The role of universities and public research in the catching-up process

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1. INTRODUCTION

Recent studies of national systems of innovation have called attention to the contributions of university and public research to technical progress. These contributions have become more significant over time as the result of the increased scientific base of technologies and of innovative activities. For example, the link between academic and public research and the R&D activities of business firms has been an important institutional feature of sectors of the economy, like biotechnology, pharmaceuticals, and the field of information and communication technologies. Contemporary discussions of the learning economy emphasize the growing importance of knowledge as an asset critical to dynamic economic performance, proposing explicitly or implicitly that the economic significance of universities and public research labs as centers for the production and dissemination of knowledge is on the rise. In the case of advanced economies, our knowledge about the role of universities and public research in a national system of innovation is reasonably well articulated. On the other hand, we do not have a coherent view of their role and significance in the context of the catching up process of developing economies. Indeed, the proposition that universities and public research are important institutional elements of the catching up process is controversial.

Rightly, it has been argued that the conceptual framework of national innovation system needs to be refined and extended in order to be useful for organizing observations and developing policy analysis concerned with developing economies (Lundvall et al., 2002). Among scholars working in this vein, Albuquerque (1999) proposes that national systems of innovation be differentiated as mature, catching up, and immature systems, while Viotti (2002) distinguishes national systems of technical change aimed at generating innovations (the case of advanced economies) from those whose primary purpose is to foster technological learning (the case of late industrializing economies). In a similar spirit, Weiss (1990) proposes a taxonomy of the stages of scientific and technological development, and characterizes the different stages with respect to the level of development of human resources and the scientific and technological infrastructure, among other things. These taxonomies associate different firm-level technological capabilities with successive stages of economic development. In this way they also support the conjecture that the contribution of university and public research institutions to the development of such capabilities undergoes qualitative and quantitative changes during the catching up process. A clear understanding of these appears necessary in order to assess the implications for economic development of policies concerned with university and public labs' activities (science and technology policy).[1] Can the study of catching up history be of any use in this intellectual endeavor?

We certainly side with Gerschenkron's (1962) rejection of an altogether deterministic understanding of economic development. Country-specific institutions and history do matter. Moreover, as a result of changes in the institutions and technologies of modern economies (eg, the growing integration of markets and the significant rise in the extent and strength of international intellectual property rights) there are reasons to believe that the process of catching up in the twenty-first century may differ in important qualitative and policy respects from its nineteenth and twentieth century precedents.

Without underestimating the importance of these elements of change and novelty in the prospects for catching up by developing countries, we believe that the historical experience of now advanced economies can generate useful lessons for contemporary policies and developments. In hindsight the late twentieth century experience of catching up in countries like Korea and Taiwan shares important institutional features with earlier instances of this economic phenomenon. Awareness of these similarities motivates a historical inquiry on the role of universities and public research labs on the development of technological capabilities during catching up. A proper assessment of this role will result hopefully from future research conducted by a group of scholars across a range of domains of knowledge relevant to economic development. These include not only knowledge about physical technologies relevant to industrial development, but also about medicine and public health, agricultural techniques, management and administration, and institutional design.

This paper conducts a preliminary exploration of the development of university education, and of academic and public research in a number of catching up countries of the nineteenth and twentieth centuries. The scope of the paper is narrower than the project described above, focusing on the national university systems' contributions to the inward transfer of technology and the development of indigenous capabilities in the manufacturing industries. Various parts of the relevant historical evidence are found in studies focusing on specific countries, industrial sectors, or in institutional histories of national educational systems. Thus, this paper's goal is to begin gathering together strands of investigation and analysis in order to identify themes and perspectives that will orient the considerable research work that is to be done.

2. UNIVERSITY TRAINING AND RESEARCH IN THE NINETEENTH CENTURY

The period considered in this section is characterized by a change in economic leadership (from the viewpoint of aggregate productivity statistics) from the U.K. to the U.S., the emergence in the second half of the nineteenth century of industries that are widely regarded as the first to be science-based, including chemicals and electrical equipment, and the emergence of formal R&D laboratories at business firms in selected industries. These economic trends overlap with a phenomenon that is obviously central to our endeavor, namely the multi-faceted transformation of university activities whose outcome defined in its broad contours the contemporary conception of university. Without

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[1] Bernardes and Albuquerque (2003) propose that in fact public support to science should take place in the early stages of the catching up process, noting that in fact a threshold level of national scientific production has to be crossed for catching-up to begin.

elaborating this subject in too much depth, we would like to highlight at least three important facts.

First, it is during the nineteenth century that research in the natural sciences is embraced by the mission of university systems across a number of countries. Second, the scope of academic education is broadened to include the students' participation in active research and the professoriate's routine duties are extended to include teaching and research, including teaching about research. These trends take hold first in Germany, and then spread at different speed to the academic systems of other countries. Third, professional training at universities, that until the end of the eighteenth century encompassed only the training of lawyers, physicians, and the clergy, becomes much broader in scope. Of particular significance are the institutional changes that promote the development of higher education programs in engineering, a body of knowledge that was until then the province of vocational schools at the secondary level and practical training. This trend too tends to unfold at different speed in different countries, and according to country-specific institutional processes.

At the beginning of the century, British economic leadership was well established. During the nineteenth century the process of catching up begins in the U.S. and much of continental Europe, and gathers momentum in the second half of the century in the U.S. and Germany, followed by France, Italy, Sweden, etc. Also, the Meiji restoration in 1869 marks a turning point for the economic development of Japan, whose technological effort at catching up with the more advanced Western economies continues well into the twentieth century. What was the role of universities and public research in the development of technological capabilities that took place in these catching up countries?

We think it is useful to approach this question by remarking that toward the end of the eighteenth century British policy aimed at defending the country's technological lead prohibited the export of machinery and blueprints, as well as the emigration of skilled artisans. The failure of the policy and the removal of the restrictions in 1843 were partly the result of the British inability to enforce them. In fact, the transfer of technological knowledge and skills from Britain to the continent went on through the a variety of channels, among which Pollard (1981) singles out for its significance the hiring by foreigners of British experts at all levels, managers, engineers, and skilled workers. In addition, the migration of skilled British nationals seeking fortunes abroad (e.g., William Cockerill), and access to the scientific literature all contributed to the transfer of knowledge and skills.

On balance, Pollard identifies in the movement of people from Britain to the continent at first, but also across countries in continental Europe, as the primary mechanism for transmission of knowledge until the 1860s. The delays in the adoption and imitation of British techniques in continental Europe were in many cases the result of technical problems that Pollard considers peculiar to the technological conditions of the period, a "phase when new methods were complex enough to exceed the experience and reach of a single craftsman, and needed the collaboration of capital goods and of other skills, but had not yet reached the level when the technology could be systematized and transmitted in the abstract, without the personal experience of human agents, and when a viable and flexible engineering industry could produce a replica of any model put before it." (p.148)[2] Pollard's comments suggest two points. First, the scope for technology transfer activities through the agency of single individuals was narrowing due to the complexity of industrial technology and of its demands on varied and collective skills. Second, technological knowledge could not be effectively transferred in an abstract form. These considerations on the nature of technological capabilities as residing in

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[2] In partial contrast to this assertion, Landes (1969) emphasizes how the inadequate skill level of the workforce in the catching up countries as a common reason for the failure to adopt successfully British technology.

collective practice and qualitatively different from any abstract description, ought to be squared against the evidence on the emerging forms of technical education and their relationship to the needs of industry.

Training programs focused on engineering and industrial technology had begun to appear in different places. In France for example, already at the end of the eighteenth century the Ecole des Ponts et Chaussees (1775), the Ecole de Mines (created in 1783, and moved to Paris in 1816), and the Ecole Polytechnique (1794) had been established. These institutions were designed to train engineers for careers in public service, and the scope of their educational mandate (basically, the training of civil engineers for the public administration) limited their relevance for industrial development. In France, industry-oriented technical education was relegated since 1803 to intermediate technical schools, the Ecoles d'Arts et Métiers, that however were no more than vocational schools with little emphasis on mathematics and scientific learning. The unmet industrial need for highly qualified technical personnel led in 1829 to the establishment of the Ecole Central des Arts et Manufactures (ECAM), an institution privately funded by an industrialist, Alphonse Lavallee. Shinn (1980)'s evaluation of the school indicates that contrary to the early plans the school curriculum drifted away from the emphasis on the application of science to industrial processes that its founders envisaged. Around mid-century, less than a quarter of the graduates were employed in jobs focused on operations engineering or the development of new products and processes. While the graduates of the school were predominantly employed in industry, they were more likely to take on administrative and managerial duties.

ECAM's experience illustrates a problem that several scholars have argued was common to the engineering educational institutions of the first half of the nineteenth century, including the polytechnical schools of the German States. The problem was how to deal with the difficult task of bridging the gap between teaching math and natural sciences (a task that began to be picked up by universities during that time period) and the provision of purely practical training (Torstendahl, 1993). The outcome of this tension between science and practice as the focus of teaching was the convergence of educational curricula toward the model set by the French Ecole Polytechnique, whose graduates have been argued to have been poorly suited to work related to industrial technology. Accordingly, the engineering schools placed increased emphasis on providing students with a broad grounding in sciences that many educators perceived to be critical for understanding technology as something different from mere practical knowledge. This process has been referred to as the 'academisation' of engineering (Manegold, 1978; Torstendahl, 1993).

The blurring of the boundary between scientific and engineering education has a mirror image in the emerging overlap between the focus of university teaching and research and that of the technical schools. This phenomenon is nowhere more visible than in Germany, where an institutional separation existed between universities –from which technology was excluded as a subject for teaching or research – and the Technische Hochschulen, as polytechnical schools came to be named around the middle of the century. In spite of this separation, a convergence between their educational curricula resulted from (1) the development of applied scientific research at universities and (2) the theoretical drift in the typical curriculum of the Hochschulen (Lundgreen, 1980).[3]

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[3] Another perspective on this phenomenon comes from the requirements for admission into the two kinds of schools. Since mid-century, access to the science faculties at universities was opened up to students graduating from the high schools that were conceived originally as preparing students for access to the Hochschulen. The academisation of engineering is also relevant to the 1899 decision by Kaiser Wilhelm II to give the Hochschulen the right to grant doctoral degrees.

As regards the former, its significance has to be understood in light of the peculiar trajectory followed by the ideology of science at universities. While scientific societies and academies of the seventeenth and eighteenth centuries had been influenced by the Baconian utilitarian ideas about the study of science and technology (Emmerson, 1973, Stokes, 1998), the founding of the University of Berlin in 1810 –where science was taught in the faculty of philosophy—was inspired by the idea of education as an act of personal development associated with Wilhelm von Humboldt, then director of public education at the Prussian Ministry of the Interior. Thus, while science was accepted as a subject of teaching and research, laboratory research and empirical science were considered as lower ranking activities and "had to fight for emancipation from the domination of idealistic natural philosophy." (Keck, 1994, p.118).

Even then, the growing emphasis on laboratory research in the universities' science curriculum should not be understood as signaling an explicit commitment by universities to the scientific exploration of industrial problems. Consider for example the cases of the academic research labs headed by Justus von Liebig at the University of Giessen (Germany), and by Louis Pasteur at the University of Lille (France). Liebig adhered to a conception of scientific research as independent of industrial need, although his research activities were very often relevant and inspired by scientific questions emerging from practical problems (Weingart, 1978).[4] Pasteur's work at Lille was often focused on scientific problems dictated to his interest by the observation of industrial practice, even if Pasteur himself considered the idea of applied science to be an oxymoron (Böhme et al., 1978, p.238). Notwithstanding these commitments to the independence of the logic of scientific research from industrial need, the research activities carried out at successful laboratories like those at Giessen and at Lille was enormously influential on contemporary industrial (and agricultural) practice. It is widely agreed among scholars that the catching up and forging ahead of the German chemical industry in the second half of the nineteenth century owed a great deal to the strength of the academic training in chemistry at German universities and the abundant supply of chemists who were accustomed to laboratory research of the kind that became common among the leading chemical firms of the period (Haber, 1958).

This last remark suggests that in fact the relevance of academic research to industrial needs and capabilities depended not so much on the institutional location of the research (universities vs technical schools nominally oriented to engineering and technology) as on the nature of the research methods learned by students at both. Thus, the laboratory training in chemistry turned out to support the acquisition of technological capabilities for chemical firms whose activities included the first forms of systematic R&D in an industrial setting. On the other hand, the curriculum at the Hochschulen had become increasingly dominated by mathematics and the pure sciences and thus its relation to industrial practice had become increasingly tenuous. In this sense, the academic training of engineers continued to have the character noted earlier with respect to the French Ecoles: while it strengthened the students' understanding of scientific subjects, it fell short of equipping industry with engineers able to reproduce, adapt, and innovate industrial technology.

During the second half of the nineteenth century, industrial firms in Germany began to develop their own research laboratories. It can be conjectured that they did so because of the perceived gap between the research activity of the Hochschulen and the needs of industry. At the same time, the

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[4] According to Haber (1958), Liebig responded to critics of his teaching method that "once the principles and methods of pure chemistry had been absorbed, the practical utilization of this knowledge would follow as a matter of course." (p.64).

growth of domestic industries in Germany ensured that the economic relevance of technological education at the Hochschulen could be assessed by educators and policy-makers on the basis of more explicit demands from industry, rather than of latent demands as perceived by the faculty (Manegold, 1978). According to Weingart (1978), a turning point in the evolution of German technological and engineering education was marked by the introduction of an experimental technical laboratory at the Hochschule in Munich in 1868. This trend gained momentum in the 1890s when the technical schools acquired large scale facilities for teaching and research where the study of technology could proceed through an understanding of the diversity of practical conditions based on experiments on machines of full scale under conditions which correspond to a realistic operation (Weingart, 1978, p.272).

In addition to qualitative changes in the education received by students at either universities or Technische Hochschulen, it is important to notice that the sheer quantitative growth of student enrollment at German universities and Hochschulen since the 1870s provided industry with a considerable pool of talent. Indeed, it is recognized that the growth of the educated labor force exceeded the German industry demand for scientific and engineering talent, resulting in the underemployment of trained individuals, and their migration to other countries in search of suitable professional opportunities. The latter was the case for German chemists who operated in Britain for years before developments in the German chemical industry induced them to return to their home country (Haber, 1958; Murmann and Landau, 1998).

The evolution of technical education in Germany and France differs in important respects from the pattern observed in the U.S., where utilitarian concerns regarding the goals of higher education had a stronger influence on the introduction of professional education in the curricula and the formation of new institutes.[5] Early on, formal education in engineering was restricted to the training of members of the Corps of Engineers at the U.S. Military Academy in West Point (New York). Training in the mechanical arts and civil engineering was on the other hand the province of secondary level and vocational schools, and was otherwise the result of practical experience and of training abroad. As Pollard notes with respect to Europe, the dominant contribution to the advance of American technology came from skilled or educated immigrants, a flow that continued throughout the nineteenth century and the early twentieth. However, this mechanism was complemented and over time supplanted in importance by the indigenous formation of a technically competent workforce. An important milestone in the U.S. development of technical education can be identified in the creation of the Rensselaer Polytechnic Institute in 1823 by Stephen Rensselaer with the purpose of promoting ‘the application of science to the common purposes of life. The Institute’s first president, Amos Eaton, drew inspiration from the teaching of science in the Prussian universities and polytechnics. During the early years of the institution, the curriculum was strongly oriented to teaching in agricultural sciences, but already in 1835 a four-year degree program in civil engineering had been developed, the first of its kind in the U.S. (Emmerson, 1973, pp.144-146)

A broader movement toward establishing formal engineering programs began only after the middle of the century. Courses in engineering and applied sciences were however common among colleges, including those elite institutions whose curriculum design followed more closely the model of the European universities. The trend received an important impulse from the Morrill Act of 1862 authorizing a grant of federal land to the states for the purpose of maintaining at least one college where the essential focus of learning would be agriculture and the mechanical arts. Over the following

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[5] The peculiarly strong orientation towards the practical applications of science in the U.S. educational institutions as early as the 1830s was emphasized by Alexis de Tocqueville (1876).

decades, the purposes of the Morrill Act were pursued at either already existing or new institutions, private or public, including Cornell University (established in 1868), the Massachussets Institute of Technology (1865), the University of Illinois (1867) and the University of California (1868).

Nelson and Rosenberg (1994) identify in the decentralization of the U.S. academic system a key reason for its success in contributing to the economic development of the country. Private institutions, dependent on tuition revenues for their financial viability, were naturally inclined to respond to the changing needs of a growing society by providing professional education in any field, with hardly any prejudice regarding the academic standing of the subject matter. Contrary to the experience of the German Hochschulen whose educational and research goals increasingly emphasized the scientific basis of engineering knowledge, during the second half of the nineteenth century American colleges responded to changes in local economic conditions with courses and programs focusing on the eminently practical knowledge that was critical to the activities of individual industries. Tighter links with science emerged first in the one area of engineering whose origin itself could be traced to important advances in the sciences, namely electrical engineering.

The different pattern of development of higher education in Germany and the U.S. is underscored by the differences in the contribution that academic training and research made in the two countries to the development of their chemical industries. Until the 1870s, Britain dominated the chemical industry focusing on the production of inorganic chemicals. Its leadership however dissolved over the following decades. First, the German industry took the lead in the production of synthetic organic chemicals, considered by many historians to be the first science-based industry. Later, in the early twentieth century, it was the U.S. industry that emerged as the leader in the large scale production of inorganic chemicals and the development of petrochemicals. Historians regard the training and research at universities as a critical factor in the catching-up of both the German and U.S. industries, indeed their rise to a leadership role.

Already in the 1830s, the University of Giessen had established itself as the leading center of research in organic chemistry. Even British students were likely to study in Germany if only to return home in order to practice their research at domestic academic institutions. The German industry's catching up with the British and forging ahead in the field of organic chemistry relied primarily on its access to talented chemists whose university training emphasized laboratory research of the kind that provide to be critical to the development of new chemical products (Murmann and Landau, 1998). On the other hand, the German industry was not nearly as successful in the large scale production of inorganic chemicals, a segment of the industry where competitive advantage rested primarily on the achievement of lower costs through large scale production. In this respect, it has been argued that the training provided by the German Hochschulen was inadequate to the formation of the needed skills in industrial process design and engineering (Rosenberg, 1998). On the contrary, engineering was an accepted field of teaching in the U.S. universities at least since the 1860s and the U.S. chemical industry's catching up during the last quarter of the nineteenth century was facilitated by the availability of the technical skills in the design of production equipment and processes typical of engineers. Indeed, the U.S. (more specifically, the MIT) was the birth place of chemical engineering as a specific field of academic instruction, and by the early twentieth century a rapid increase in the number of students attending chemical engineering courses had taken place.[6]

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[6] The emergence of chemical engineering in the U.S. as a body of specialized knowledge capable of broad applications to the design of continuous flow processes for the production of chemicals is regarded by Rosenberg (1998) to have been a critical factor influencing the strides made by the U.S. chemical industry when it pioneered the use of petroleum as the dominant feedstock .

It should be noted that during the early development of the domestic chemical industry U.S. students were likely to pursue advanced training in chemistry at German universities, predominantly, but also at French and British ones. This was the case in spite of a relatively strong tradition of teaching in the field (Haber, 1958) and the adoption during the last quarter of the nineteenth century of the German model of university based on the conduct of research and teaching. Thus, while the German experience illustrates an instance of catching-up wherein the growth of the industry relied upon a strong pre-existing base of scientific research and training, the U.S. case makes it clear that a considerable amount of technological progress can occur in a science-based industry even when national excellence in the science base has not been achieved (Rosenberg, 1998, p.211).

This last remark suggests that the international movements of students of science and technology was also an important aspect of the diffusion of technology and science during the nineteenth century, one that has to be distinguished from the international movement of skilled industry personnel singled out by Pollard as the key transmission mechanism. Thus, a significant fraction of the scientists working in the U.S. chemical industry received their scientific education in Germany. British students accounted for about 12% of the students at Liebig's laboratory in Giessen between 1830 and 1850 (Murmann and Landau, 1998). The international character of academic education in the sciences was also an important factor in the development of national academic institutions.[7] The influence of the German model on the evolution of U.S. universities is quite remarkable. It is well known that the first incarnation of the modern graduate school in the U.S. at the Johns Hopkins University (founded in 1876) was heavily influenced by the German universities' emphasis on scientific research. Under the leadership of his first president, Daniel Coit Gilman, Johns Hopkins' faculty reached 53 units in 1884, "13 of whom had German doctorates and nearly all of whom had studied in Germany." (Emmerson, 1973, p.288). We would note also that the influence alluded to here was much stronger in the organization of university programs in the sciences than it was in engineering, where in general the U.S. universities held onto a curriculum that placed distinctly less emphasis on scientific training and more on practical learning.

The influences upon academic institutions in many catching up countries brought along by educators and administrators who received their training abroad, were often strengthened by the recruitment of foreign scientists to teaching and research positions. This trend was nowhere more visible and significant than in Japan as of the early years of the Meiji restoration. After the long period of commercial isolation during the Tokugawa dynasty (1603-1868), the government promoted policies whose aim was to catch up with Western technology and science. Through them, scientists and engineers from Western Europe were invited to Japan. For example, 519 engineers arrived to Japan on official visits between 1870 and 1885, mostly from Britain but also from France, Germany, U.S., Italy and other countries. A primary goal of the Meiji government was to create training programs for national students. Among these, the College of Engineering was founded in 1873 under the direction of the British J. Dyer and with a faculty of eight British professors. The College merged in 1886 with another Technical School to become the Engineering Department of the Imperial University (later University of Tokyo) and continued to rely extensively on foreign professors in the sciences, engineering, medicine, and agriculture. Under the supervision of the Ministry of Education, substantial numbers of Japanese students were sent abroad (380 in 1872, Emmerson, 1973). Odagiri and Goto

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[7] Thwing (1928) set at over 4,600 the number of American students who had matriculated in German universities by the end of the nineteenth century.

(1994) emphasize how the engineering programs at the College of Engineering was based on the interaction between classroom studies and on-site training at laboratory facilities of the school or operated by the Ministry of Industries.

By way of summary, we would like to point out a few important characteristics of the institutional mechanisms at work in the catching up countries of the nineteenth century.

There seems to be little doubt that the diffusion of advanced British techniques to continental Europe and the U.S. was primarily stimulated by the migration of skilled personnel to these countries (Pollard, 1981; Landes, 1969). But we believe that this mechanism was complemented by the processes of knowledge transmission and creation associated with the universities and related institutions of higher education. Three phenomena have to be identified.

First, the absorptive capacity of the catching up economies was enhanced by the development of a variety of educational institutions, ranging from secondary-level professional and polytechnical schools to universities and higher educational institutes focused on the training of respectively scientists and engineers. Among the countries where these reforms of the school system took place, France and Germany are characterized by a significant public investment in higher education whereas in the U.S. private initiative played a more important role at least until the Morrill Act of 1862.

Second, the role of formal training increased over the course of the century as a result of widening and deepening interactions between scientific knowledge and technology on the one hand, and of the adaptation of educational curricula at universities and technical institutes of higher education taking place in response to among other things, the development of indigenous industries.

Third, the development of the educational systems in the catching up countries opened up a new channel for the diffusion of scientific and technical knowledge. Along this channel, at least three important phenomena deserves emphasis. To begin with, students could receive their scientific and technical training at leading foreign institutions, and return to their home country to take up positions in industry. Second, students could return from abroad and take up positions in national universities and similar institutions. Third, foreign teachers could be recruited in order to enhance the quality of domestic training early in the history of national academic institutions. Interestingly, the directions of these flows reflect the relative strength of the educational institutions in different countries. Britain was predominantly a supplier of teachers, and its firms and scientific circles were the destination of study missions for academics, industrial technologists, but not for large numbers of students. Germany’s lead in the sciences since the mid-nineteenth century made its universities a common destination for foreign students, and a model for the ongoing changes that were taking places in the programs offered at universities in other countries.

3. CATCHING UP IN THE LATE TWENTIETH CENTURY: UNIVERSITIES AND PUBLIC RESEARCH IN KOREA AND TAIWAN

In this section, the discussion will focus on the characteristics of the catching up process during the second half of the twentieth century in Korea and Taiwan, arguably the most successful instances of rapid economic growth for the period. The variety of studies on the development of these two countries suggest that the international flow of people that Pollard considered to be most important in the diffusion of British technology to continental Europe in the nineteenth century, has continued to be an important vehicle in the twentieth century. But it is clear that the institutional context for the flow of people between advanced and developing economies has changed significantly, and a variety of mechanisms have been at work that played a modest role in earlier times. Accordingly, it is generally recognized that a significant contribution to the development of technological capabilities of Korea and Taiwan resulted early on from the flow of technical consultants associated with foreign business enterprises and the interaction between local and foreign firms. In addition, capital goods' imports, technology licensing and reverse engineering, all provided mechanisms for enabling Korean and Taiwanese enterprises to begin the process of catching up with advanced technology. The effectiveness of these channels and the ability of Korean and Taiwanese firms to acquire increasingly sophisticated production and technological capabilities appears to have a lot to do with the domestic availability of an educated workforce.

The stronger scientific base of industrial technologies and the wider disciplinary scope of tertiary educational institutions of the latter half of the twentieth century have enhanced the importance of scientific and technical education for the acquisition of the technological capabilities that appear crucial for a country to develop an indigenous innovation system. Indeed, a recognition that domestic universities play such a critical institutional role in the absorption of foreign scientific and technological knowledge seems to have been common in the design of government policies broadly aiming at catching up. For these reasons, the following paragraphs will outline in some detail the development of the systems of higher education in Korea and Taiwan, and highlight its relation to the government support to research activities through specialized institutes. This review will set up the discussion in the next section of the paper regarding elements of continuity and change between the nineteenth and twentieth centuries.

3.1 KOREA

Studies of the Korean experience typically emphasize three stages of development (Kim, 1993; Lee, W., 2000; Amsden, 1989) differentiated according to the mode of indigenous technological learning. Thus, early development efforts targeted mature industries where capital goods imports, foreign technical assistance, reverse engineering, and local learning, provided the most important mechanisms for upgrading production capabilities. Later on, product and process design capabilities acquired by Korean companies played an increasing role in reducing their dependence on the adoption of packaged technology. Since the end of the 1980s, Korean firms had become capable in at least a few sectors to conduct original R&D independently or as part of collaborative efforts. Progress through these stages was accompanied in Korea by a significant transformation of the educational institutions of the country in general, including universities, and of the public research infrastructure.

Policies aimed at fostering the Korean economy's catching up with advanced industrialized nations considered the reform of university education to be part and parcel of the catching up process, much like it happened in Japan toward the end of the nineteenth century. However, the details of the historical development of universities and public research labs in Korea illustrate both common elements with the experience of other countries and the importance of country-specific factors.

At the time of its liberation from the Japanese colonial rule, Korea's system of higher education was underdeveloped by most standards of performance.[8] In 1945, eight thousand students were enrolled in programs in Korea's nineteen higher education institutions employing 753 faculty. The educational level of the work force was poor, as 40% of all workers had no schooling and another 53% only primary education. The growth in the educational attainment of Koreans since then has been breathtaking. Already in 1960 enrollment ratios in primary and secondary schools had reached 96% and 29%, respectively. From the viewpoint of this paper, it is even more remarkable that the enrollment of students in higher education increased to about 90,000 by the same year.

While industrial development concentrated at first on labor-intensive industries with a low demand for highly skilled scientific and technical personnel, the growth of the higher education sector in Korea proceeded so rapidly that already in 1953 the problem of unemployment among the college-educated labor force made its appearance.[9] The Park government's attempts since the early 1960s at managing enrollment growth in higher education institutions achieved only partial success. On the other hand, attempts at increasing the enrollment in science and engineering fields succeeded. But in spite of the rapid pace of economic growth and the development of heavy and light industries, unemployment or underemployment of scientists and engineers soon became evident (Seth, 2002).

Amsden (1989) notes that these problems were similar to those encountered by the German university system in the 1890s. But while German universities were attracting then a considerable number of foreign students, the growth of the Korean university system was accompanied by a substantial flow of students to foreign universities. By the late 1950s they accounted for the third largest contingent of foreign students at U.S. universities and throughout the 1960s, about 5% of all Korean students enrolled in higher education programs were studying abroad, with an increasing share going to Japanese universities (UNESCO, 1969). A similar pattern holds for graduate education, whose development began in Korea around the mid-1960s following the Japanese model at first and the U.S. one later on. The number of graduate education institutions rose in the twenty years from 1965 from 37 to 203, and the number of students reached 70,000 in 1986 (Lee, S., 1989).[10] Even in this case, the growth of domestic enrollment in graduate education was accompanied by a substantial migration of Korean students pursuing graduate degrees abroad.

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[8] The beginnings of higher education in the country are associated with the arrival of Western missionaries during the latter decades of the nineteenth century, but the annexation of Korea to Japan in 1910 marked the start of a period of thirty-six years during which the colonial government did little to promote the development of higher education for Koreans and directed the educational system toward the propagation of Japanese cultural values. Between 1910 and 1924 there were no formal higher education programs in the country. Then, in 1924, a Japanese university was established in Seoul (Keijo Imperial University) and the missionary colleges were allowed to regain college status in 1925. Keijo Imperial University was however an institution whose main goal was to provide higher education for the Japanese expatriates. Korean students accounted for only between a quarter and a third of the total, and only very small numbers of Koreans attended universities in Japan (Lee, S., 1989).

[9] This increase in higher education attainment levels has been attributed to the significant amount of foreign aid received from the U.S. McGinn et al. (1980) estimate that between 1952 and 1963 19% of the $100 million in aid for education provided by the U.S. government were spent for higher education, with the bulk of the funds ($17 million) being used to upgrade the faculties at Seoul National University (p.91).

[10] The growth of doctoral students was heavily concentrated in the field of medical sciences (30% in 1986), while engineering accounted for only 18% of the degrees awarded in 1986. At that time, graduate research was also heavily concentrated in four universities accounting for 50% of the degrees awarded.

These trends were the basis for the government's concern with the brain drain phenomenon, and the resulting enactment of policies aimed at supporting the repatriation of Korean scientists. In fact, since the quality of graduate education at domestic institutions was inferior to what was available abroad, foreign academic degree-holders played a dual role in the Korean catching up. On the one hand, foreign trained scientists and engineers, whose skills and training were often complemented by work experience abroad, represented the most valuable human resource for the upgrading of technological capabilities at Korean firms since the 1970s. On the other hand, the development of graduate education programs at domestic institutions relied extensively on the recruitment of foreign-degree holders. For example, Sungho Lee (1989)'s case study of Yonsei University and Hanyang University indicates that in 1986 a large majority of their graduate faculty held doctoral degrees in fields like biology, biochemistry, computer science, physics and electrical engineering earned at foreign institutions.

The emerging weaknesses of the domestic university system led the Korean government to adopt policies aimed at improving the quantity and quality of graduate level education, including the transformation of Seoul National University into an institution almost exclusively dedicated to graduate education, and the establishment in 1981 of the Korea Advanced Institute of Science and Technology (KAIST).[11] The latter was exclusively committed to science and engineering training and research, and was intended to be a research institution that could assist the industrial community. Five years after its establishment, KAIST had a total of 142 faculty members, virtually all of them holding a foreign doctoral degree. In spite of these efforts, research activities at universities remained underdeveloped as a result of the deterioration of the environment for quality education and research brought about by rising student-professor ratios and the low level of R&D funding provided to university scientists on a per capita basis (Kim, 1993).

Far from indicating a lack of public support for R&D, the latter trend is the outcome of the government's increasing reliance on corporate R&D and public research laboratories for conducting scientific and technological research. Since the late 1960s, a significant number of public research labs operating under the direction of the Ministry of Science and Technology and other ministries became the locus of publicly funded research activities and the focus of collaborative research projects involving private industrial partners. Having peaked in the mid-1970s (more than 50% in 1975, Kim, 1994, p.272), the percentage of R&D personnel employed at public research labs has declined steadily (less than 10% in 2000) as a result of the growth in private sector R&D as well as the continuing growth of academic R&D personnel. However, while universities account for about a third of the researchers active in Korea, the amount of R&D expenditure per R&D employee performed at public research labs continues to exceed by a wide margin that at academic institutions (1.46 mil won vs. .03 mil won in 2000). While recent government policy has heeded calls coming from many quarters for greater support to academic research, the universities' role in the development of national technological capabilities has been confined mainly to training a technical workforce. In this way, universities have supported the processes of learning and problem-solving associated with the adoption of foreign technology through mechanisms such as capital goods imports, technology licensing, reverse engineering, and so on.

While the insufficient quality of the research training provided by domestic universities constrained the scope of their contributions to the development of national technological capabilities, the growth

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[11] KAIST resulted from the merger of two existing public research institutions, the Korea Institute of Science and Technology founded in 1966 and the Korea Advanced Institute of Science founded in 1971 (Lee, S., 1989).

of R&D centers at business enterprises and public labs received a considerable impetus from the reverse brain-drain of many Koreans who had received their college and graduate training at foreign universities. To a lesser extent, foreign-trained Koreans were also central to the growth of domestic universities. The return of highly skilled Koreans was an explicit focus of government policies, and became increasingly common with the emergence of R&D centers that could satisfy their professional ambitions (Kim, 1999).

Although a few scholars downplay the significance of the public labs' R&D activities for the country's industrial development (Pack, 2000; Kim, 2000), it should perhaps be recognized that at least from the late 1960s to the 1980s public research institutes provided the institutional vehicle for attracting foreign-trained Koreans. In addition to the aforementioned KAIST, numerous research institutes had been created by the Ministry of Science and Technology (itself formed in 1966) and others. Among these, the public institutes focused on research in electronics and telecommunications pioneered the development of a national research capability in the relevant fields of science. During the 1980s, government policy and the growing technological sophistication of business firms in these manufacturing sectors provided an important stimulus to the growth of corporate R&D labs.[12] Upon this development, research at public institutes became more closely linked with the needs of industrial development, although its contribution to the advancement of technology appear to have been significant only in a few areas, such as electronics and telecommunications (Mowery and Steinmueller, 1994; Amsden, 2001).

3.2 Taiwan

The Taiwanese catching up experience during the past fifty years shares important traits with the Korean. These two countries were both Japanese colonies during the first half of the twentieth century, and much like we saw in the case of Korea the Taiwanese system of higher education was only modestly developed after the liberation from Japanese rule in 1945. Throughout the following decades, the Taiwanese government increased the commitment of public resources to education (as a fraction of GNP, education expenditure went from 1.73% of GNP in 1950 to 5.83% in 1985). Illiteracy was almost completely eradicated by the early 1990s, and enrollment in secondary and tertiary educational institutions grew very rapidly. By the late 1980s more than 10% of the population had a higher education (Hou and Gee, 1993). The growth of the university system in Taiwan was remarkable by any indicator. Between 1950 and 1986, the number of higher education institutions went from 7 to 105, the number of enrolled students from about 6,600 to 440,000, and the number of teaching faculty from 1,000 to almost 22,000 (Hsieh, 1989).

In Taiwan too, the rapid growth of the university sector was accompanied by the kinds of problems that we discussed above in relation to the Korean experience. Namely, it was accompanied by government efforts to promote enrollments in the sciences and engineering disciplines both at the undergraduate level and beginning in the 1980s at the graduate level. As a result of these efforts, science and engineering accounted for about half of all students in the late 1980s (64% of Master level students and 48% of doctoral students).

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[12] The National R&D Programs established in 1982 by the Ministry of Science and Technology provided an important institutional vehicle for fostering collaborative R&D projects between public research institutes and private firms (see Won-Young Lee, 2000).

The “brain drain” problem plagued Taiwan at least since the 1960s. A considerable number of Taiwanese students migrated to foreign higher education institutions. In 1962, about 20% of all Taiwanese university-enrolled students were abroad, with the U.S. universities accounting for half of them. The migration of students was particularly strong in the natural sciences: in 1966 one third of the students were pursuing their degrees in U.S. institutions (UNESCO, 1972). Even at the end of the 1970s, the share of non-returning students among those who went abroad to pursue postgraduate studies was greater than 20% in the natural sciences and engineering (Hou and Gee, 1993).

The large numbers of foreign-trained Taiwanese proved instrumental to the early development of higher education institutions in the country and to staffing the emerging R&D institutes and laboratories in the public and private sector. With respect to the former, a 1989 study of the National Taiwan University and the National Tsing Hua University revealed that respectively 74% and 84% of the faculty had received their degrees abroad (Hsieh, 1989). Likewise, the Academia Sinica, a public research institute, was in the late 1980s almost entirely staffed by Chinese Americans who had maintained their ties with academic activity in Taiwan. Following the establishment of the Hsinchu Science-based Industrial Park in 1980, large numbers of foreign-trained nationals returned home as founders or investors in more than one-half of the new firms based in the Park (National Science Council, 1997).

The private sector R&D activities provide an interesting contrast between the Korean and Taiwanese experience. Whereas by 1987 private firms accounted for about 80% of all R&D funds and 50% of all R&D personnel in Korea, their share in Taiwan’s R&D spending was only 40% and that in employed researchers was 43%. By the mid-1990s, the private sector’s shares in R&D spending and employment of researchers had increased to 55% and 53% respectively.[13] These statistics indicate that the government has played and continues to play a more important role in the Taiwanese R&D effort relative to Korea.

Since the 1968 National Science Development Plan government policy emphasized increasingly the funding of technological research aimed at the industrial development needs of the country. Public research labs have been particularly important in light of the prevalence of small and medium enterprises in the Taiwanese economy whose ability to conduct internal R&D has been limited. Among the research institutes established by the government during the 1970s are the Institute for the Information Industry (III) and the Industrial Technology Research Institute (ITRI), whose activities focused on the development of technologies for the electronic and information industries. One of the divisions of ITRI, the Electronic Research and Service Organization (ERSO) has played a crucial role in the evolution of the national integrated circuit industry.

Until the 1970s production technology in the Taiwanese electronics industry had been mostly acquired from foreign sources through foreign direct investment, joint ventures, and linkages of domestic with foreign firms through original equipment manufacturer (OEM) contracts. ERSO’s research activities contributed to the development of technological capabilities according to a variety of patterns. It often acted as the gateway for absorbing foreign technology and disseminating it to local firms. For example, in 1976 ERSO acquired RCA’s metal oxide semiconductor technology and diffused the relevant know-how to private firms through a demonstration factory (Amsden, 2001; Hobday 1995). Later on, in the 1980s, ERSO promoted the formation of private spin-off companies by contributing

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[13] An indicator of the quality of the R&D activities carried out in industry is the share of researchers holding doctoral or masters degrees employed in industrial R&D labs. This increased from 21% in 1987 to 34.5% in 1996.

venture capital and technological assistance to researchers who intended to exploit technologies developed or acquired through ERSO (Hou and Gee, 1993).

It is worth noticing that the government support to R&D at public research institute and universities may have played a rather important role in inducing a qualitative change in the inward transfer of technology taking place as a result of other kinds of activities, including foreign direct investment, joint ventures between local and foreign firms, and subcontracting relations with foreign firms.

4. CONTINUITY AND CHANGE IN THE CATCHING UP PROCESS: A PRELIMINARY ASSESSMENT

An important difference between the catching up experiences of the nineteenth and twentieth centuries briefly reviewed in this paper concerns the development of the university systems themselves. The development of the university systems in both Germany and the U.S. did not occur as an attempt to replicate the educational institutions of Britain, the economic leader of the time. While there was certainly a considerable amount of learning from other national experiences, it is unquestionable that the German universities first, and the U.S. universities later introduced fundamental innovations in the definition of their own activities. By most accounts, these innovative features played an important role in laying the foundations for the two countries' industrial development and for their ability to leapfrog Britain in the development of the new science-based industries, where German and U.S. firms and entrepreneurs rapidly moved into the role of pioneers and innovators.

Already at the end of the nineteenth century, Japanese policies aimed at catching up with Western technology considered the organization of domestic universities an essential part of the process. From this perspective, Korea and Taiwan were standing on the shoulders of giants when at the time of the liberation from Japanese colonial rule they could model their own universities after the institutional templates that had been developed elsewhere. Lest the advantages of being a follower in the development of academic institutions appear to be overstated, it is important to notice that the twentieth century followers faced a variety of problems and constraints that were much less important a century earlier.

First, the increased scientific basis for industrial technology and its rapid pace of change has multiplied the size of the educational catching up effort required of follower countries. As Alice Amsden points out in her book on Korean economic development (1989), late industrializing countries of the twentieth century began their catching up phase from relatively further behind than, say, Germany in the mid-nineteenth century. Amsden emphasizes two sources of difference regarding the catching up process in the two centuries, namely, the increased scientific basis for industrial technology and the spread of mass education systems.[14] There is no doubt that the standards of educational attainment in the leading countries are much higher now than in the nineteenth century, and that public demand for education is almost certainly higher now than it was for economic as well as cultural reasons. These trends raise important challenges for the development of academic institutions in follower countries that can be illustrated with some data.

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[14] In particular, primary school enrollment rates presented in Easterlin (1981) have been interpreted as indicating how enrollment rates in primary schools were generally higher at the beginning of the catching up phase of the late industrializing countries relative to the earlier industrializing countries of continental Europe.

Consider first estimates of the student enrollment levels at German universities during the nineteenth century from McClelland (1980). During the 1830s, university enrollment fluctuated between 15,838 (1830) and 11,518 (1940). The number of students attending courses at the Technische Hochschulen was in the hundreds per year. By 1870, university enrollments had only increased by a few thousand (14,134), while around 5,000 students attended the Hochschulen. The following thirty years marked an unprecedented expansion in higher education: in 1903 enrollments at universities and Hochschulen had reached 35,000 and 17,000, respectively. Thus, over the course of seventy years the total number of students enrolled in higher education institutions increased by a factor of three. In Korea, instead, the number of students increased from 7,819 in 1945 to 296, 640 in 1975, and exceeded three million in 2001 (McGinn et al., 1980; UNESCO, n.d.). The post-secondary student to population ratio was .07% in 1905 Germany. In Korea, that ratio was 2.09% in 1975 and 8.4% in 1995.

Second, the cost of scientific and technological research has increased dramatically and developing countries' ability to sustain the financial costs associated with frontier R&D may be significantly constrained. Moreover, there are also powerful forces favoring the geographic concentration of knowledge production in centers of excellence (Geuna, 1999). This phenomenon is partly responsible for the observed drain of the most talented scientists and engineers, whose professional ambitions draw them toward established centers of research, whether academic or not. It should be noted in this regard that the dominance of U.S. universities in the post-WWII period has induced a significant migration of scientists from advanced European countries to the U.S.

These two factors suggest that the organizational complexity and the financial costs associated with developing higher education institutions have increased considerably. To the extent that the growth of higher education is an inherent aspect of the development process, the acquisition of capabilities relevant to the effective management of academic institutions has to be considered itself an important learning process. Among the most obvious problems suggested by the experience of Korea and Taiwan are the difficulties in recruiting competent teachers in the context of rapidly expanding student enrollments. As noted earlier, the quality of education is likely to be negatively influenced by escalating teaching loads and student to faculty ratios. The experience of several countries highlights also the difficulties in managing enrollments across fields of specialization in order to enhance the relevance of the academic training and research to development needs and the industrial sector's demands for skills and knowledge, particularly when the latter have yet to be formulated clearly or are subject to relatively rapid shifts. These conditions appear to be typical of the early phases of the catching up process.

In this environment, it is open to question whether or not universities in a catching up economy should be or can be involved effectively in the conduct of significant scientific and technological research. Past evidence suggests that the differentiation of national academic institutions in terms of their training policies and research goals may be a necessary condition if the combination of teaching and research that is the hallmark of the world's leading academic institutions is to be usefully implemented in the catching up economy. At one extreme, concentrating government support on the R&D activities of public research laboratories may be a sensible policy.

While these differences call for further analysis and reflection, there also appear to be important parallels between the nineteenth century and the twentieth century experiences of catching up. In particular, the lack of employment opportunities for scientists and engineers early in the German, Korean, and Taiwanese development process suggests that in each of these countries the growth of the educational achievements of the population preceded the growth of the industrial demand for high-level skills and education. The brain drain observed in Korea and Taiwan has a parallel in the migration of German chemists to Britain in the nineteenth century. Furthermore, reverse flows were set in motion once the level of industrial development in the home country provided expatriates with adequate professional opportunities.

However, while Koreans and Taiwanese were going abroad to receive their training at foreign academic institutions, the Germans did not need to do so. In fact, the quality of education at German universities attracted foreign students, including British and American. In the latter case, returning students proved to be instrumental to the development of innovative university programs and for conducting teaching and research activities at home. This process too, occurred in similar form in Korea and Taiwan during the late twentieth century.

These facts raise important questions that can only be addressed by conducting much additional research. What is the proper scope of academic programs in a catching up economy? What policies have been effective at ensuring that the brain drain phenomenon will lead to later economic benefits for the developing country? How important is it to promote the conduct of scientific and technological research at universities rather than at specialized R&D institutions? The same facts suggest that in spite of the considerable changes that have occurred since the nineteenth century, there are enough similarities among the experiences of early and late catching up countries to give legitimacy to the claim that part of the research needed in order to address these issues ought to consist of a systematic review of the historical record.

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