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The Role of Higher Education in High tech Industry Development: What Can International Experience Tell Us?

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Introduction

There is an extraordinary level of policy attention being given to higher education today. The reason is clear; with the rise of knowledge economies and science-based high tech industries, higher education is considered key to economic development. At the same time, the world has observed that high tech industry can emerge in a diverse set of countries including those with limited industrial bases or low levels of economic development, such as Ireland, China or India. It is not surprising that innovation policies to create and support high tech industries are a priority in almost all OECD and many developing countries. Developing an appropriate higher education sector is becoming a critical component of such policies.

There is much written on the role of American universities in high tech industries and more generally in their industrial development, including some that compare their roles against those in Europe or Japan. For other countries, there are studies which conclude that a significant role was or is being played by well trained engineers and scientists, and by implication higher education systems. However, few studies go beyond referring to higher education as one of multiple – albeit often citical – factors. There is also a whole body of comparative higher education literature, but they describe similarities and differences across systems without comparing the roles they play in economic development.

Lester (2005) makes an important step in arguing that different types of industrial transformations require different roles to be played by universities based on a comparative study of several countries. There is also an emerging literature on university-industry relationships in developing countries. However, there has been little written on how different roles may be played by different higher education institutions across countries, and how these may be related to different institutional characteristics.

This is a particularly striking gap in our knowledge given the fact that high tech industry is not monolithic across countries; different capabilities are being developed in high tech industries and different levels of 'high tech' content is evident in different locations.

The objective of this paper is to begin to fill such gaps by addressing the following two questions:

1. what is the role higher education can play in the development of high tech industry?
2. what are the key characteristics of higher education institutions and systems that are important in playing such roles?

The ultimate objective of the paper is to draw lessons for the future for developing higher education systems, particularly in developing countries.

The paper seeks to consolidate evidence about the role of higher education in the development of high tech industry in a range of countries. Wherever possible, this has been complemented by country specific literature on higher education systems and their development. The main emphasis has been given to two 'recent' high tech industrial sectors: ICT (including hardware as well as software) and biotechnology.

Although different countries exhibit different paths in developing high tech industries, the point of this paper is not to provide a full contrast of these paths taken, nor to examine all the contributing factors for high tech industry development. That high tech industry took off for a variety of reasons is taken as a given, and the paper focuses on what possible specific roles higher education could have played within that context.

The paper gives some weight in examining differences in high tech industry capabilities among countries – but only to the extent that they may be related to different roles played by higher education systems.

In order to explore the variety of roles played by higher education at different stages of industrial development, four sets of countries were included in the paper:

(a) the US, which has held a leading position in both industries from their birth;
(b) Japan and Finland, which entered the global competition in high tech products relatively early, but based on significant industrial capability that already existed;
(c) a group of late-developers including Taiwan and Korea which nonetheless were building industrial capabilities around the time when these industries were born; and
(d) a group of countries which developed high tech industry from a much less developed industrial base (Ireland, Israel, China and India).

The paper attempts to draw on comparative historical data to the extent they exist, so that the comparisons can be made not only across countries but also across time.

Roles of Universities in the Development of High Tech Industry

What are the roles universities played in different national and industrial settings? This section gives a brief summary of country cases, presented in chronological order in terms of when (roughly) these countries "took off" as new centres for high tech industries. Several cases, such as Korea and Taiwan, are presented together, mainly because their timing of entry into high tech arena was similar, but also because they have key contrasting points in terms of the roles played by higher education.

US. The birth and development of biotechnology and ICT industry in the US was one of the key reasons why policy makers around the world took note of the importance of universities. While there were many myths in the early days, the literature today gives a consistent portrait of where and how universities contributed.

It is well documented that some American universities played a particularly visible role in the birth and the early development of biotechnology industry. Fundamental scientific discoveries in university laboratories and resulting patents (such as Cohen and Boyer's discovery of the recombinant DNA technique) led to the development of a whole new industry with strong linkages with academic scientific research (Henderson, Orsenigo and Pisano 1999). The early evolution of the industry was characterized by a number of new firms, many of which were academic spinoffs – usually with academics working in conjunction with professional managers, backed by venture capital. The early academic inventors were labelled as 'star scientists' as they were key players both in basic science and in their applications and had a special role mainly because of the significant amount of tacit knowledge associated with the original scientific discoveries (Zucker and others 1996, Zucker and others 1998, Zucker and Darby 2002). The norms in American universities which permitted academics to get deeply engaged in commercialization played a key role in this process (Henderson, Orsenigo and Pisano 1999).

American universities also played key roles in the development of the computer hardware and software industry, though their visibility varied over time (Bresnahan and Malerba 1999, Mowery 1999, Rosenberg and Nelson 1994). For instance, universities were actively engaged in the early development of computers in the 1940s (and indeed during this period, European universities such as Manchester, Cambridge and Berlin were as active as American universities). They also played a critical role in the development of microcomputers as exemplified by spinoffs from MIT, Stanford and University of Texas (only Cambridge University in the UK played a similar role in Europe).

The development of the software industry was facilitated by an early establishment of computer science as a new discipline (Mowery 1999). This helped not only in universities' contribution to key knowledge formation but also in organizing and delivering education programmes to supply updated skills. Indeed, the American universities' ability to create and legitimate computer science as a new field was unparalleled by European or Japanese universities (Mowery 1999).

This 'responsiveness' of American universities is not new; they have been responsive consistently over a period of time, for instance in the emergence of electrical, chemical and aeronautical engineering (Rosenberg and Nelson 1994). It is also not an accident that a group of responsive institutions emerged in the US. A whole group of American universities, called land grant colleges, were founded with an explicit mission to serve the practical needs of the community in the late 19th century, and the government specifically funded some of their service activities such as agricultural extension. Similarly, the government research funding in the post-war period was huge but also 'mission-oriented,' coming from key agencies with application interests such as defence, health and energy (Rosenberg and Nelson 1994, Geiger 2004b). The role played by the Defence Advanced Research Project Agency (DARPA) is funding application oriented basic research was legendary; so much so that the American National Academy of Science recommended a creation of 'DARPA-like' agency in energy to the government for ensuring continued competitiveness of American science (National Academy of Science 2005).

Japan. Japanese experience of developing ICT and biotechnology was one of catching up. In the case of ICT, this was achieved through established electrical equipment and electronics companies entering the market in the 1960s (Bresnahan and Malerba 1999). One important role Japanese universities played was in supplying engineers and scientists to these companies, particularly with a massive expansion of undergraduate programmes, orchestrated by the government in the late 50s (Nakayama 1991).

However, this seems to be the only visible role universities played in the development of high tech industry. Indeed, the popular perception has been that Japan developed in spite of its weaknesses in higher education (Goodman 2005). Large Japanese companies developed a practice of lifetime employment, hiring candidates with best potential with a view to training in-house (Dore and Sako 1989). While these companies did recruit large numbers of engineers and scientists, they were less concerned about their academic performance or specialization so long as they came from reputable universities known to be highly selective at entrance (Nakayama 1991).

It appears that Japanese universities did not develop in a manner that permitted them to play proactive roles with respect to industry. Universities were recovering from war-related disruptions while industry was actively acquiring foreign technology and played minimal roles in such a process in the 1950s (Hashimoto 1999). Industrialists are quoted to have boasted that they no longer needed to depend on universities when they started to establish their own corporate laboratories in the 1960s (Nakayama 1991). In the late 1960s the relationship between universities and industry received an additional blow; student uprising led to further criticisms about university-industry relationships, and a strong mood to censor such relationships began to prevail (Hashimoto 1999, Hatakenaka 2004). Various rules and norms emerged in this culture of censorship; the bulk of scientists and engineers were civil servants in national universities, which effectively forbade them from consulting with industry, and universities did not have the autonomy to create their own rules about their engagement (Hatakenaka 2004).

However, it does not mean that Japanese academics were not good enough in their science to collaborate with industry. Japanese scientific performance was the equivalent of other industrialized nations by the early 1990s (Hicks 1993). It is also untrue to assume that they had no linkages with industry. One unusual mechanism that brought university academics and industry together was the industry practice of sending their own staff to universities, some times for a whole year, which was often motivated by their desire to learn about some fields of science, in which industry had limited expertise (Hicks 1993, Darby and Zucker 1996). Accordingly, in biotechnology, ‘star scientists’ are found to be actively working with company employees in their university labs – with higher levels of co-authorships than in the US. Other researchers also find that Japanese academics have an equivalent level of relationships with companies as in the US or UK, at least as measured by co-authorships, but that much depended on the ability of companies to be proactive in drawing scientific and technological information from them (Kodama and Suzuki 2007).

In biotechnology, new firms played a negligible role in Japan, in a striking contrast to the US and UK where academic spinoffs were dominant (Henderson and others 1999). This was partly reflective of relative weaknesses of Japanese science; there were literally no researchers in Japan working in genetic engineering at the time of the scientific breakthroughs (Darby and Zucker 1996). But even when they did catch up in science, universities as organizations did not permit their civil servant ‘star scientists’ to work in the same way in new companies (Darby and Zucker 1996).

This is consistent with the fact that Japanese universities were generally slow to respond to emerging industrial skills need, for instance in new areas such as software related engineering, semiconductors and biotechnology (Baba et al 1996, Mowery 1999, Kobayashi 2001, Darby and Zucker 1996). Curricular change was found to be infrequent and limited in scope in Japan compared with the US, where updating took place organically and almost constantly (Hoshino et al 2003). They were also slow in establishing relevant research training. Although masters programmes in engineering became commonplace by the 80s, PhD programmes in science and engineering remained small and unattractive for industry (Clark 1995, Shimizu and Mori 2001 also see Table 1 for size). PhDs from universities were too narrow and too academically oriented for industry. Thus, industry recruited bright potential researchers and trained them in-house – using the uniquely Japanese system in which doctorates were awarded by universities to dissertations which were written solely in the companies, unsupervised by academics (Shimizu and Mori 2001). The companies took the extreme route of developing an in-house training for cultivating PhD level researchers.

[insert table 1]

Korea and Taiwan. If Japan demonstrated that a miracle can take place, Korea and Taiwan proved that it was no accident. However, the roles their higher education played in their high tech industry development were different from that of Japan; subtly in the case of Korea, and dynamically in the case of Taiwan.

At the surface level, Korea’s development experience looks similar to that of Japan, in importing key technologies, developing industrial giants, most notably in electronics, which in turn made the transition to high tech industry. A well balanced education system has played a critical role in this process along with the early emphasis in engineering education; however little reference is made to the role of higher education in the transition Korean electronics companies made during the 1980s to high tech fields such as computers and semiconductors (Kim 1993).

One reason for the lack of visible participation by universities had to do with inadequately developed research capacity in universities arising from underinvestment by the government (Kim 2000). Korean higher education went through massive expansion in enrolments in the 1970s and the 1980s (see Table 2), with the key consequence of rising student staff ratios whiwh was 23% in 1966 but 36% in 1985 (Kim 1993). In 1985, nearly a half of national and public universities revenues came from tuition and fees (KCUE 1990). The lack of public resources is still evident in Korea’s higher education. As Tables 3 and 4 show, Korea’s public spending is at a strikingly low level in per student terms, compared with that of other countries. Research orientation was also slow to develop, partly because of the historical division of labour in which public research institutions were responsible for research (Sohn and Kenny 2007). It is not surprising that universities continued to be teaching dominated and could not play effective research related roles, and that academic spinoffs have been largely absent in Korea (Sohn and Kenny 2007).

[Table 2-4]

At the same time, competition for entry for reputable universities intensified, resulting in proliferation of similar programmes, as all universities aspired to be like Soul National University (Kim and Nam 2007). The emerging hierarchy of higher education institutions, based on their selectivity at university entrance, however, did serve industry. Large high tech companies such as Samsung could recruit directly from the best universities (Kim and Nam 2007).

It is not that no action was taken. The government began to invest in research and graduate education in the 1980s. The insufficiently developed university-industry relationships were also recognized as a problem and the government invested in special programmes to strengthen such ties in the late 1980s (Kim 1993) leading to some measurable increases in their relationships (Kim 2000). However, it was not until the BK21 programme in 1999, which for the first time concentrated large amounts of resources in the best institutions for research and graduate education, that the impact was felt (Kim and Nam 2007).

However, some of the quoted statistics indicate a high, rather than low, level of engagement with industry. About a half of university research had been funded by industry in the early 1990s (Kim 2000), and one survey of industry found that nearly a half of surveyed companies had worked with universities (Sohn and Kenny 2007). The industry share of research funding declined in the late 1990s to about 15%, presumably reflecting increasing levels of government funding in research (see Table 5). However, it remains higher than the 6% in OECD countries, indicating that industry engagement continues to be important for universities, even if such relationships lead to little visible contribution.

[Table 5]

The 1980s were also the critical period in which Taiwan's high tech industry in computers and semiconductors emerged. Taiwan's higher education system and its development shares with Japan and Korea both the selectivity of universities and emphasis in engineering and sciences, but the sector remained small for a little longer than in Korea (Cheng 1992 – also see Table 2). Also, Taiwan's experience is markedly different in the role played by a public research institution called Electronic Research Service Organization (ERSO), a branch of Industrial Technology Research Institute (ITRI). ERSO orchestrated the first major technology transfer agreement with RCA in the 1970s, and subsequently developed a IC fabrication technology to establish a spinoff company, which in turn played a critical role in the diffusion of technological know (Wade 1990, Saxenian 2004). Since the Taiwanese industry comprised many small to medium scale enterprises (unlike Japan or Korea), they did not have the capability to undertake significant R&D in-house, and public investment in applied research was essential for their technological upgrading (Wade 1990).

The most striking difference in Taiwan's high tech development is the role played by their diaspora of engineers, particularly in Silicon Valley, and how 'brain drain' turned into 'brain circulation' (Saxenian 1999, 2002, 2004, 2006). Almost eighty percent of the Taiwanese diaspora professionals in Silicon Valley had gone to the US to study and remained there for work (Saxenian 2002). Early generations of the diaspora were instrumental in informing the Taiwanese government about Silicon Valley and its unusual dynamism, the reason why Taiwanese had an early policy for building a cluster rather like Silicon Valley (Saxenian 2004). In 1980, they invested in a science park in Hsinchu, close to two of Taiwan's best technical universities, and relocated ERSO (Saxenian 2004). The science park became an active recipient of the returning diaspora with 40% of companies started by them. (Wade 1990, Saxenian 2004).

If it was ERSO, the public research institute, which played a critical role in applied research, what role did higher education play in Taiwan? The first and foremost role appears to be the supply of well trained engineers. Engineering was a popular subject, as the labour market rewarded engineers well (Wade 1990). Scientists and engineers accounted for more than a third of graduates during the 1960s, more than 40% in the 1970s and 50% by 1980 (Wade 1990). Though the size of the sector remained relatively small until the mid-1980s (about 14%), this was already a significant concentration of engineers.

It is well known that Taiwan suffered from a massive brain drain which started from the 1950s until the 1990s. Interestingly, this did not stop the government in having organized programmes of overseas study to complement Taiwan's own education system. In 1975, there were 2300 students studying under government auspices; in 1986 7000 were in such a programme (Wade 1990). This is to be contrasted to the size of the brain drain, which was as large as 20% of the engineering graduates in Taiwan in the late 1970s (Hou and Gee 1993). Instead of stopping to send people, Taiwanese government simply stepped up efforts to keep in touch with the diaspora community (Wade 1990), the benefit of which was finally felt in the 1990s when the brains started to return.

Even in brain drain, selectivity appears to have played a role. Having a competitive system of higher education entrance meant that some engineering colleges and universities had an elite status – and it was largely graduates from such institutions who became critical members of the diaspora and formed vibrant alumni networks (Saxenian 2004). Such networks were important for solving technical problem, as former teachers as well as former classmates represented important sources of technical information.

Israel, Finland, and Ireland. These three small countries provide an interesting contrast as they share the experience of having their ICT industry take off in the 1990s, with very different configurations and capabilities (Roper and Grimes 2005). This section will discuss how such differences in industrial capabilities reflect, at least in part, the shape and nature of their higher education and public research systems.

Israel started by attracting multinational R&D as early as the late 1960s and gradually developed a vibrant and R&D-oriented ICT sector dominated by export oriented domestic companies (de Fontenay and Carmel 2004). Finland emerged out of a serious economic downturn in the early 1990s and managed to develop a globally competitive telecom industry centred around Nokia (Dahlman, Roper and Grimes 2005). Ireland turned around from being a recession ridden poor country in Europe to become a dynamic centre for ICT industry, led principally by an inflow of multinational companies (Sand 2005, Arora et al 2004, Roper and Grimes 2005). The biggest contrast among the three countries is in their R&D capabilities (Roper and Grimes 2005). Whereas Israeli industry contains significant R&D activities, leading to small scale production of niche-products, Finland covers a whole range of value chain from R&D to mass production, and Irish ICT industry is characterized by mass production of products which are developed elsewhere, with only a small product oriented domestic software sector emerging.

In **Israel**, universities played two roles, in supplying highly skilled human resources and in being a source of leading technologies not only in ICT but also in biotechnology and agriculture related research (de Fontenay and Carmel 2004, Breznitz 2007). The Israeli government had made significant public investments in application oriented scientific research in universities, public research institutions and in the military soon after its formation. Their universities were well established scientific centres from the early days; a high number of publications per unit population characterizes Israeli academia (see Table 6). They have also long been application-oriented as their patenting records demonstrate (Trajtenberg 2001). It is not surprising that Israel became one of the first R&D sites abroad for US multinational companies. Universities' contribution tends to be overshadowed by that of the Military in the stories told about Israel's high tech industry, but they have contributed to the emergence of an entrepreneurial sector directly and indirectly, through spinoffs as well as science parks some of which had been established as early as the 1960s (Roper and Grime 2005).

[Table 6]

The military played an interesting role both as a source of new technologies which could lead to civil applications, but also as a key selector and shaper of future scientists. Through the three year compulsory military service, high calibre young people were identified early and trained intensively in their science and engineering programmes, before they went on to universities (de Fontenay and Carmel 2004). In the late 1990s, 'graduates' from the military were starting up even without going on to universities (Breznitz 2007)

Israel's already rich human resource received a further boost, when a total of a million immigrants from the former Soviet Union flooded the country in the early 1990s. Many had science and engineering backgrounds, and played a key role in boosting the technical human resource base of the country on the eve of the ICT take-off (de Fontenay and Carmel 2004).

In **Finland**, the government implemented an information society strategy to grow out of the deep economic recession in the early 1990s. The idea was to restructure the economy into a knowledge-based one through public investments in R&D, along with education reforms (OECD 2003). There had been significant concerns that universities were detached from industry, and were unable to meet changing labour market needs (OECD 2003). Significant public investments were subsequently made in R&D emphasizing collaboration between between companies and universities, and the government took a decisive move in creating a polytechnic sector as part of the (Srinivas and Viljamaa 2008, Dahlman and others 2007, OECD 2003). These two actions are consistent with the fact that a large telecommunication sector emerged, active both in high quality R&D but also in mass production which requires significant skills in the labour force at the mid level.

However, universities' inclination to work with industry appears to have been quite variable across institutions. Some universities with technological orientation or regional development missions appear to have been much more active in working with industry, with much larger shares of funding from Finnish Funding Agency for Technology and Innovation (TEKES), which provide competitive grants for application oriented research (Ministry of Education, Finland 2005).

In Oulu, which was a region that transformed itself from being a sleepy backwater to becoming a vibrant high tech centre, its university played an important role (Donnelly and Hyry 2004). Established in the 1950s with a specific mission to help the region develop, the University of Oulu has been both proactive and responsive in its education. Electrical engineering department was established early, well before industrial needs emerged, but they also responded quickly to meet emerging skills shortages, for instance in management education (Donnelly and Hyry 2004). The university's responsiveness also led to developments of relevant research centres, in which both basic and applied research were undertaken, often jointly with industry – and there appear to be some cases of academic spinoffs, though the degree of their success is not well documented.

Finland also made a decisive move in creating a set of responsive institutions when they established 29 polytechnics in the 1990s. By 2000, nearly 60% of entrants to higher education were going to polytechnics. Though it is early to understand the full impact of polytechnics in Finland, their performance reviews have been generally positive, with indications that their expansion coincided with the timing of major industrial needs, particularly in telecommunications (OECD 2003). In one survey of high tech industry in Northern Finland, 47% of companies said that polytechnics were important, compared with 38% which thought the University of Oulu to be important, and 10-20% that found other universities in Finland important (Juahiainen 2006).

In **Ireland**, the government led expansion of technically trained manpower in the 1970s and 1980s played a key role in attracting MNCs including in ICT. The starting point was the consensus that emerged early among policy makers that technical education was critically needed, but that universities were overly academic, and that different institutions were needed to provide the critically needed technical manpower (White 2001). Thirteen Regional Technical Colleges and two National Institutes of Higher Education were established in the 1970s for this purpose, representing the bulk of expansion in the tertiary sector. They were established specifically to be responsive to economic needs, and are today known to have well-established practices, for instance, in assessing industrial needs or in obtaining industrial inputs in curricular content (Breznitz 2007).

Starting from the late 1970s, the Industrial Development Authority (IDA) also began to have direct influence in the major expansion of engineering and science education, not only in RTCs and NIHEs but also in universities (White 2001, Sands 2005, Breznitz 2007). Between 1978 and 1983, engineering graduates increased by 40% and computer science graduates doubled in number (White 2001). This 'early' investment in technical skills was a key factor in attracting MNCs particularly in software industry as the skills shortages became pronounced elsewhere in the 1990s (Arora and others 2004, Sands, Breznitz).

Interestingly, though research capacity was slow to develop in universities, owing to lack of policy emphasis on research until the late 1990s, universities also played an important role in developing the indigenous software industry through academic spinoffs (Sands 2005). There was in fact, an early development of computer science departments in two leading institutions through what now appears to be a historical accident (Breznitz 2007). The government had announced a plan to disband the faculty of engineering in one university and to move it to the other university. Both institutions took defiant steps to establish and expand computer science departments, and began to be research-active largely through European research funding (Breznitz 2007). One of the two universities became one of the largest recipients in Europe for grants in computer science, and soon, became home for product-oriented, highly successful academic spinoffs (Breznitz 2007).

A rapid expansion of technical manpower also led to serious brain drain particularly in the 1980s when the economy was still weak. 25% of all graduates were emigrating in the late 1980s, to be contrasted with 5-6% in the early 1980s and again in the early 2000' (Kapur and McHale 2005). The situation was much worse for technical skills, as nearly a half of graduates in electronic engineering and over a quarter of graduates in computer sciences were reported to emigrate in the mid 1980s (Sands 2005). The dynamic economic development, however, led to a dramatic turn around of this trend. In 1989, net emigration was as high as 43,900; by 1999 there was a net inward migration of 18,600. There are less detailed accounts of the Irish diaspora phenomenon that demonstrates the nature of brain circulation than for Taiwan or India. However, the returning Irish emigrants were substantially better educated than the home labour force, with 58% educated at the tertiary level, compared with 29% for non-returnees (Kapur and McHale 2005). The returning diaspora not only contributed to the ICT industry avoiding skills shortages experienced by many other countries in the 1990s, but also brought back valuable international experience and connections to the market abroad (Sands 2005).

China and India. The experience of China and India are significantly different from each other, and contain important departures from other countries as well. China adds its own variation to the East Asian experience of industrial development, with heavy involvement of MNCs, many of which started their operations in China for mass production of simple products, allured by the availability of cheap labour and the promise of large domestic markets. Chinese industry gradually built up capabilities in high tech products over the past two decades. India's experience appears to be an interesting case of leap-frogging. Not only did India leap into the heart of high tech service industry, but unlike others, it did so without there being any linkages to computer hardware industry. There has been little role played by MNCs except at the beginning stage (Kapur 2002, Saxenian 2006)); the Indian software industry evolved largely as a group of domestic companies, providing key customized services to overseas clients (Athreye 2005).

The first role is the one both higher education systems appear to have played, in providing well educated manpower in science and engineering. However, it is not clear that the large number of graduates all contributed. Both countries report serious unemployment and underemployment among graduates coexisting with key skills shortages, which suggest that they both have problems of highly variable quality standards (Agrawal 2007). Large numbers also do not mean that large proportions of their youths attend higher education either; at the time of their take off in the mid 1990s, their gross enrolment rates were still low at 5-7% (Table 2). The proportion of engineering graduates has been high in China but not particularly so in India (Table 7). One possible explanation is that both countries have had highly selective institutions which recruited high calibre students into engineering nationally, and these have set certain quality standards in engineering schools more generally. At the time of the take off, graduates from these selective schools are unlikely to have had strong competing labour market demand and even though the numbers of these graduates are small in Indian terms, they are significant and attractive enough for individual firms. The software industry's success is also likely to have led to a significant expansion of private engineering institutions – the quality of which may be questionable.

[Table 7]

Chinese universities and public research institutes also played an unusual second role in establishing university enterprises since the late 1980s. Though they are often described as 'spin-offs,' they are owned and managed by universities and in that sense different from the normal academic spinoffs in the US or Europe (Eun and others 2006). Some of these companies have been spectacularly successful. For instance, three of the most successful PC companies, Lenovo, Founder and Tongfang were enterprises created by the Chinese Academy of Sciences, Beijing University and Tsinghua University respectively. Some 40 university enterprises are already listed in stock markets in China and Hong Kong (Eun and others 2006). Of the 5000 or so university enterprises that were founded in the early 2000s, about 900 were 'high-tech' with a total profit of US$600 million (Ma 2007). The idea for universities to have their own enterprises was not new; in the 1950s and 60s universities often had affiliated production units which were used for training students (Ma 2007). What was new in the 1980s was the idea to use the same vehicle for commercializing university knowledge.

The trend to set up university enterprises was prompted by several specific factors in the mid 1980s (Eun and others 2006, Ma 2007). The S&T reform starting in the 1980s transformed the roles of various S&T institutions, reduced the privileged role that public research institutions had in government funding, and strongly supported the research role of universities relevant for the society for the first time (Ma 2007). However, the endorsement of universities role in relevant research did not mean government funding was forthcoming, on the contrary, university budgets were extremely tight; universities had strong incentives to generate their own incomes through industrial contracting (Ma 2007). While universities were to play a key role in technology transfer, the absorptive capacity of industry was low. Creating their own enterprises may have been the simplest option through which universities could contribute to strengthening industrial capabilities (Eun and others 2006). Interestingly, the nature of knowledge content in these companies appears to be significantly different from that observed in academic spinoffs in the US. It was not that significant scientific research results were commercialized, rather, skilled personnel moved from universities to the commercial sector (Chen and Kenney 2007).

It is questionable how long the old tradition of university enterprise will continue into the future. Both the government and many universities may be going through a re-thinking process, as many enterprises have not been successful and managerial responsibilities are increasingly demanding (Kroll and Leifner 2008). It is possible that China's university enterprise experience was a phenomenon dictated by the specific context at a specific time, with a new model of spinoffs which are a little closer to Western models emerging (Eun and others 2006, Kroll and Leifner 2008).

The third role is one of brain drain/brain gain that the both countries experienced. China followed Taiwan in the brain gain that followed their brain drain experience in the 1980s. The Chinese government opened the door to aspiring students going abroad in the 1980s, and even developed their own fellowship programmes at the height of it. They were prepared to endorse this mass exodus because they knew that they needed them to go abroad to acquire key knowledge and skills. India had a longer experience of brain drain most evident in their best institutions such as the Indian Institute of Technology (IITs) dating back to their founding days in the 60s. It was not uncommon for these institutions to find that a large proportions of their graduating class would find graduate education possibilities in the US.

In the survey of Silicon Valley professionals, Saxenian found that over half of Indians and nearly 80% of mainland Chinese had originally come to the US for their education (Saxenian 2002). Over 70% of mainland Chinese and nearly 60% of Indians had arrived in the US in the 1990s (Saxenian 2002).

China was able to benefit doubly from diasporas, as Hsinchu-Silicon Valley- Shangai increasingly became connected by broadly defined overseas Chinese engineers including those originally from Taiwan (Saxenian 2006). In the early 2000s, the Chinese government also stepped up effort to recruit back the overseas Chinese. For India, highly entrepreneurial diaspora also played a key 'reputational intermediary' role in connecting Indian firms to client US firms or to bring American MNCs to India (Kapur and McHale 2005, Saxenian 2006). The dominance of Indian entrepreneurs not only in Silicon Valley but more broadly in US high tech companies is well documented (Saxenian 2002, Wadha and others 2007). They appear to have been slower than their Chinese counterparts to return to India to play more visible roles, however, this appears to be happening now (Saxenian 2006, Kapur and McHale 2005, Kapur forthcoming).

The fourth role that both Chinese and Indian higher education institutions are beginning to play is one of joint research with companies, which are increasingly including MNCs. In China, the significant component of joint R&D with MNCs appears to be redevelopment of foreign technology by Chinese universities to cater to Chinese firms or markets (Wu 2007). In India, elite institutions which are relatively more research-intensive did have a range of research-oriented relationships including those with MNCs (Basant and Chandra 2007).
This is significantly different from any of the other country cases described above, except for the US and Israel.

What is motivating the MNCs and what specific roles are being played by universities in China and India? In China, the government has been applying pressures for MNCs to invest in R&D as a price to pay for accessing China's vast market, and competition among MNCs to win government approval has been a factor in driving up R&D (Walsh 2003). MNCs' partnerships may well be little more than the lip-service to satisfy governmental requirements. On the other hand, it is possible that the MNC need for certain R&D to 'localize' products to suit the Chinese market is being met by increasingly research-savvy Chinese universities. The need for round-the-clock R&D in software development or the need for cheap intelligent labour for R&D related to software or biotechnology may also be reasons why MNCs would want to work in environments such as India or China.

However, the possibility that both Chinese and Indian institutions may be playing similar research roles in their relationships with MNCs is surprising, as the two governments could not have been more different in their approach to creating scientific research capacity in their universities.

In China, the government has been taking steps to reform the system since the 1980s – and in the retrospect, these steps appear to be remarkably consistent ones that pushed the system towards the American research university model (Ma 2007). They have been systematically supporting the emergence of elite research universities through a series of programmes, starting from the key university and key laboratory programmes in the 1980s, the more famous Project 211 and Project 985 which concentrated government funding in top 100 and top 9 institutions respectively in the 1990s (Ma 2007). Together with the gradual development of competitive funding for research starting 1986, these resulted in strong incentives for universities to become research-oriented – to compete globally to become world class universities (Ma 2007). It is no accident that one of the first global rankings of universities came from one Chinese university – they were developing such indicators to inform themselves of their positions in the world.

In India, there is a sense of crisis about the state of higher education (Agrawal 2007, Kapur and Mehta 2007). There has been no consistent set of policies to establish elite institutions after the creation of the Indian Institutes of Technology in the 1950s and 60s, and other specialized institutions such as the Indian Institute of Science (Jayaram 2007). The recommendations to develop high class universities had been made by a high level commission in the 1960s, but they were duly ignored, and the system expanded rapidly conditioned by policy makers who were more concerned about providing equitable opportunities than the quality of education (Jayaram 2007, Kapur and Mehta 2007). There has been little consistent policy push either to promote universities to work with industry or for them to become research oriented. The lack of research-orientation in higher education institutions at least in part reflect the fact that there is an extensive set of public research institutes, which are supposed to play the research role for the nation (Jayaram 2007). Still, it is true that India has globally respected professional/technical institutes as well as well established public research organizations, many of which appear to play critical roles in regions that have become hubs (Kapur 2001). Also, the policy context appears to be changing, as the government now plans a major expansion of professional institutions such as Indian Institutes of Technology, Indian Institutes of Science and Engineering Research (IISER) and Indian Institutes of Information Technology. It is possible that they play equivalent roles of Chinese elite institutions.

Summarizing Roles of Higher Education

The international experience in developing high tech industry suggests that universities can and do play a diverse set of roles. First, there are three different types of education roles differentiated both by the level of education and the level of curricular relevance. Second, there is a role that higher education plays in selecting/screening. Third, there are two types of knowledge adaptation/dissemination role that may not require knowledge creation role. Fourth, there is a knowledge creation role in conducting relevant and fundamental science. As the international examples showed, many higher education institutions play multiple roles, and their role may change over time as well.

*Education related roles***.** The roles universities play differ significantly, not only in terms of the level of education provided (e.g. undergraduate vs. MA and PhDs), but also in terms of the relevance of what is taught.

- *Providing generic science and engineering graduates*. In some cases, high tech industry evolved on the back of science and engineering graduates who were not necessarily trained in a specialization relevant to the industry. In Japan (and increasingly in India) where companies took large numbers of graduates, with a view to training them on the job, universities were merely expected to provide generic science and engineering skills. However, without such institutional willingness on the part of firms, this role is unlikely to be sufficient for the subsequent evolution of high tech industry.

- *Relevant education in emerging technical fields*. Some institutions and countries were quicker to offer new fields or skills relevant to industrial needs than others. This responsiveness was particularly important when new disciplines such as computer science emerged, and appeared to give countries a competitive edge, as was clear in the case of Ireland.

- *Relevant advanced research training (masters and PhDs).* The knowledge-intensive end of high tech industry requires key scientific capabilities inside firms. The fact that some American universities were capable of producing relevant research training was deemed critical for the evolution of Silicon Valley (Moore and Davis 2004). The fact that these universities were research-active in new fields relevant to industry, clearly helped them in producing research-trained graduates in relevant fields. However, the linkage between research capacity and related teaching is not automatic. Research capacity built outside universities (as in ITRI) may not necessarily be linked to graduate education. Even when research capacity within universities is improved, it does not automatically lead to the development of graduate schools, as the Japanese case demonstrates.

Selecting/screening high calibre individuals. Selectivity in higher education institutions can provide a critical role in screening and bringing together similar calibre individuals. This can help industry directly in screening their new recruits, as in Japan or Korea. Even when such selectivity led to serious cases of brain drain as in Taiwan, India or China, this led to the formation of entrepreneurial and highly informed diaspora which in time played a critical role in introducing high tech industry to their homeland.

Knowledge dissemination/adaptation roles. Higher education institutions in developing countries often start out as teaching focussed institutions and develop some form of research capacity over time. However, two of the research related roles have little to do with 'creating scientific knowledge,' but are to do with bringing up the level of understanding to an international level.

- *Application oriented research*. Some institutions have played key roles in conducting application oriented research or in deepening the local understanding of existing technologies. Taiwan's ITRI/ERSO provides a vivid example of how local industrial capabilities were built around a public research institute, which in turn helped upgrade the technological capabilities of a whole group of high tech firms. Whether universities are expected to play this role depends on whether there are public research institutes which are dedicated to applied research. In Taiwan, this role was given to a public research institute, in spite of the fact that there were two university candidates near the Science Park. In Korea and India, the presence of public research institutes may have inhibited universities to develop significant application oriented research capacity (Jayaram 2007). In contrast, Chinese universities appear to have developed capacity for application oriented research which helps localization of technologies, with an increasing emphasis on fundamental research (Ma 2007).

- *Disseminating scientific information*. Universities can also play a role by generally providing updated scientific information. This is not a trivial role in the world where high tech companies are constantly required to keep up with progress in multiple fields. As the industry evolves, it is also likely that companies are faced with constant needs to develop capabilities in new areas. Japanese universities appeared to have played a consistent role in this arena, which was necessary for domestic companies to update and modify their scientific base over time.

Knowledge creation: relevant fundamental research. This is the role most visibly played by some American universities at the birth and evolution of some key high tech industry. Many universities in the world conduct excellent scientific research, and yet they may not play the proactive role that American scientists did. The difference may be that some scientists conduct research that are not only fundamental scientifically, but also highly relevant to the world of applications. They are also aware about the practical relevance of their scientific research. The star scientists in the early biotechnology revolution were not only prolific in basic research but were also highly aware of their potential applications. They were highly active in networking with relevant industries and took direct roles in the dissemination of tacit knowledge around fundamental discovery through academic spinoffs. Some institutions are better at promoting relevant fundamental research than others, but equally, some countries are better at supporting a whole group of such institutions than others.

There is a significant literature that discusses different linkages or forms of relationships between universities and industry such as spinoffs, research contracts, patenting/licensing, consulting, network meetings and science parks. Interestingly, the above discussions of international experience suggest that these 'linkages' may represent very different roles played by universities. For instance, university 'spinoffs' appeared to play visible roles when there is a significant capacity/knowledge gap between universities and surrounding industry, but the nature of this capacity/knowledge gap was very different between biotechnology in the US and ICT in China. In biotechnology in the US, the knowledge gap had to do with fundamental scientific discoveries with significant related tacit knowledge. In China, the nature of the knowledge gap appears to have been about existing technology that was new to China. The capacity gap may also arise because of the selectivity of universities; they may be better positioned to assemble a group of high calibre individuals to lead and work in new ventures.

Technology transfer around patenting/licensing is another form of university-industry relationship which has been highly emphasized in many countries. Similar to spinoffs, it is a mechanism through which university-based knowledge can be transferred to industry. However, its effectiveness depends on the extent to which universities undertake significant knowledge creation and the level of development of intellectual property related institutions in the country. In the celebrated case of the US, the patenting practice evolved as one of many mechanisms of technology transfer from universities, predicated upon huge government funding in relevant scientific research (Mowery and others 2004, Rosenberg and Nelson 1994). It is also increasingly clear that for most of the universities in the US, patenting/licensing is a net drain rather than a source of additional income (Thursby and Thursby 2007).

It is true that the wider acceptance of WTO and other international regimes related to intellectual property will undoubtedly have consequences for the paths that future developing economies can take in catching up. While it is important for developing countries and their universities to increase their understanding about intellectual property, indiscriminate opening of technology transfer offices in universities with a view to patenting their inventions may be unwarranted.

The extent to which reversed brain drain – or brain circulation – contributed to the rise of high tech industry is a pertinent one related the role of higher education. While the full effects of brain drain/brain circulation are outside the scope of this paper, brain circulation appears to play an increasingly important role in the introduction of high tech industry into a new country. This undoubtedly reflects the increasingly global nature of the labour markets in developed countries, many of which are actively recruiting professionals from developing countries in areas of key skills shortages such as ICT.

It is interesting to see approaches taken by some governments in dealing with brain drain. The Taiwanese were sending fellowships abroad even at the height of their worst brain drain. They apparently did so with the belief that they will gain in the end. A decade later, the mainland Chinese government was doing something similar. Both valued the foreign education sufficiently to send them abroad in the first place, but both also worked hard to bring them back. It is almost as though for the Taiwanese and Chinese governments, foreign institutions, particularly in the US, were a critical component of their higher education system, providing the kind of education that their domestic institutions could not provide.

Institutional Characteristics

It is clear that not all the institutions can play the same roles. Indeed institutions have very different characteristics depending on their historical development paths as well as the phase of development. From the above discussions, three dimensions or 'traits' emerge as critical in defining the nature of higher education institutions and the roles they can play: (a) responsiveness; (b) fundamental science orientation; (c) selectivity.

Some institutions or systems appear more '**responsive**' to the needs of the society than others. They are tuned into societal needs in education and research, able to detect changes in labour market needs as well as social demand/student preferences, and take appropriate actions in updating curricular content as a matter of course, and introduce new fields of specialization.

It is also evident that there are two types of 'responsiveness.' One is to respond to an existing demand, and the other is to respond to an anticipated demand. The former is an issue that can be readily undertaken by institutions – though this will require certain institutional capacity. Responding to future demand is harder for individual institutions and indeed this is where there appears to be a role for government. Many governments played the critical role of establishing generic science and engineering education well before there is labour market demand, and that turned out to be a critical investment that started the chain of events.

Government can also play a critical role in identifying future demand for certain types of scientific research – as the US or Israeli governments did. 'Defence' played an active role in these countries, perhaps because defence related R&D is one for which many nations are willing to invest heavily. But future demand in other civilian sectors may equally be articulated through government research agenda, for instance, in agriculture as seen both in the US and Israeli cases, or in health as exemplified by the US case.

The second dimension concerns the commitment to fundamental science. Again, some institutions are more committed to this than others. This means they value cutting edge science, reward key scientific discoveries, and encourage their researchers to actively define the direction of scientific research. Those that are developing such an orientation are unlikely to be active at the frontiers of international science, and may undertake research activities which does not change fundamental understandings. However, their engagement in international science gives them valuable exposure to the changing body of scientific knowledge – and this helped them to keep the rest of the country abreast of scientific developments. Yet others conduct hardly any research at all and remain teaching focussed institutions.

Responsiveness – or application-orientation - and fundamental science orientation expressed as two distinct dimensions was an idea first proposed by Stokes (1997). This separation of dimensions is powerful in that it immediately allows us to understand four different types of institutions. Institutions can be scientifically oriented, but not responsive – as many of the Japanese and European universities appear to have been. Second, some institutions can be scientific but at the same time responsive to societal needs, as some of the American institutions appear to be. Third, some institutions are responsive but not fundamental science -oriented – as Chinese universities appear to have been until recently. Other examples may include the Grandes Ecoles in France as well as polytechnics and their equivalents in a number of countries. Fourth, institutions may indeed be neither responsive nor research oriented. Liberal arts colleges in the US and a vast majority of teaching focussed institutions in the world probably fall into this category.

There is one further dimension that helps us understand differences in institutional characteristics: selectivity. In the extreme case, a highly selective institution may not do anything other than being selective and still play a key role in helping screening talent. Non selective institutions will have to do a lot more to play significant roles. And again, 'selectivity' may be established in an institution irrespective of whether they are responsive or scientific. This is the dimension that distinguishes between the Grandes Ecoles in France from polytechnics in various countries which otherwise occupy the same space in terms of high responsiveness and low scientific orientation.

Concluding remarks

This paper has argued that higher education institutions can play a variety of roles in supporting high tech industry. The roles they play in turn can influence the shape and nature of the high tech industry. The paper also argued that not all higher education institutions or systems can play the same set of roles. Rather, the roles they play are themselves determined by the characteristics that the institutions developed over the years in terms of their responsiveness, fundamental science orientation and selectivity. Goverments can play a critical role in influencing the orientations of institutions –through subtle or not so subtle means.

The fact that there are these three apparently independent dimensions leads to a question about which one (or what combination) should be given a priority in the development of higher education systems. Is there a logical sequence through which these dimensions be developed?

'Selectivity' is one dimension of higher education institutions which often emerges naturally as the demand for higher education expands and the competition for places increases. However, over time, such selectivity needs to be underpinned by robust selection systems that are fair but also provide good learning incentives for future students. This is not easy, but worth considerable attention, as selection systems can influence directly the reputational hierarchy of institutions as well as learning incentives of students for years to come. Some examinations inadvertently encourage students to become tactical rather than learning oriented. Equally, some scoring systems give spurious impression of accuracy.

Fundamental science orientation is something that requires serious commitment and investments usually from the government. Investments are needed not only in human capital in terms of advanced research training, but also in infrastructures such as libraries and laboratories, and actual expenses associated with research. It is a tradition that cannot be developed overnight. However, it is also a tradition which is hard to change once introduced, as PhD trained academics usually gravitates towards research rather than teaching, and there is often a sense of elitism associated with being research-oriented.

Responsiveness is also not a dimension that develops naturally –indeed it is arguably the hardest one to build either in a system or an institution. There are standard practices that can be used to introduce scientific orientation in higher education systems, such as peer review or competitive research funding processes, and indeed developing countries have an option to 'piggy back' on the institutional infrastructures such as PhD training or international journals. In contrast, there is no simple recipe to encourage institutions to become responsive. 'Demand' to which institutions must learn to be responsive is often local and intangible. Governments may demand institutions to provide new educational programmes or to expand them; simply responding to such a top-down requirement does not make them responsive. Korean government's central mandate to keep up the quota for engineering programmes may not have led institutions to become responsive. Indeed, one could imagine a scenario in which the more frequent government interferences, through regulations or even through financial incentives, the less institutions learn to be creative and strategic about what they do. In Ireland and Finland, a whole new group of institutions had to be established from a scratch, to become responsive.

Founding ethos does seem to matter, as the examples of Land Grant Colleges in the US show. Equally, societal expectations that universities should be relevant also can help. American government's expectation that universities must be useful for agriculture was a starting point in their funding agricultural extension activities in universities. Chinese government's explicit demands that universities must play a key role in technological upgrading of the society, no doubt provided a powerful starting point for them to work with industry. The fact that 'funding' for such activities had to be sought from individual enterprises rather than some central agency was probably helpful in that universities had to learn to work with a variety of 'stakeholders.' On the whole, there appear to be more examples of institutions which developed responsiveness first followed by fundamental science orientation (one good example being Massachusetts Institute of Technology – see Etzkowitz 2002), and it is probably easier to do so than the other way around.

The fact that the three dimensions are important in enabling institutions to play key roles does not mean that all institutions must be the same. On the contrary, as the case of Finland showed, there may be a strong case for requisite variety – or diversification in a country. Indeed, it is reasonable for a national system of higher education to contain all types of institutions – each playing somewhat different roles.

One historical legacy that the case countries share is some form of national championship of science and technology. The post war US was a special place in terms of policy makers endorsing the role of science for societal benefit, and that commitment and belief led to the development of a whole host of federal funding institutions which were to support fundamental science for different reasons (Geiger 2004). Similarly, without the highest commitment from

Jawaharlal Nehru, the first post-independence leader in India, the Indian Institutes of Technology would have never received the extraordinary technical assistance from the US, Soviet Union and Germany to develop the high standards that they did. Without the commitment of Deng Xiaoping, the Chinese government would have not committed as much resources to science and technology, which in turn helped attract the best and the brightest to the field. Such visible support of science and technology at highest levels, probably help foster commitment to science and technology within the society such that their students more readily choose to study science and engineering.

Such national championship is not easy to maintain over time. Science is expensive and it takes a long time before its impact can be felt. It is easy for commitment to science to give way to fiscal pressures, particularly given that it is never clear how much is needed. It is also not easy to cultivate a high level of interest within the society to induce students to choose science and engineering. Many OECD countries, such as the US, UK and Japan are increasingly concerned about the level of interest among their students in science. Even in India, there is an emerging concern that less students are taking a science track.

One final point for reflection is the role of governance arrangements at both institutional and national levels. Quality assurance considerations often lead government bodies to become overly prescriptive about inputs as well as outputs. This is a significant dilemma in developing countries, where there is little tradition and culture about the quality of higher education. Attempts by governments to ‘control’ quality can lead to institutions becoming similar to each other and to being passive in defining what they are. To make the matters worse, some dimensions are easier to measure than others; publications and citations are often used for evaluating the quality of scientific research, but there are no established metrics that look at responsiveness. Metrics used to ‘control’ or ‘guide’ could themselves be skewed.

Tight regulatory control by the government can also be a serious impediment when institutions need to respond to changing needs of the nation. And yet, the desire to ‘respond’ to national needs both from labour markets and from future students, particularly in dynamically developing countries, often pushes governments to centralize key decisions about the size and directions of the higher education system.

Institutional capabilities to ‘respond’ to complex demands are unlikely to develop if institutions are not allowed to make strategic decisions. Managerial autonomy and academic autonomy to decide what to teach and research are critical elements to foster responsiveness in institutions. At the same time, institutions are also unlikely to be able to make strategic decisions without governance arrangements which allow appropriate structures and processes to develop internally. The key for the future is to put in place governance arrangements at both institutional and system levels, which meet the balance of such competing concerns and which guide evolving higher education systems effectively.

Table 1: Total enrollments: advanced research (PhD) progammes

	1970	1980	1990	2000	2003	2006	% of Tertiary
China				54,038	108,737	...	...
Finland				19,750	19,846	22,145	7.2
India				55,019	65,357	36,519	-
Ireland				2,904	3,816	5,146	2.8
Israel				6,647	7,944	9,715	3.1
Japan	13,243	18,211	28,354	59,007	68,245	75,028	1.8
Republic of Korea				28,924	34,712	41,055	1.3
Taiwan				13,822	21,658	29,839	2.3
United States				293,002	306,889	388,685	2.2

Source: UNESCO database accessed May 7, 2008, Education Statistics, Ministry of Education, Science and Technology, Japan; Education statistics, Ministry of Education, Taiwan

Tanble 2: Tertiary gross enrollment ratio

	1970	1975	1980	1985	1990	1995	2000	2005	2006
China	0	1	2	3	3	5	8	..	22
Finland	13	28	32	34	48	70	83	92	93
India	5	5	5	6	6	7	10	11	12
Ireland	12	17	18	22	31	40	49	58	59
Israel	18	23	29	33	36	41	50	58	58
Japan	18	26	31	28	31	42	47	55	57
Korea, Rep.	7	9	15	34	39	52	73	90	91
Taiwan						39	56	82	84
United States	47	55	56	60	72	81	69	82	82

Source: Unesco database and World Bank database accessed May 7, 2008, Education indicators from Ministry of Education, Taiwan

*Total number of students in tertiary education including graduate schools as a percentage of the poputation in the five year age group following on from secondary school leaving age

Table 3: Public expenditure per pupil as a % of GDP per capita (Tertiary level)

	1999	2000	2004	2005
China	90	...	...	...
Japan	15	18	21	19
Republic of Korea	8	...	9	...
Finland	41	39	37	35
Ireland	29	31	24	25
Israel	33	32	26	...
United States	27	...	23	23
India	...	91	94	58

Source: UNESCO database accessed May 7, 2008

Table 4: Tertiary education expenditures as % of GDP

		1999	2000	2004	2005
China	Private expenditure as % of GDP	...	...	...	...
	Public expenditure as % of GDP	0.4	...	...	...
	Total expenditure as % of GDP	...	...	...	...
Japan	Private expenditure as % of GDP	0.6	0.6	0.8	0.9
	Public expenditure as % of GDP	0.5	0.5	0.5	0.5
	Total expenditure as % of GDP	1.1	1.1	1.3	1.4
Republic of Korea	Private expenditure as % of GDP	1.7	...	1.9	...
	Public expenditure as % of GDP	0.4	...	0.5	...
	Total expenditure as % of GDP	2.2	...	2.3	...
Finland	Private expenditure as % of GDP	...	...	0.1	0.1
	Public expenditure as % of GDP	1.7	1.7	1.7	1.7
	Total expenditure as % of GDP	...	1.7	1.8	1.8
Ireland	Private expenditure as % of GDP	...	...	...	0.2
	Public expenditure as % of GDP	1.0	...	0.9	0.9
	Total expenditure as % of GDP	...	...	...	1.2
Israel	Private expenditure as % of GDP	...	0.9	1.0	...
	Public expenditure as % of GDP	1.2	1.1	1.0	...
	Total expenditure as % of GDP	...	2.0	2.0	...
United States	Private expenditure as % of GDP	...	1.7	2.0	2.0
	Public expenditure as % of GDP	1.1	0.9	1.1	1.1
	Total expenditure as % of GDP	...	2.6	3.1	3.0
India	Private expenditure as % of GDP	...	-	0.2	...
	Public expenditure as % of GDP	...	0.9	1.0	...
	Total expenditure as % of GDP	...	0.9	...	...

Source: UNESCO database as accessed May 7, 2008

Table 5: Academic R&D financed by industry, by selected OECD countries: 1981–2006
(Percent)

Year	France	Germany	Japan	South Korea	UK	U.S.	All OECD	China	Russia
1981	1.3	1.8	1.0	NA	2.8	4.4	2.9	NA	NA
1986	2.0	5.8	1.7	NA	5.7	6.5	4.5	NA	NA
1991	4.2	7.0	2.4	NA	7.8	6.8	6.0	NA	NA
1996	3.2	9.2	2.4	50.5	6.7	7.1	6.9	NA	23.7
2001	3.1	12.2	2.3	14.3	6.2	6.5	6.4	NA	26.5
2002	2.9	11.8	2.8	13.9	5.8	5.8	6.2	NA	27.2
2003	2.7	12.6	2.9	13.6	5.6	5.3	6.0	35.9	27.9
2004	2.7	13.2	2.8	15.9	5.1	5.1	6.2	37.1	32.6
2005	NA	NA	NA	15.2	NA	5.2	NA	36.7	29.3
2006	NA	NA	NA	NA	NA	5.3	NA	NA	NA

Source: National Science Foundation Science and Engineering Indicators 2008

Table 6: Science and engineering articles by country: 1995-2005

Region/country/economy	1995	2000	2005	Pulibcation per million population	Average annual change (%) 1995–2000	2000–2005	1995–2005
Finland	4,077	4,844	4,811	914	3.5	–0.1	1.7
Ireland	1,218	1,581	2,120	502	5.4	6.0	5.7
China	9,061	18,479	41,596	31	15.3	17.6	16.5
India	9,370	10,276	14,608	13	1.9	7.3	4.5
Israel	5,741	6,290	6,309	926	1.8	0.1	0.9
Japan	47,068	57,101	55,471	434	3.9	–0.6	1.7
South Korea	3,803	9,572	16,396	341	20.3	11.4	15.7
Taiwan	4,759	7,190	10,841	474	8.6	8.6	8.6
United States	193,337	192,743	205,320	678	–0.1	1.3	0.6

NOTES: Article counts from set of journals covered by Science Citation Index (SCI) and Social Sciences Citation Index (SSCI). Articles classified by year of publication and assigned to region/country/economy on basis of institutional address(es) listed on article. Articles on fractional-count basis, i.e., for articles with collaborating institutions from multiple countries/economies, each country/economy receives fractional credit on basis of proportion of its participating institutions.

SOURCES: Thomson Scientific, SCI and SSCI, http://scientific.thomson.com/products/categories/citation/; ipIQ, Inc.; and National Science Foundation, Division of Science Resources Statistics, special tabulations.as published in *Science and Engineering Indicators 2008, population data from the World Bank database accessed May 7,2008, National Statistics, Taiwan,*

Table 7: Total tertiary enrollments in science and engineering

	2000		2005			% of total enrollments			Science/Engineering ratio
	Science	Engineering	Science	Engineering	Total	Science	Engineering	S&Eng	
China	...		...						
Finland	28626	69230	35468	80827	305996	12%	26%	38%	0.4
India **+	1528841	418193	1689504	696609	11777296	14%	6%	20%	2.4
Ireland	27087	18241	22851	19233	186561	12%	10%	23%	1.2
Israel	35057	39138	29967	56812	310937	10%	18%	28%	0.5
Japan	112428	706998	118704	668526	4038302	3%	17%	19%	0.2
Republic of Korea	208691	1096304	264259	1022845	3224875	8%	32%	40%	0.3
United States	...		1537243	1154971	17272044	9%	7%	16%	1.3

Source: UNESCO database accessed May 7, 2008

** India's data on 2000 are actually from year 2001

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