, Luxembourg, Netherlands, New Zealand, Norway, Portugal, Spain, Sweden, Switzerland, United Kingdom and United States

High-income non-OECD countries

Andorra, Aruba, The Bahamas, Bermuda, Brunei, Cayman Islands, Channel Islands, Cyprus, Faeroe Islands, French Guyana, French Polynesia, Greenland, Guam, Hong Kong, Iceland, Israel, Kuwait, Liechtenstein, Macao, Martinique, Monaco, Netherlands Antilles, New Caledonia, Northern Mariana Islands, Qatar, Reunion, Singapore, United Arab Emirates, Virgin Islands

Upper-middle income countries

American Samoa, Antigua and Barbuda, Argentina, Bahrain, Barbados, Brazil, Chile, Croatia, Czech Republic, Gabon, Guadeloupe, Hungary, Isle of Man, Libya, Malaysia, Malta, Mauritius, Mayotte, Mexico, Oman, Palau, Poland, Puerto Rico, Saudi Arabia, Seychelles, Slovak Republic, Slovenia, South Africa, St. Kitts and Nevis, St. Lucia, Trinidad and Tobago, Uruguay

Lower-middle income countries

Albania, Algeria, Belarus, Belize, Bolivia, Botswana, Bulgaria, Cape Verde, Colombia, Costa Rica, Cuba, Djibouti, Dominica, Dominican Republic, Ecuador, Egypt, El Salvador, Estonia, Fiji, Georgia, Grenada, Guatemala, Indonesia, Iran, Iraq, Jamaica, Jordan, Kazakhstan, Kiribati, Korea dem. rep., Latvia, Lebanon, Lithuania, Macedonia, Maldives, Marshall Islands, Micronesia, Morocco, Namibia, Panama, Papua New Guinea, Paraguay, Peru, Philippines, Romania, Russian Federation, Samoa, Solomon Islands, St. Vincent and the Grenadines, Suriname, Swaziland, Syrian Arab Republic, Thailand, Tonga, Tunisia, Turkey, Turkmenistan, Ukraine, Uzbekistan, Vanuatu, Venezuela, West Bank and Gaza, Yugoslavia

Low-income countries

Afghanistan, Angola, Armenia, Azerbaijan, Bangladesh, Benin, Bhutan, Bosnia Herzegovina, Burkina Faso, Burundi, Cambodia, Cameroon, Central African Republic, Chad, China, Comoros, Congo dem. rep., Congo rep., Côte d'Ivoire, Equatorial Guinea, Eritrea, Ethiopia, The Gambia, Ghana, Guinea, Guinea-Bissau, Guyana, Haiti, Honduras, India, Kenya, Kyrgyz Republic, Lao PDR, Lesotho, Liberia, Madagascar, Malawi, Mali, Mauritania, Moldova, Mongolia, Mozambique, Myanmar, Nepal, Nicaragua, Niger, Nigeria, Pakistan, Rwanda, Sao Tomé and Principe, Senegal, Sierra Leone, Somalia, Sri Lanka, Sudan, Tajikistan, Tanzania, Togo, Uganda, Vietnam, Yemen, Zambia, Zimbabwe

Source: World Bank (1998)