Universities in national innovation systems

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I. Introduction

The research university plays an important role as a source of fundamental knowledge and, occasionally, industrially relevant technology in modern knowledge-based economies. In recognition of this fact, governments throughout the industrialized world have launched numerous initiatives since the 1970s to link universities to industrial innovation more closely. Many of these initiatives seek to spur local economic development based on university research, e.g., by creating "science parks" located nearby research university campuses, support for "business incubators" and public "seed capital" funds, and the organization of other forms of "bridging institutions" that are believed to link universities to industrial innovation. Other efforts are modeled on a U.S. law, the Bayh-Dole Act of 1980, that is widely (if perhaps incorrectly) credited with improving university-industry collaboration and technology transfer in the U.S. national innovation system.

This chapter examines the roles of universities in industrial-economy national innovation systems, the complex institutional landscapes that influence the creation, development, and dissemination of innovations (See Edquist's chapter in this volume for further discussion). The inclusion of a chapter on university research in a volume on innovation is itself an innovation—it is likely that a similar handbook published two decades ago would have devoted far less attention to the role of universities in industrial innovation.[i] But scholarship on the role of universities in the innovation process, as opposed to their role in basic research, has grown rapidly since 1970. One important theme in this research is the re-conceptualization of universities as important institutional actors in national and regional systems of innovation. Rather than “ivory towers” devoted to the pursuit of knowledge for its own sake, a growing number of industrial-economy and developing-economy governments seek to use universities as instruments for knowledge-based economic development and change.

Governments have sought to increase the rate of transfer of academic research advances to industry and to facilitate the application of these research advances by domestic firms since the 1970s as part of broader efforts to improve national economic performance. In the “knowledge-based economy,” according to this view, national systems of higher education can be a strategic asset, if links with industry are strengthened and the transfer of technology enhanced and accelerated. Many if not most of these “technology-transfer” initiatives focus on the codification of property rights to individual inventions, and rarely address the broader matrix of industry-university relationships that span a broad range of activities and outputs.

Universities throughout the OECD also have been affected by tighter constraints on public funding since 1970. Growth in public funding for higher education has slowed in a number of OECD member states. In the United States, Cohen et al. (1998) note that federal research funding per full-time academic researcher declined by 9.4% in real terms during 1979-91, in the face of significant upward pressure on the costs of conducting state-of-the-art research in many fields of the physical sciences and engineering. Financial support from state governments for U.S. public universities’ operating budgets (which obviously include more than research) declined from nearly 46% of total revenues in 1980 to slightly more than 40% in 1991 (Slaughter and Leslie, 1997, Table 3.2), while the share of federal funds in U.S. public university operating budgets declined from 12.8% to 10% during the same period (the share of operating revenues derived from tuition and fees rose from 12.9% to 15%). The UK government reduced its institutional funding of universities (as opposed to targeted, competitive programs for research) during the 1980s and 1990s, as did the government of Australia (Slaughter and Leslie, 1997).

Faced with slower growth in overall public funding, increased competition for research funding, and continuing cost pressures within their operating budgets during the past two decades, at least some universities have become more aggressive and "entrepreneurial" in seeking new sources of funding. University presidents and vice-chancellors have promoted the regional and national economic benefits flowing from academic research and have sought closer links with industry as a means of expanding research support.

Both internal and external factors thus have led many nations' universities to promote stronger linkages with industry as a means of publicizing and/or strengthening their contributions to innovation and economic growth. In some cases, these initiatives build on long histories of collaboration between university and industry researchers that reflect unique structural features of national university systems and their industrial environment. In other cases, however, these initiatives are based on a misunderstanding of the roles played by universities in national innovation systems, as well as the factors that underpin their contributions to industrial innovation.

Although universities fulfill broadly similar functions in the innovation systems of most industrial and industrializing economies, the importance of their role varies considerably, and is influenced by the structure of domestic industry, the size and structure of other publicly funded research performers, and numerous factors. Following a discussion of the (limited) evidence on the contrasting importance of universities within R&D performance and employment in national innovation systems, we examine other evidence on the contributions of universities to industrial innovation. Based on this discussion, we critically examine recent initiatives by governments in a number of OECD nations to enhance the contributions of universities to innovation and economic growth. We conclude with a discussion of the broad agenda for future research.

II. What functions do universities perform within national innovation systems?

In varying degrees universities throughout the OECD now combine the functions of education and research. This joint production of trained personnel and advanced research may be more effective than specialization in one or the other activity.[ii] For example, the movement of trained personnel into industrial and other occupations can be as a powerful mechanism for the diffusion of scientific research, and demands from students and their prospective employers for "relevance" in the curriculum can strengthen links between the academic research agenda and the needs of society.

The economically important "outputs" of university research have come in different forms, varying over time and across industries.[iii] They include, among others: scientific and technological information[iv] (which can increase the efficiency of applied R&D in industry by guiding research towards more fruitful departures), equipment and instrumentation[v] (used by firms in their production processes or their research), skills or human capital (embodied in students and faculty members), networks of scientific and technological capabilities (which facilitate the diffusion of new knowledge), and prototypes for new products and processes.[vi]

Universities are widely cited as a critical institutional actor in national innovation systems (see Nelson, 1993; Edquist, this volume, and numerous other works). As Edquist notes in his chapter, the precise definition of "national innovation systems" remains somewhat hazy, but most of the large literature on the topic defines them as the institutions and actors that affect the creation, development, and diffusion of innovations. The literature on national innovation systems emphasizes the importance of strong linkages among these various institutions in improving national innovative and competitive performance, and this emphasis applies in particular to universities within national innovation systems.[vii] The "national" innovation systems of the industrial economies appear more and more interdependent, reflecting rapid growth during the post-1945 period in cross-border flows of capital, goods, people, and knowledge. Yet the university systems of these economies retain strong "national" characteristics, reflecting significant contrasts among national university systems in structure and the influence of historical evolution on contemporary structure and policy.

One influential conceptualization of the role of academic research within national innovation systems and economies was the so-called "linear model" of innovation widely associated with Vannevar Bush and his famous "blueprint" for the U.S. post-1945 R&D system, Science: The Endless Frontier. Bush argued for expanded public funding for basic research within U.S. universities as a critical contributor to economic growth, and argued that universities were the most appropriate institutional locus for basic research. This "linear model" of the innovation process asserted that funding of basic research was both necessary and sufficient to promote innovation. Bush's argument anticipated parts of the "market failure" rationale for the funding of basic academic research subsequently developed by Nelson (1959) and Arrow (1962). This portrayal of the innovation process has been widely criticized (see Kline and Rosenberg, 1986, for one such rebuttal of the linear model). Many U.S. policymakers during the 1970s and 1980s cited the Japanese economy as evidence that basic research may not be necessary *or* sufficient for a nation to improve its innovative performance.

Yet another view of the role of university research focuses on the contrasting "norms" of academic and industrial research. Merely contrasting the "fundamental" research activities of academics with the applied research of industrial scientists and engineers obscures as much as it illuminates—after all, there are abundant examples of university researchers making important contributions to technology development, as well as numerous cases of important basic research advances in industrial laboratories. Paul David and colleagues (Dasgupta and David, 1987; David, Foray, and Steinmueller, 1999) argue that the norms of academic research differ significantly from those observed within industry. For academic researchers, professional recognition and advancement depend crucially on being first to disclose and publish their result. Prompt disclosure of results and in most cases, the methods used to achieve them, therefore is central to academic research. Industrial innovation, by contrast, relies more heavily on secrecy and limitations to the disclosure of research results. The significance of these "cultural differences" for the conduct and dissemination of research may assume greater significance in the face of closer links between university and industrial researchers (see below).

But these contrasts also can be overstated, as David et al. (1999) acknowledge. The history of science is replete with examples of fierce competitions ("discovery races") between teams of researchers in a given field that systematically seek to mislead one another through the disclosure of false information. And recent research by Henderson and colleagues (Henderson, Pisano, and Orsenigo, 1999; Henderson and Cockburn, 1998) on pharmaceutical industry R&D highlights the increased emphasis by a number of large pharmaceutical firms on publication by industrial researchers as a means of improving their basic science capabilities. Nevertheless, the potential for clashes between the disclosure norms of academia and industry, and in particular, the potential risks posed by more restrictive disclosure norms for the educational functions and the broader pace of advance in scientific understanding, remains significant.

Still another conceptual framework that has been applied recently to descriptions of the role of academic research in "post-modern" industrial societies is the "Mode 2" concept of research identified with Michael Gibbons and colleagues (Gibbons et al., 1994). "Mode 2" research is associated with a more interdisciplinary, pluralistic, "networked" innovation system, in contrast to the previous system in which major corporate or academic research institutions were less closely linked with other institutions. Gibbons and other scholars argue that the growth of "Mode 2" research reflects the increased scale and diversity of knowledge inputs required for scientific research, a point echoed in the chapter by Pavitt in this volume. Increased diversity in inputs, in this view, is associated with greater interinstitutional collaboration and more interdisciplinary research. Because "Mode 2" involves the interaction of many more communities of researchers and other actors within any given research area, purely academic research norms may prove less influential even in such areas of fundamental research as biomedical research.

The “Mode 2” framework assuredly is consistent with some characteristics of modern innovation systems, notably the increased interinstitutional collaboration that has been remarked upon by numerous scholars. But this framework’s claims that the sources of knowledge within modern innovation systems have become more diverse need not imply any decline in the role of universities as fundamental research centers. Several studies (Godin and Gingras, 2000; Hicks and Hamilton, 1999; see below for further discussion) support the “Mode 2” assertion that that cross-institutional collaboration and diversification in knowledge sources have grown, but indicate no such decline.

Still another conceptual framework for analyzing the changing position of universities within national innovation systems is the “Triple Helix” popularized by Etzkowitz and Leytesdorff (1997). Like the “Mode 2” framework, the triple helix emphasizes the increased interaction among these institutional actors in industrial economies’ innovation systems. Etzkowitz and co-authors (Etzkowitz et al. 1998) further assert that

> In addition to linkages among institutional spheres, each sphere takes the role of the other. Thus, universities assume entrepreneurial tasks such as marketing knowledge and creating companies even as firms take on an academic dimension, sharing knowledge among each other and training at ever-higher skill levels. (p. 6).

The “triple helix” scholarship devotes little attention to the “transformations” in industry and government that are asserted to complement those in universities. The helix’s emphasis on a more “industrial” role for universities may be valid, although it overstates the extent to which these “industrial” activities are occurring throughout universities, rather than in a few fields of academic research. But the “triple helix” has yet to yield major empirical or research advances, and its value as a guide for future empirical research appears to be limited.

The “national systems,” “Mode 2,” and “triple helix” frameworks for conceptualizing the role of the research university within the innovation processes of knowledge-based economies emphasize the importance of strong links between universities and other institutional actors in these economies. And both “Mode 2” and the “Triple Helix”argue that interactions between universities and industry, in particular, have grown. According to the "Triple Helix" framework, increased interactions are associated with change in the internal culture and norms of universities (as noted, this framework has much less to say about the change in the characteristics of industrial and governmental research institutions). What is lacking in all of these frameworks, however, is a clear set of criteria by which to assess the strength of such linkages and a set of indicators to guide the collection of data.

III. The role of universities in national innovation systems: cross-national data

A. Comparative data on the structure of national systems

The first universities appeared during the Middle Ages in Bologna and Paris, and were autonomous, self-governing institutions recognized by both church and local governmental authorities.[viii] This situation persisted through much of the period prior to the 18th century. But the rise of the modern state was associated with the assertion by governments of greater control over public university systems in much of Continental Europe, notably France and Germany, as well as Japan.[ix] Such centralized control was lacking, however, in the British and especially, the U.S. higher education systems throughout the 19th and 20th centuries. Throughout the 20th century, U.S. universities retained great autonomy in their administrative policies. Rosenberg (1999) and Ben-David (1968) argue that this lack of central control forced American universities to be more "entrepreneurial" and their research and curricula to be more responsive to changing socio-economic demands than their European counterparts. Data allowing for systematic cross-national comparisons of the structure of the higher educational systems of major industrial economies are surprisingly scarce.

This section summarizes and assesses the limited comparative data on the training and research roles of higher educational systems, as well as their relationships with industry. Enrollment data (summarized in Geiger, 1986, and Graham and Diamond, 1997) indicate that the U.S. system enrolled a larger fraction of the 18-22 year old population than those of any

European nations throughout the 1900-1945 period. Not until the 1960s did European enrollment rates exceed 10% of the relevant age cohorts, by which time U.S. enrollment rates within this group were reaching 50% (Burn et al., 1971). These contrasts in enrollment rates are reflected in enduring differences between the United States and European nations in the shares of their populations with university education. The share of the U.S. population with university or "tertiary" educational degrees exceeded that of any other OECD economy as late as 1999.

These data also reveal that the U.S. university degreeholder share is followed closely by that of Norway, at 25% (OECD Education Database, 2001). Surprisingly, Austria, with 6% of the relevant population holding university or tertiary degrees, exhibits the lowest degreeholder share in this database. As Fagerberg and Godinho note in their chapter in this volume, however, the large output of university degreeholders in the United States includes a significantly smaller share of natural science and engineering degreeholders than is true of such other nations as the United Kingdom, Singapore, Finland, South Korea, and France. The share of 24-year-olds in the United States with "first degrees" from universities in natural sciences and engineering also lags well behind these and other nations.[x]

The limited data on the role of national higher education systems as R&D performers highlight other cross-national contrasts, including differences in their significance within the overall national R&D enterprise, their scale, their roles as employers of researchers, and their relationships with industry. As Figure 1 shows, the role of universities as R&D performers (measured in terms of the share of national R&D performed within higher education) is greatest in Italy, the Netherlands, and Canada, all of which show universities performing more than 25% of total national R&D by 1998-2000 (Figure 1). The share of national R&D performance accounted for by U.S. and Japanese universities, by contrast, was slightly more than 14% during the same period.

FIGURE 1 HERE

Cross-national data highlighting differences in the "division of labor" between universities and government laboratories in basic research indicate that the higher education sector's share of basic research performance is similar in most Western European economies and the United States, although higher than in most of the Eastern European and Asian countries for which data are available (OECD 2001b, Annex Table A.6.4.1). But a key difference between the United States and most European countries for which data are available is that a relatively low share of basic research outside the academic sector in the United States is performed by the government, and a relatively high share by industry. [xi]

The data also reveal considerable variation among OECD member nations in the scale of the higher-education research enterprise. Although the U.S. higher education system is larger in absolute terms than those of other OECD member states, U.S. universities' performance of R&D in fact accounts for a smaller share of GDP than is true of Sweden, France, Canada, the Netherlands, and Norway (Figure 2). Indeed, Figure 2 indicates that U.S. universities' R&D as a share of GDP has in fact declined slightly during the 1989-1999 period. At least a portion of this decline reflects the rapid growth in industrially funded R&D performed within U.S. industry, especially during the 1995-99 period.

FIGURE 2 HERE

Comparison of the share of "employed researchers" in various nations' R&D systems that work in universities reveals that the United States and Japan rank very low, reflecting the fact that a much higher share of researchers in both nations are employed by industry rather than higher education. In 1997, the last year for which reasonably complete data are available, 82.5% of researchers were employed by industry in the United States (OECD 2001c, Table 39), significantly higher than in any other OECD nation. Korea ranks second (68.1%) and Japan third (64.6%), while the overall average for EU countries is much lower (48.4%).

Figure 3 depicts the share of R&D funding within national higher education systems that is provided by industry. Despite the widely remarked closeness of U.S. university-industry research ties and collaboration (see Rosenberg and Nelson, 1994; Mowery et al., forthcoming), the share of R&D in higher education that is financed by industry is higher for Canada, Germany, and the United Kingdom than for the United States in the late 20th century.

FIGURE 3 HERE

Other qualitative data from the OECD 2002 study of "science-industry relationships" (2002, p. 37) compare the labor mobility and other "network relationships" linking universities and industry for Austria, Belgium, Finland, Germany, Ireland, Italy, Sweden, the UK, the US, and Japan. "R&D consulting with firms by university researchers" is greater than the EU average (the basis for these characterizations is not provided by the OECD study) in Austria, Germany, the UK, US, and Japan; such consulting is rated as "low" in Belgium, Finland, Ireland, and Italy. The annual flow of university researchers to industrial employment, another potentially important channel for knowledge exchange, is significantly higher than the EU average in Belgium, Finland, Germany, Sweden, the UK, and the United States. Finally, the "significance of networks" linking universities and industry is rated as above the EU average for Finland, Germany, Sweden, the UK, the US, and Japan.

Surprisingly, in view of the frequency with which the United States is cited approvingly for the close links between university and industrial researchers, the evidence that university-industry relationships are "stronger" in the U.S. than elsewhere is mixed: the qualitative data on labor mobility support this characterization, while the data on industrial support of academic research do not. An important gap in research on the role of universities in national innovation systems and a corresponding research opportunity is the development of better quantitative measures or indicators of the scope and importance of this role. If the stereotypical view of U.S. universities as more closely linked with industrial research and innovation is indeed valid (and we believe that it is), it is striking that the available indicators shed so little light on the dimensions of these closer links.

Although universities serve similar functions in most industrial economies, these indicators suggest that their importance in training scientists and engineers and in research performance differs considerably among OECD member nations. These differences reflect cross-national differences in industry structure, especially the importance of such "high-technology" industries as electronics or information technology that are highly research-intensive and (at least since the end of the Cold War) rely heavily on private-sector sources for R&D finance. In addition, of course, the role of nonuniversity public research institutions differs among these economies, and is reflected in the contrasts in universities as performers of publicly funded R&D. These structural contrasts are the result of a lengthy, path-dependent process of historical development, in which institutional evolution interacts with industrial growth and change.

B. Recent trends in university-industry linkages

Although comparative cross-sectional data reveal substantial differences in the sources of funding and other characteristics of the national systems of higher education among OECD member states, longitudinal data reveal an increase in co-authorship between university and industry researchers in many of these nations. Among other things, this evidence on increased co-authorship may indicate some growth, rather than decline, in the role of universities as centers for knowledge production within national innovation systems, the arguments of the "Mode 2" model notwithstanding. A recent paper by Calvert and Patel (2002) based on an examination of slightly more than 22,000 papers reveals a threefold increase in co-authorship between UK industry and university researchers during 1981-2000. Papers co-authored by industrial and university researchers expanded from approximately 20% to nearly 47% of all UK scientific papers published by industrial researchers during the 1981-2000 period. The share of papers with UK university authors that were co-authored by industrial and university scientists also grew during this period, from 2.8% in the early 1980s to 4.5% in 2000.[xii] Co-authored papers in computer science grew by more than eightfold, although the fields of chemistry, medicine, and biology accounted for the largest shares of co-authored papers (respectively, 20%, 20%, and 14%).

Calvert and Patel found that the 1981/85 – 1986/90 period was characterized by the most rapid growth in such co-authorship. This finding is particularly interesting since the 1980s were characterized by cuts in UK central government spending on higher education, and the 1990s were a period of more aggressive governmental promotion of university-industry collaboration and technology transfer. In other words, the growth in co-authorship measured by these scholars appears to have occurred without any specific encouragement (beyond funding cuts) from government policy. The UK universities responsible for the majority of the co-authored papers were among the most distinguished research universities in Great Britain.

Another study of co-authorship between university and industry researchers is that by Hicks et al. (1996), which compares trends during the 1980-89 period in co-authorship in Japan and Western Europe. Overall co-authorship rates (covering all industrial sectors and including both domestic and foreign universities) were similar (roughly 20% for European papers and slightly less for Japanese papers) for Western Europe and Japan in 1980. By 1989, however, co-authorship rates for Western Europe had risen to nearly 40% of published papers, while Japanese co-authorship rates only slightly exceeded 20%.

There is surprisingly little empirical work on co-authorship in the United States. A study by Hicks and Hamilton (1999) reports that between 1981 and 1994, the number of U.S. papers co-authored by university and industry researchers more than doubled, considerably exceeding the 38% increase in the total number of scientific papers published by U.S. researchers during this period. The authors also suggest that these co-authored papers are less "basic" than academic articles without industrial co-authors.

Overall, these bibliometric studies present a rich descriptive and a relatively weak explanatory analysis of an important type of university-industry collaboration, inasmuch as they provide little explanation for trends or cross-national differences. Nonetheless, these data highlight a broad trend of growth in such co-authorship, and this area remains a very fruitful one for future research that spans more fields, nations, and types of publications. The results of the bibliometric work in this area provide some support for the "Mode 2" and "Triple Helix" frameworks' arguments that research collaboration between universities and industry is growing throughout the industrial economies, in university systems with very different structures (see the chapter by Edquist in this volume, as well as the studies in Laredo and Mustar, 2001).

IV. How does university research affect industrial innovation? A summary of some U.S. studies

The quantitative indicators discussed in the previous section provide some information on the structure of universities within the OECD and their links with national innovation systems. But these data shed very little light on the characteristics of the knowledge flows between university research and the industrial innovation process. This issue is especially important in light of the numerous government policy initiatives that seek to enhance or exploit such knowledge flows (see below). Although their coverage is limited to U.S. universities and industry, a number of recent studies based on interviews or surveys of senior industrial managers in industries ranging from pharmaceuticals to electrical equipment have examined the influence of university research on industrial innovation, and thereby provide additional insight into the role of universities within the U.S. national innovation system.

All of these studies (GUIRR, 1991; Mansfield, 1991; Levin et al., 1987; Cohen, Nelson, & Walsh, 2002) emphasize the significance of interindustry differences in the relationship between university and industrial innovation. The biomedical sector, especially biotechnology and pharmaceuticals, is unusual, in that university research advances affect industrial innovation more significantly and directly in this field than is true of other sectors. In these other technological and industrial fields, universities occasionally contributed relevant "inventions," but most commercially significant inventions came from nonacademic research. The incremental advances that were the primary focus of the R&D activities of firms in these sectors were almost exclusively the domain of industrial research, design, problem-solving, and development.

University research contributed to technological advances by enhancing knowledge of the fundamental physics and chemistry underlying manufacturing processes and product innovation, an area in which training of scientists and engineers figured prominently, and experimental techniques.

The studies by Levin et al. (1987) and Cohen et al. (2002) summarize industrial R&D managers' views on the relevance to industrial innovation of various fields of university research (Table 1 summarizes the results discussed in Levin et al., 1987). Virtually all of the fields of university research that were rated as "important" or "very important" for their innovative activities by survey respondents in both studies were related to engineering or applied sciences. As we noted previously in this chapter, these fields of U.S. university research frequently developed in close collaboration with industry. Interestingly, with the exception of chemistry,

TABLE 1 HERE

very few basic sciences appear on the list of university research fields deemed by industry respondents to be relevant to their innovative activities.

The absence of fields such as physics and mathematics in Table 1, however, should not interpreted as indicating that academic research in these fields does not contribute directly to technical advance in industry. Instead, these results reflect the fact that the effects on industrial innovation of basic research findings in such areas as physics, mathematics, and the physical sciences are realized only after a considerable lag. Moreover, application of academic research results may require that these advances be incorporated into the applied sciences, such as chemical engineering, electrical engineering and material sciences. The survey results summarized in Cohen et al. (2002) indicate that in most industries, university research results play little if any role in triggering new industrial R&D projects; instead, the stimuli originate with customers or from manufacturing operations. Here as elsewhere, pharmaceuticals is an exception, since university research results in this field often trigger industrial R&D projects.

Cohen et al. (2002) further report that the results of "public research" performed in government labs or universities were used more frequently by U.S. industrial firms (on average, in 29.3% of industrial R&D projects) than prototypes emerging from these external sources of research (used in an average of 8.3% of industrial R&D projects). A similar portrait of the relative importance of different outputs of university and public-laboratory research emerges from the responses to questions about the importance to industrial R and D of various information channels (Table 2). Although pharmaceuticals once again is unusual in its assignment of considerable importance to patents and license agreements involving universities and public laboratories, respondents from this industry still rated research publications and conferences as a more important source of information. For most industries, patents and licenses involving inventions from university or public laboratories were reported to be of very little importance, compared with publications, conferences, informal interaction with university researchers, and consulting.

TABLE 2 HERE

Data on the use by industrial R&D managers of academic research results are needed for other industrial economies. Nonetheless, the results of these U.S. studies consistently emphasize that the relationship between academic research and industrial innovation in the biomedical field differs from that in other knowledge-intensive sectors. In addition, these studies suggest that academic research rarely produces “prototypes” of inventions for development and commercialization by industry—instead, academic research informs the methods and disciplines employed by firms in their R&D facilities. Finally, the channels rated by industrial R&D managers as most important in this complex interaction between academic and industrial innovation rarely include patents and licenses. Perhaps the most striking aspect of these survey and interview results is the fact that they have not informed the design of recent policy initiatives to enhance the contributions of university research to industrial innovation.

V. From "Science Push" to "Technology Commercialization"

As we suggested in Section I, since 1980 a number of industrialized countries have implemented or considered policies to strengthen "linkages" between universities (and public research organizations) and industry, in order to enhance the contributions of university-based research to innovation and economic performance. These initiatives all share the premise that universities support innovation in industry primarily through the production by universities of "deliverables" for commercialization (e.g., patented discoveries), despite the modest support for this premise in the research discussed above. We illustrate these points in this section with case studies of two types of policies: (1) policies encouraging the formation of regional economic "clusters" and spin-offs based on university research, and (2) policies attempting to stimulate university patenting and licensing activities.

The global diffusion of these "technology commercialization" policies illustrates a phenomenon that has received too little attention in the literature on innovation policy—the efforts by policymakers to "borrow" policy instruments from other economies and apply these instruments in a very different institutional context. As Lundvall and Borras point out in their chapter, history, path dependence, and institutional "embeddedness" all make this type of "emulation" very difficult. Nonetheless, such emulation has been especially widespread in the field of technology policy. International policy emulation of this sort is characterized by two key features: (1) the "learning" that underpins the emulation is highly selective; and (2) the implementation of program designs based on even this selective learning is affected by the different institutional landscape of the emulator.

A. Universities and Regional Economic Development

In many OECD countries, efforts to increase the national economic returns from public investments in university research have attempted to stimulate the creation of "regional clusters" of innovative firms around universities. These undertakings seek to stimulate regional economic development and agglomeration via facilitating the creation of "spin-off" firms to commercialize university technologies (OECD, 2002).[xiii]

These policy initiatives are motivated by the high-technology regional clusters in the United States, notably Silicon Valley in California and Route 128 in the Boston area. Both of these high-technology clusters have a spawned a large number of new firms and have major research universities in their midst (in California, the University of California at Berkeley, Stanford University, and the University of California at San Francisco; in Boston, Harvard University and MIT). At least some of the successful new firms in these regions have been involved in commercializing technologies developed at regional universities.

Other evidence (notably, Trajtenberg, Jaffe, and Henderson, 1997) suggests that the "knowledge spillovers" from university research within the United States, measured by the location of inventors citing university patents, tend to be localized at the regional level. Recent work by Hicks et al. (2001) similarly indicates that patents filed by U.S. inventors disproportionately cite scientific papers from research institutions located in the same state as these inventors.

But little evidence supports the argument that the presence of universities somehow "causes" the development of regional high-technology agglomerations. And even less evidence supports the argument that the regional or innovation policies of governments are effective in creating these agglomerations. One can point to high-technology clusters with highly productive research universities in a number of areas in the United States and other industrial economies; but there are also a number of research universities that have not spawned such agglomerations. Moreover, efforts to replicate the "Silicon Valley model" in other economies have proven difficult and the results of these efforts have been mixed (a fascinating historical account of the efforts by Frederick Terman of Stanford University to promote such "exports" may be found in Leslie and Kargon, 1996).

National and local governments in many OECD countries have attempted to stimulate the formation of these clusters via funding for "science parks" (occasionally also called incubators, technology centers, or centers of excellence.) Interestingly, there is considerable disagreement about exactly what a "science park" is and what they do; the International Association of Science Parks characterizes them as follows:

> A Science Park is an organisation managed by specialised professionals, whose main aim is to increase the wealth of its community by promoting the culture of innovation and the competitiveness of its associated businesses and knowledge-based institutions … To enable these goals to be met, a Science Park stimulates and manages the flow of knowledge and technology amongst universities, R&D institutions, companies and markets; it facilitates the creation and growth of innovation-based companies through incubation and spin-off processes; and provides other value-added services together with high quality space and facilities. (http://www.iaspworld.org/information/definitions.php).

Despite the widespread interest in science parks, there is little evidence that they positively affect universities' contributions to innovation or spur regional economic development. Using data on U.S. science parks, Felsenstein (1994) finds no evidence that firms located on university-based science parks are more innovative than other local firms, and Wallsten (2001) finds that science parks have a *negative* effect on regional economic development and rates of innovation.

The research on "science parks" in other industrial economies is also limited. One examination of "science parks" in the UK (Massey et al., 1992) is dated, but presents interesting evidence on the characteristics of nearly 200 firms in 20 UK science parks. The study found that startup firms represented 25-30% of the tenants in the science parks surveyed; in the absence of some kind of "control population," it is difficult to reach conclusions about whether startup firms are over-represented or under-represented in these UK science parks. Perhaps more surprising was the study's finding that

> …formal research links between academic institutions and establishments on science parks were no more evident than similar links with firms located off-park…Formal research links such as "employment of academics," "sponsoring trials or research," "testing and analysis," "student project" work and "graduate employment" were fairly

similar for park firms and off-park firms. However, significantly more park firms than off-park firms mentioned “informal contacts with academics” and the use of academic facilities such as computers, libraries or dining facilities as being important. (Massey et al., 1992, p. 38).

This and other evidence on the results of government policies to promote university-based regional agglomerations suggests that such policies have a mixed record of success. And even successful regional agglomerations may require considerable time to emerge. Recent work by Sturgeon (2000) argues that Silicon Valley’s history as a center for new-firm formation and innovation dates back to the early decades of the 20th century, suggesting that much of the region’s innovative “culture” developed over a much longer period of time and predates the ascent to global research eminence of Stanford University. Similarly, the North Carolina “Research Triangle,” which was promoted much more aggressively by the state government, was established in the late 1950s and became a center for new-firm formation and innovation only in the late 1980s.

Still other work on the development of Silicon Valley by Leslie (1993, 2000) and Saxenian (1988) emphasizes the massive increase in federal defense spending after 1945 as a catalyst for the formation of new high-technology firms in the region. In this view, the presence of leading research universities may have been necessary, but was by no means sufficient, to create Silicon Valley during the 1950s and 1960s. Saxenian in particular emphasizes the very different structure of British defense procurement policies in explaining the lack of similar dynamism in the Cambridge region.

The links between university research and the emergence of regional high-technology agglomerations thus are more complex than is implied by the correlation between the presence of high-technology firms and research universities in a number of locales. The U.S. experience suggests that the emergence of such agglomerations is a matter of contingency, path-dependence, and (most importantly) the presence of other supporting policies (intentional or otherwise) that may have little to do with university research or the encouragement of university-industry linkages.

The policy initiatives in the United States and other OECD economies that seek to use university research and "science parks" to stimulate regional economic development suffer from a deficiency that is common to many of the other recent efforts to stimulate university-industry linkages in OECD countries, i.e. a lack of attention to supporting institutions, a focus on "success stories" with little attention to systematic evidence on the casual effects of the policies, and a narrow focus on commercialization of university technologies, rather than other more economically important outputs of university research. These characteristics are also seen in recent efforts elsewhere within the OECD to emulate the Bayh-Dole Act.

B. Patenting the results of publicly funded academic research

As we noted above, this increased interest by governments in "Bayh-Dole- type" policies is rooted in motives similar to those underpinning policy initiatives that seek to create "high-technology" regional clusters. But the "emulation" of Bayh-Dole in other industrial economies overlooks the importance and effects on university-industry collaboration and technology transfer of the many other institutions that support these interactions and the commercialization of university technologies in the United States. In addition, these "emulation" initiatives are based on a misreading of the empirical evidence on the importance of intellectual property rights in facilitating the "transfer" and commercialization of university inventions, as well as a misreading of the evidence on the effects of the Bayh-Dole Act.

1. Origins of the Bayh-Dole Act

Although some U.S. universities were patenting patent faculty inventions as early as the 1920s, few institutions had developed formal patent policies prior to the late 1940s, and many of these policies embodied considerable ambivalence toward patenting. Public universities were more heavily represented in patenting than private universities during the 1925-45 period, both within the top research universities and more generally.

These characteristics of university patenting began to change after 1970, as private universities expanded their share of U.S. university patenting, universities generally expanded their direct role in managing patenting and licensing, and the share of biomedical patents within overall university patenting increased. Lobbying by U.S. research universities active in patenting was one of several factors behind the passage of the Bayh-Dole Act in 1980.

The Bayh-Dole Patent and Trademark Amendments Act of 1980 provided blanket permission for performers of federally funded research to file for patents on the results of such research and to grant licenses for these patents, including exclusive licenses, to other parties. The Act facilitated university patenting and licensing in at least two ways. First, it replaced a web of Institutional Patent Agreements (IPAs) that had been negotiated between individual universities and federal agencies with a uniform policy. Second, the Act's provisions expressed Congressional support for the negotiation of exclusive licenses between universities and industrial firms for the results of federally funded research.

The passage of the Bayh-Dole Act was one part of a broader shift in U.S. policy toward stronger intellectual property rights.[xiv] Among the most important of these policy initiatives was the establishment of the Court of Appeals for the Federal Circuit (CAFC) in 1982. Established to serve as the court of final appeal for patent cases throughout the federal judiciary, the CAFC soon emerged as a strong champion of patentholder rights. But even before the establishment of the CAFC, the 1980 U.S. Supreme Court decision in Diamond v. Chakrabarty upheld the validity of a broad patent in the new industry of biotechnology, facilitating the patenting and licensing of inventions in this sector.

Rather than emphasizing public funding and relatively liberal disclosure and dissemination, the Bayh-Dole Act assumes that restrictions on dissemination of the results of many R&D projects will enhance economic efficiency by supporting their commercialization. In many respects, the Bayh-Dole Act is the ultimate expression of faith in the “linear model” of innovation—if basic research results can be purchased by would-be developers, commercial innovation will be accelerated.

2. The Effects of Bayh-Dole

How did the Bayh-Dole Act affect technology transfer by U.S. universities? Figure 4 depicts U.S. research university patenting as a share of domestically assigned U.S. patents during 1963-99, in order to remove the effects of increased patenting in the United States by foreign firms and inventors during the late 20th century. Universities increased their share of patenting from less than 0.3% in 1963 to nearly 4% by 1999, but the rate of growth in this share begins to accelerate before rather than after 1980. The ratio of research university patents to academic research spending remains surprisingly constant through the 1963-93 period, suggesting no significant increase in universities' "patent propensity" after passage of the Bayh-Dole Act in 1980.

FIGURE 4 HERE

Figure 5 displays trends during 1960-1999 in the distribution among technology classes of U.S. research university patents, highlighting the growing importance of biomedical patents in the patenting activities of the leading U.S. universities during the period.

FIGURE 5 HERE

Non-biomedical university patents increased by 90% from the 1968-70 period to the 1978-80 period, but biomedical university patents increased by 295%. The increased share of the biomedical disciplines within overall federal academic R&D funding, the dramatic advances in biomedical science that occurred during the 1960s and 1970s, and the strong industrial interest in the results of this biomedical research during this period all contributed to this shift in the composition of university patent portfolios.

During the late 1990s and early 21st century, many commentators and policymakers portrayed the Bayh-Dole Act as a critical catalyst to growth in U.S. universities' innovative and economic contributions. Indeed, the OECD went so far as to argue that the Bayh-Dole Act was an important factor in the remarkable growth of incomes, employment, and productivity in the U.S. economy of the late 1990s.[xv] Remarkably, virtually none of these characterizations of the positive effects of the Bayh-Dole Act cite any evidence in support of their claims beyond the clear growth in patenting and licensing by universities. Nor does evidence of increased patenting and licensing by universities by itself indicate that university research discoveries are being transferred to industry more efficiently or commercialized more rapidly, as Colyvas et al. (2001) and Mowery et al. (2001) point out.

These "assessments" of the effects of the Bayh-Dole Act also fail to consider any potentially negative effects of the Act on U.S. university research or innovation in the broader economy. Some scholars have suggested that the "commercialization motives" created by Bayh-Dole could shift the orientation of university research away from "basic" and towards "applied" research (Henderson et al., 1998), but thus far there is little evidence of substantial shifts since Bayh-Dole in the content of academic research.

A second potentially negative effect of increased university patenting and licensing is the potential weakening of academic researchers' commitments to "open science," leading to publication delays, secrecy, and withholding of data and materials (Dasgupta and David, 1994; Liebeskind 2001). In view of the importance assigned by industrial researchers to the "nonpatent/licensing" channels of interaction with universities in most industrial sectors, it is crucially important that these channels not be constricted or impeded by the intensive focus on patenting and licensing in many universities. The effects of any increased assertion by institutional and individual inventors of property rights over inputs to scientific research have only begun to receive serious scholarly attention. Patenting and restrictive licensing of inputs into future research ("research tools") could hinder downstream research and product development (Heller and Eisenberg 1998; Merges and Nelson 1994).

Although there is little evidence as yet that the Bayh-Dole Act has had significant, negative consequences for academic research, technology transfer, and industrial innovation in the United States, the data available to monitor any such effects are very limited. Moreover, such data are necessarily retrospective, and in their nature are likely to reveal significant changes in the norms and behavior of researchers or universities only with a long lag. Any negative effects of Bayh-Dole accordingly are likely to reveal themselves only well after they first appear.

3. International "emulation" of the Bayh-Dole Act

The limited evidence on the Act's effects (both positive and negative) has not prevented a number of other OECD governments from pursuing policies that closely resemble the Bayh-Dole Act. Like the Bayh-Dole Act, these initiatives focus narrowly on the "deliverable" outputs of university research, and typically ignore the effects of patenting and licensing on the other, more economically important, channels through which universities contribute to innovation and economic growth. Moreover, such emulation is based on a misreading of the limited evidence concerning the effects of Bayh-Dole and on a misunderstanding of the factors that have encouraged the long-standing and relatively close relationship between U.S. universities and industrial innovation.

The policy initiatives that have been debated or implemented in most OECD economies have sought to shift ownership of the intellectual property rights for academic inventions to either the academic institution or the researcher (See OECD, 2002, for an excellent summary). In some university systems, such as those of Germany or Sweden, researchers have long had ownership rights for the intellectual property resulting from their work, and debate has centered on the feasibility and advisability of shifting these ownership rights from the individual to the institution. In Italy, legislation adopted in 2001 shifted ownership from universities to individual researchers. In Japanese universities, ownership of intellectual property rights resulting from publicly funded research is determined by a committee, which on occasion awards title to the researcher. No single national policy governs IPR ownership within the British or Canadian university systems, although efforts are underway in both nations to grant ownership to the academic institution rather than the individual researcher or the funding agency. In addition, the Swedish, German, and Japanese governments have encouraged the formation of external "technology licensing organizations," which may or may not be affiliated with a given university.

These policy proposals and initiatives display the classic signs of international emulation described above—selective "borrowing" from another nation's policies for implementation in an institutional context that differs significantly from that of the nation being emulated. Inasmuch as patenting and licensing are of rated by industrial R&D managers as relatively unimportant for technology transfer in most fields, emulation of the Bayh-Dole Act is insufficient and perhaps even unnecessary to stimulate higher levels of university-industry interaction and technology transfer. Instead, reforms to enhance inter-institutional competition and autonomy within national university systems, as well as support for the external institutional contributors to new-firm formation and technology commercialization, appear to be more important. Indeed, emulation of Bayh-Dole could be counterproductive in other industrial economies, precisely because of the importance of other channels for technology transfer and exploitation by industry.

VI. Conclusion

Universities play important roles in the "knowledge-based" economies of modern industrial and industrializing states as sources of trained "knowledge workers" and ideas flowing from both basic and more applied research activities. But conventional (and, perhaps, evolutionary) economic approaches to the analysis of institutions are very difficult to apply to universities, for several reasons. First, with the exceptions of the U.S. and British university systems, inter-university "competition" has been limited in most national systems of higher education. Inter-university competition was a very important historical influence on the evolution of U.S. universities and their links with industry; but this aspect of the "selection environment" is lacking in most other national systems of higher education.

Second, analyzing universities as economic institutions requires some definition of the objectives pursued by individual universities. Partly because universities perform multiple roles in many national systems and partly because the internal structure of most research universities more closely resembles that of a cooperative organization rather than the hierarchical structure associated with industrial firms, characterizing "the objectives of the university" is difficult if not meaningless. The modern university has its roots in the Middle Ages, rather than the Industrial Revolution, and its medieval origins continue to influence its organization and operation. If universities are to be conceptualized as economic institutions for purposes of analyzing their evolution, the current analytic frameworks available in neoclassical or evolutionary economics are insufficient.

The development of such an analytic framework is important, not least for understanding the consequences for academic research of government policies that seek to accelerate the transfer of research results to industrial firms. The intensified demands from governments to raise the (measurable) economic returns to their substantial investments in academic research and education makes the development of better tools for understanding and measuring the operations and outputs of universities all the more important. As we argued above, many of the current initiatives in the United States and other industrial economies to enhance the economic returns from university research are based on a poor understanding of the full spectrum of roles fulfilled by research universities in industrial economies, as well as a tendency to emphasize the outputs of university research that can be easily quantified.

Although the analytic frameworks provided by the "national innovation systems," "Mode 2," and "Triple Helix" models of scientific research and innovation shed some light on the roles of universities and largely agree in their assessment of these roles, these frameworks provide limited guidance for policy or evaluation. Moreover, these frameworks tend to downplay the very real tensions among the different roles of research universities within knowledge-based economies. Such tensions are likely to intensify in the face of pressure from policymakers and others on universities to accelerate their production and transfer to commercial interests of tangible, measurable research outputs.

The development of useful theoretical or conceptual tools or models for analyzing universities as economic or other institutions within knowledge-based economies is seriously hampered by the lack of data on the roles of universities that enable comparisons across time or across national innovation systems. Indicators that enable longitudinal analysis of the roles of universities in training scientists and engineers, contributing to "public knowledge," or transferring inventions to industrial firms are scarce if not entirely lacking for most national systems of higher education. Few of these indicators incorporate information on the geographic dimensions of university-industry interactions, despite the importance of agglomeration economies in the current policy approaches of many governments in this area. Moreover, such indicators as do exist rarely are comparable across national systems of higher education.

The absence of broader longitudinal and cross-nationally comparable indicators of university-industry interaction thus impedes both the formulation and the evaluation of policies. And the lack of better indicators reflects the lack of a stronger analytic framework for understanding the roles of universities within national innovation systems. Such a framework must adopt a more evolutionary, historically grounded approach to the understanding of the roles of universities, especially the influence of the structure of national higher education systems on these roles. As we have argued in this chapter, many of the efforts by OECD governments to encourage technology transfer and to increase the economic payoffs to investments in university research are hampered by a lack of such understanding. More comparative institutional work on the evolution and roles of research universities, including the contrasting "division of labor" among universities and other publicly supported research institutions in both industrial and industrializing economies, is an indispensable starting point for analysis of the current and likely future position of the research university within national innovation systems.

The development of better indicators of the full array of channels through which industries and universities interact within knowledge-based economies represents another important research opportunity. In addition, more information is needed on measures of firm-level "absorptive capacity" and investments in its creation and maintenance—how do existing firms develop these various channels of interaction? How and why are new firms formed to exploit university research advances, and how does this "spinoff" process vary across time, geographic space, and national innovation systems? The extensive discussion of all of these important economic phenomena still lacks a strong evidentiary basis for making comparisons among the higher education systems of the industrialized economies. The current emphasis on the countable rather than the important aspects of university-industry interactions could have unfortunate consequences for innovation policy in the industrial and industrializing world.

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Table 1: The relevance of university science to industrial technology

Science	# of Industries with "relevance" scores		Selected industries for which the reported "relevance" of university research was large (≥ 6).
	≥ 5	≥ 6	
Biology	12	3	Animal feed, drugs, processed fruits/vegetables
Chemistry	19	3	Animal feed, meat products, drugs
Geology	0	0	None
Mathematics	5	1	Optical instruments
Physics	4	2	Optical instruments, electronics?
Agricultural science	17	7	Pesticides, animal feed, fertilizers, food products
Applied math/operations research	16	2	Meat products, logging/sawmills
Computer science	34	10	Optical instruments, logging/sawmills, paper machinery
Materials science	29	8	Synthetic rubber, nonferrous metals
Medical science	7	3	Surgical/medical instruments, drugs, coffee
Metallurgy	21	6	Nonferrous metals, fabricated metal products
Chemical engineering	19	6	Canned foods, fertilizers, malt beverages
Electrical engineering	22	2	Semiconductors, scientific instruments
Mechanical engineering	28	9	Hand tools, specialized industrial machinery

Source: Previously unpublished data from the Yale Survey on Appropriability and Technological Opportunity in Industry. For a description of the survey, see Levin et al. (1987).

Table 2: Importance to Industrial R&D of Sources of Information on Public R&D (including university research)

Information source	% rating it as "very important" for industrial R&D
Publications & reports	41.2%
Informal Interaction	35.6
Meetings & conferences	35.1
Consulting	31.8
Contract research	20.9
Recent hires	19.6
Cooperative R&D projects	17.9
Patents	17.5
Licenses	9.5
Personnel exchange	5.8

Source: Cohen et al. (2002).

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[i] Godin and Gingras (2001) note that "After having been left out of major government policies centered on industrial innovation, universities seem, over the past 5 years, to have become the object of a renewed interest among students of the system of knowledge production." (p. 273).

[ii] Mowery and Rosenberg (1989) note that the conduct of scientific research and education within many research universities "…exploits a great complementarity between research and teaching. Under the appropriate set of circumstances, each may be performed better when they are done together." (p. 154).

[iii] This list draws from Rosenberg (1999), Cohen et al. (1998), and other sources.

[iv] David, Mowery, and Steinmueller (1992) and Nelson (1982) discuss the economic importance of the "informational" outputs of university research.

[v] See Rosenberg's (1994) discussion of universities as a source of innovation in scientific instruments.

[vi] See Rosenberg (1999).

[vii]Thus, Nelson's concluding chapter in his 1993 collection of studies of national innovation systems argues that "One important feature distinguishing countries that were sustaining competitive and innovative firms

was education and training systems that provide these firms with a flow of people with the requisite knowledge and skills. For industries in which university-trained engineers and scientists were needed, this does not simply mean that the universities provide training in these fields, but also that they consciously train their students with an eye to industry needs." (1993, p. 511).

[viii] According to Ben-David (1971), "To create order among the turbulent crowds of scholars and to regulate their relationships with the environing society, corporations were established. Students and scholars were formed into corporations authorized by the church and recognized by the secular ruler. The relationships of their corporation with that of the townspeople, with the local ecclesiastical officials, and with the king were carefully laid down and safeguarded by solemn oaths….The important result of this corporate device—which was not entirely unique to Europe but which attained a much greater importance there than elsewhere—was that advanced studies ceased to be conducted in isolated circles of masters and students. Masters and/or students came to form a collective body. The European student of the thirteenth century no longer went to study with a particular master but at a particular university. (p. 48).

[ix] The Japanese higher education system has a large number of private universities, although the bulk of these are devoted primarily to undergraduate education.

[x] U.S. "science and engineering" degreeholders also account for a smaller share of all advanced degrees awarded in the United States in 1999 than is true of France, Taiwan, and the United Kingdom, although this share in the United States exceeded those for Finland and South Korea (National Science Foundation, 2002).

[xi] These data must be interpreted with caution, since the definitions used by the national statistical agencies whence they are drawn often differ. For example, in France CNRS is classified as part of the Higher Education Sector, whereas in Italy similar organizations are treated as part of the government sector. See OECD 2001b, Annex 2

[xii] By comparison, the share of US university publications co-authored by industrial and university researchers grew from 4.9% in 1989 to 7.3% in 1999, while this share in Canadian university publications grew from 1.4% in 1980 to 3.5% in 1998.

[xiii] A recent OECD report notes that "Spinning off is the entrepreneurial route to commercializing knowledge developed by public research and as such is attracting a great deal of attention, given the 'start-

up' fever in many countries" and that governments "have a special interest in this specific type of industry-science linkage because it may be one of the factors that explain differences in performance in new-fast growing science based industries" (OECD, 2002, p. 41).

[xiv] According to Katz and Ordover (1990), at least 14 Congressional bills passed during the 1980s focused on strengthening domestic and international protection for intellectual property rights, and the Court of Appeals for the Federal Circuit created in 1982 has upheld patent rights in roughly 80% of the cases argued before it, a considerable increase from the pre-1982 rate of 30% for the Federal bench.

[xv] "Regulatory reform in the United States in the early 1980s, such as the Bayh-Dole Act, have [sic] significantly increased the contribution of scientific institutions to innovation. There is evidence that this is one of the factors contributing to the pick-up of US growth performance…" (OECD 2000, p. 77).