Universities in National Innovation Systems

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Outline

- Universities and industrial innovation in knowledge-based economies.
  - Characteristics of the university-industry technology transfer process.
- Comparative data on the structure of OECD higher education systems.
- Comparing OECD, developing-economy systems.
- Universities in “catching-up” economies in the 19th & 20th centuries.
  - Challenges for developing-economy higher-education systems.
- Recent policy initiatives within the OECD.
  - Science parks.
  - The Bayh-Dole Act of 1980.
- Conclusions.

Why do universities matter?

- They perform a substantial share of R&D, especially basic research, in most OECD economies.
- Innovation now draws more heavily on fundamental knowledge, an important output of universities.
- Important sources of trained S&Es and potentially, new firms.
  - Combination of research & training provides an important channel for flows of knowledge, practice, knowhow between university and industry.
- Important institutions in the absorption of technology from external sources.
  - Stronger international IPR will increase importance of domestic innovation, "inventing around" patents.
- Governments in OECD & developing economies see universities as important engines of economic development.
- But, consistent with the "NSI view," universities cannot be analyzed in isolation from other components of a national innovation system.
  - Overall higher education system (including other institutions for "tertiary" education, such as community colleges, technical schools, etc.).
    - "Bridging" institutions may be especially important for SMEs.
  - Systems of finance for industrial innovation.
  - Labor markets.
  - Broader "demand for innovation" from domestic firms, which in turn may reflect macroeconomic policy, influences on capital investment.

Universities in developing economies

- Increasing role of science in innovation => need for stronger indigenous research capability in order to "absorb" knowledge, technology from foreign sources.
- Developing-economy university research can complement, aid in absorption of, research results from international S&T networks.
  - Especially important for research on issues unique to developing-economy agriculture, public health, etc.
- University-based research trains S&Es and professionals more generally (e.g., primary & secondary teachers, physicians).
- Domestic research universities may provide an attractive "re-entry" opportunity for citizens working as S&Es in foreign economies.

The role of academic research in industrial innovation

- Surveys of US industrial R&D managers: patents & licenses are not the most important channels for access to university research for innovation (Cohen et al. 2002, Levin et al., 1987).
- All agree that "biomedical research is different": links are more direct and industrial innovation depends on academic research.
  - A "linear model" in this sector?
- In other sectors, relationship is more indirect and the supply of trained graduates, publications, faculty consulting, conferences are all more important than patents & licenses in knowledge flow (Cohen et al., 2002).
- Patents and licensing contracts rarely convey the necessary knowhow for commercialization.

Comparing OECD higher ed. systems

- Although widely cited as an important research institution, US higher ed. system ranks below those of other OECD systems on following indicators:
  - Share of national R&D performed.
  - Share of gov't R&D performed.
  - Share of higher ed. R&D supported by industry.
- Based on qualitative evidence, OECD (2002) claims that labor mobility between US higher education and industry is greater than in other systems.
- Unusual behavior of US system may reflect broader set of structural influences than those in the following indicators.

Figure 1: Universities' performance share of total national R&D, 1981-99

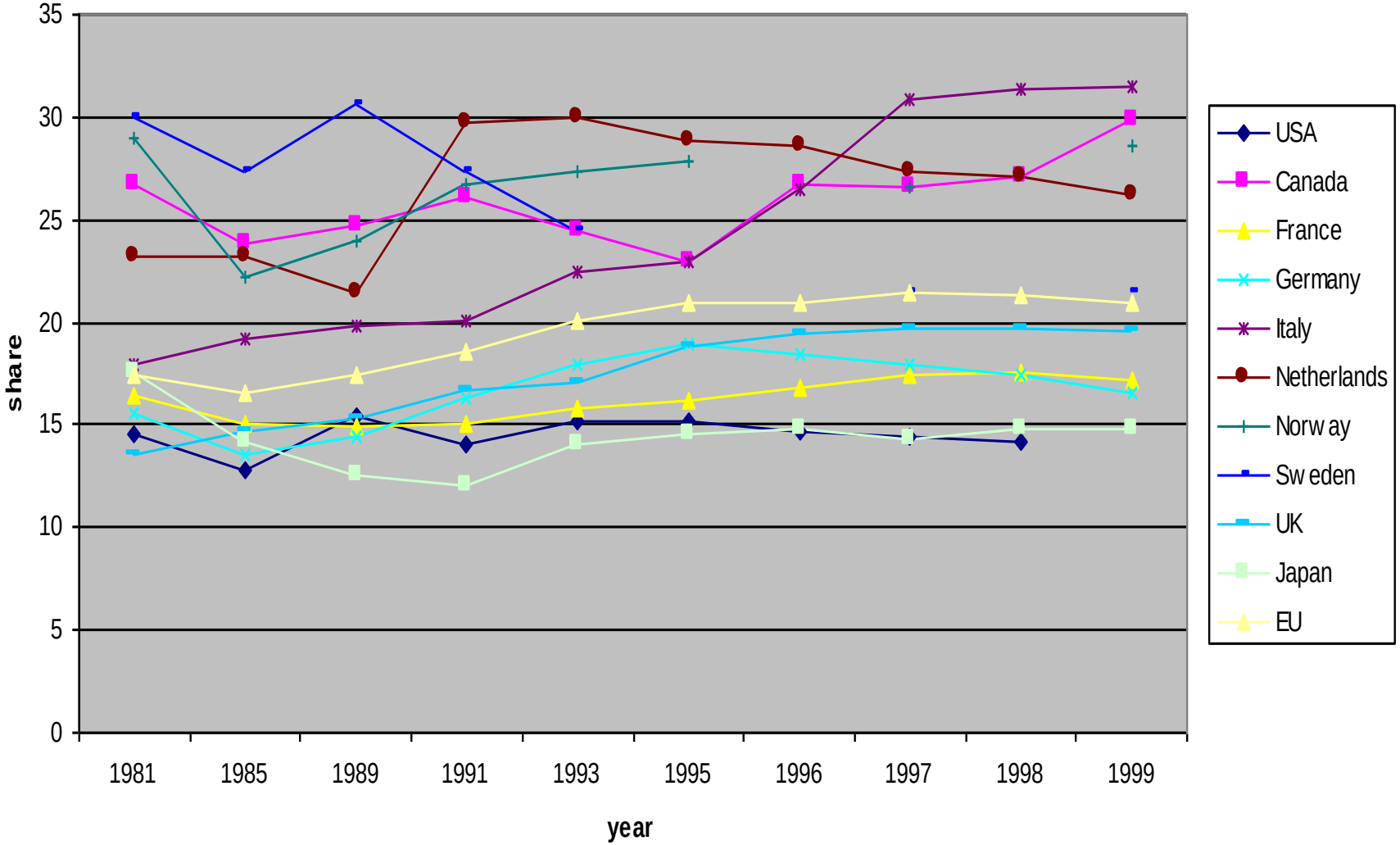


Figure 2: Universities' performance share of gov't-funded R&D, 1981-95

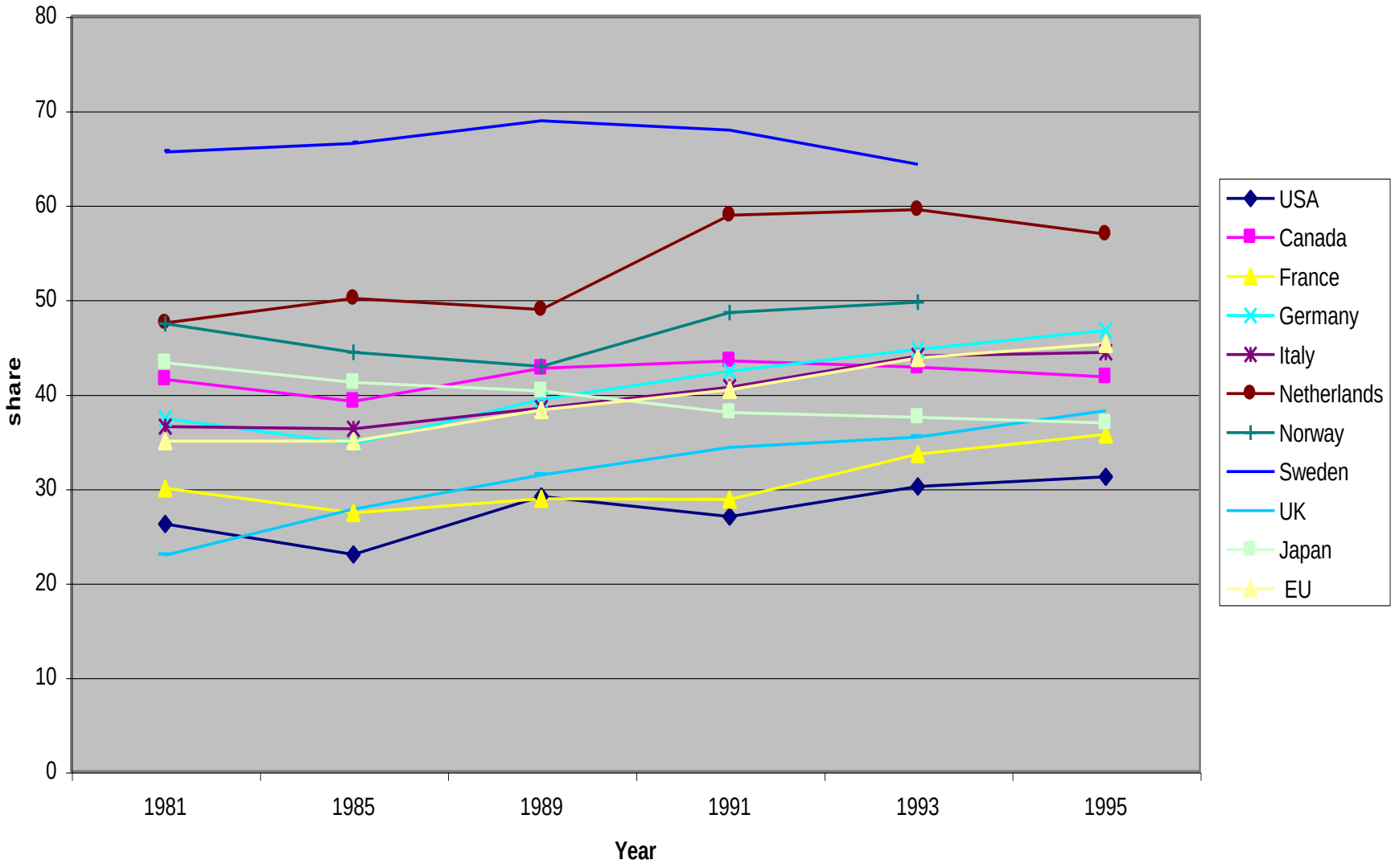
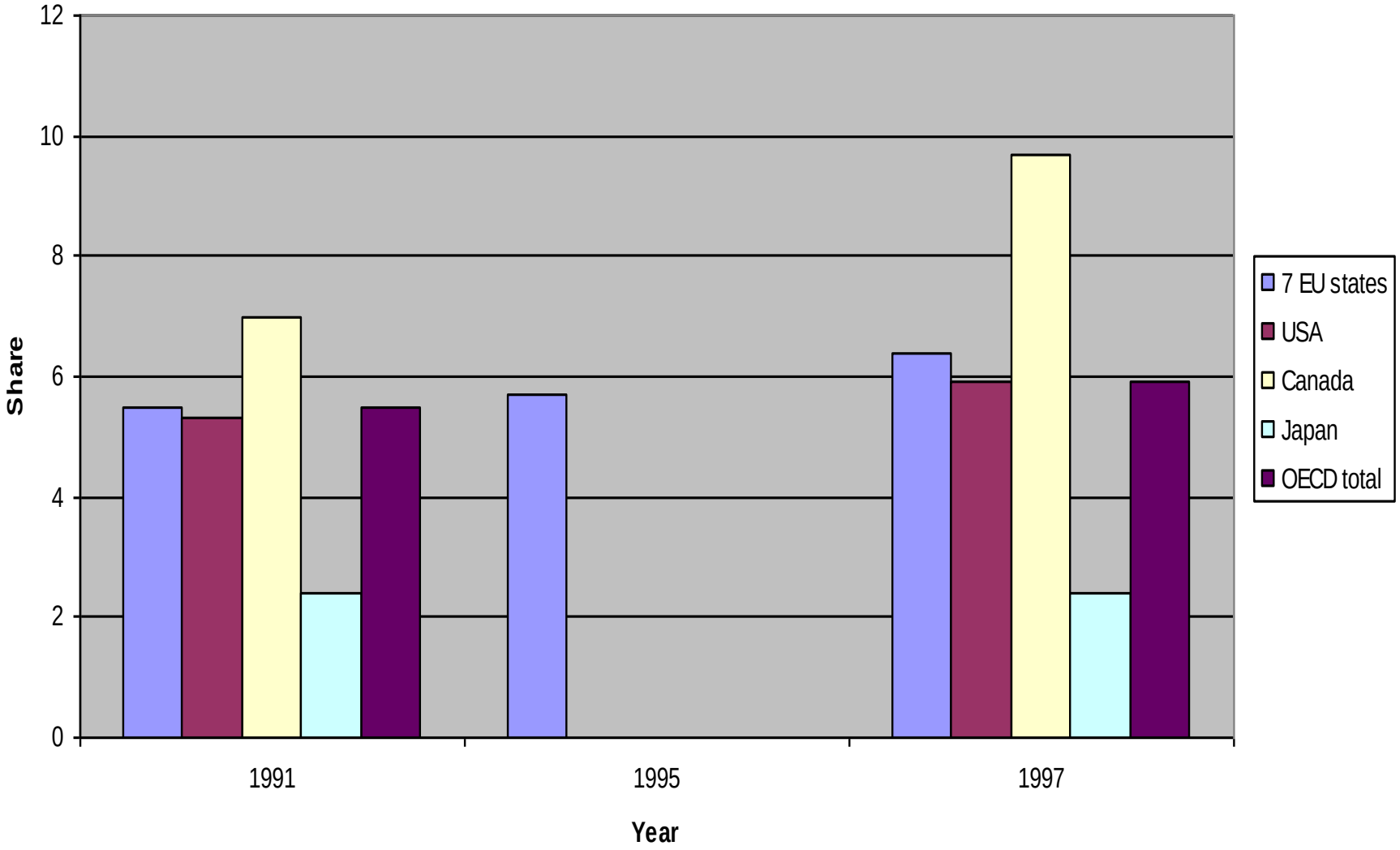


Figure 5: Fraction of HERD financed by business



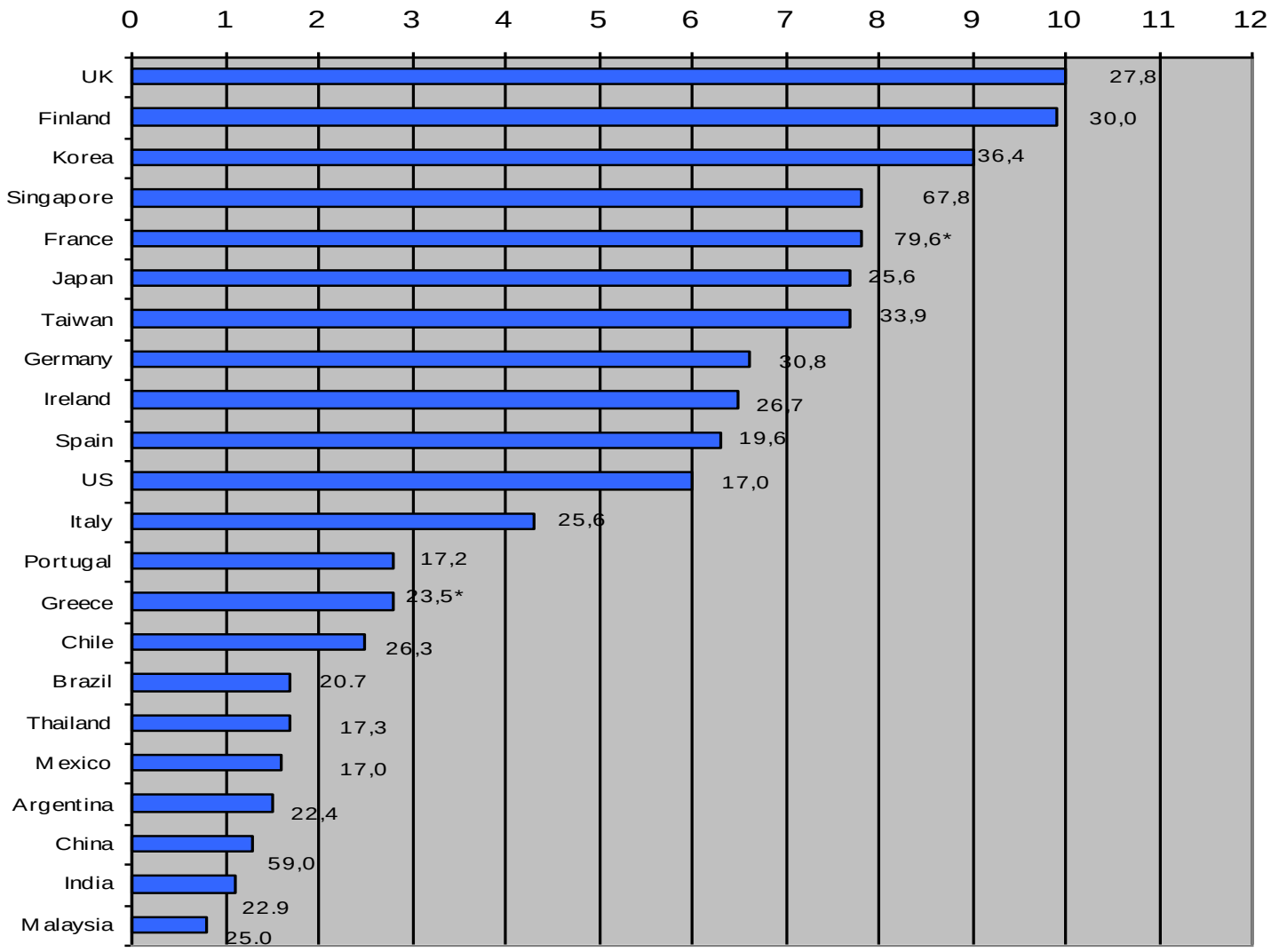
Developing-economy university systems

- Smaller share of relevant populations is enrolled in "tertiary" education (including universities) than in most OECD economies, and this gap has widened since 1980.
  - 1980: US enrollment rate 55% vs. developing-economy enrollment rate of 5%.
  - 1995: US enrollment rate 81% vs. developing-economy enrollment rate of 9%.
  - 1995 enrollment rates within E. Asia range from 2% in Cambodia to 51% in South Korea.
- Smaller share of students in tertiary education in most developing economies are enrolled in postgraduate (MA/MS, PhD, MD) degree programs.
  - A key channel for "brain drain" is outmigration of students to enroll in foreign postgraduate programs.
- Nonuniversity institutions account for much smaller share of tertiary education in many developing economies.
  - 2-year colleges, private vocational training institutes, polytechnics serve important training function in many OECD economies.
- Incomplete data suggest that universities perform a smaller share of publicly funded R&D in most developing economies.
  - Weakens research-training links within domestic higher-education systems, NSIs.

Universities in economic "catchup": common themes and contrasts

- Rapid enrollment growth, particularly undergraduate enrollment, is common in early years of catchup.
- Other than Germany, universities often are weak in research during the early catchup period.
  - A major economic contribution is through training, especially in engineering, rather than research.
- Primary focus of training is industry, not gov't.
- Universities' research role often complemented by other types of "tertiary education" institutions, public labs in early period.
  - But over time, greater pressure on universities to expand quality, importance of their research role, generally at the expense of public labs.
- Access by qualified students to university systems in "catchup" economies generally is open to large segments of population.
  - Relatively low fees and/or availability of financial aid, loans.
- Universities are linked into global S&T system, especially through international flows of faculty & researchers.
  - Hiring foreign scholars, bringing back expatriate S&Es.
- Great contrasts in structure of higher education systems, extent of centralized control, linkages between universities and industry, among these 6 economies.

Ratio of First University Degrees in Natural Sciences and Engineering to 24 year-olds in the Population, 1999 (all values in %)



Issues in developing-economy higher education systems

- Low enrollment rates.
  - But rapid expansion in degree output can also create problems in the labor market.
- Limited institutional differentiation, variety within developing-economy tertiary educational systems.
  - Few alternatives to universities for training.
- Inequality in access, unequal financial support => many developing-economy higher education systems reinforce, rather than eroding, social inequality.
- Postgraduate education is lacking.
- Domestic higher-education systems respond slowly if at all to changing labor markets.
  - Many tertiary education systems remain focused on training graduates for careers in government,
- Underfunding of research, facilities, salaries.
  - "Social returns" to investment in tertiary education may be underestimated if one focuses solely on earnings—can't overlook knowledge spillovers.
  - Greater reliance on competitive research funding can improve performance.
  - Stronger links between R&D performance, S&E training can improve efficiency of both activities and aid domestic technology transfer.

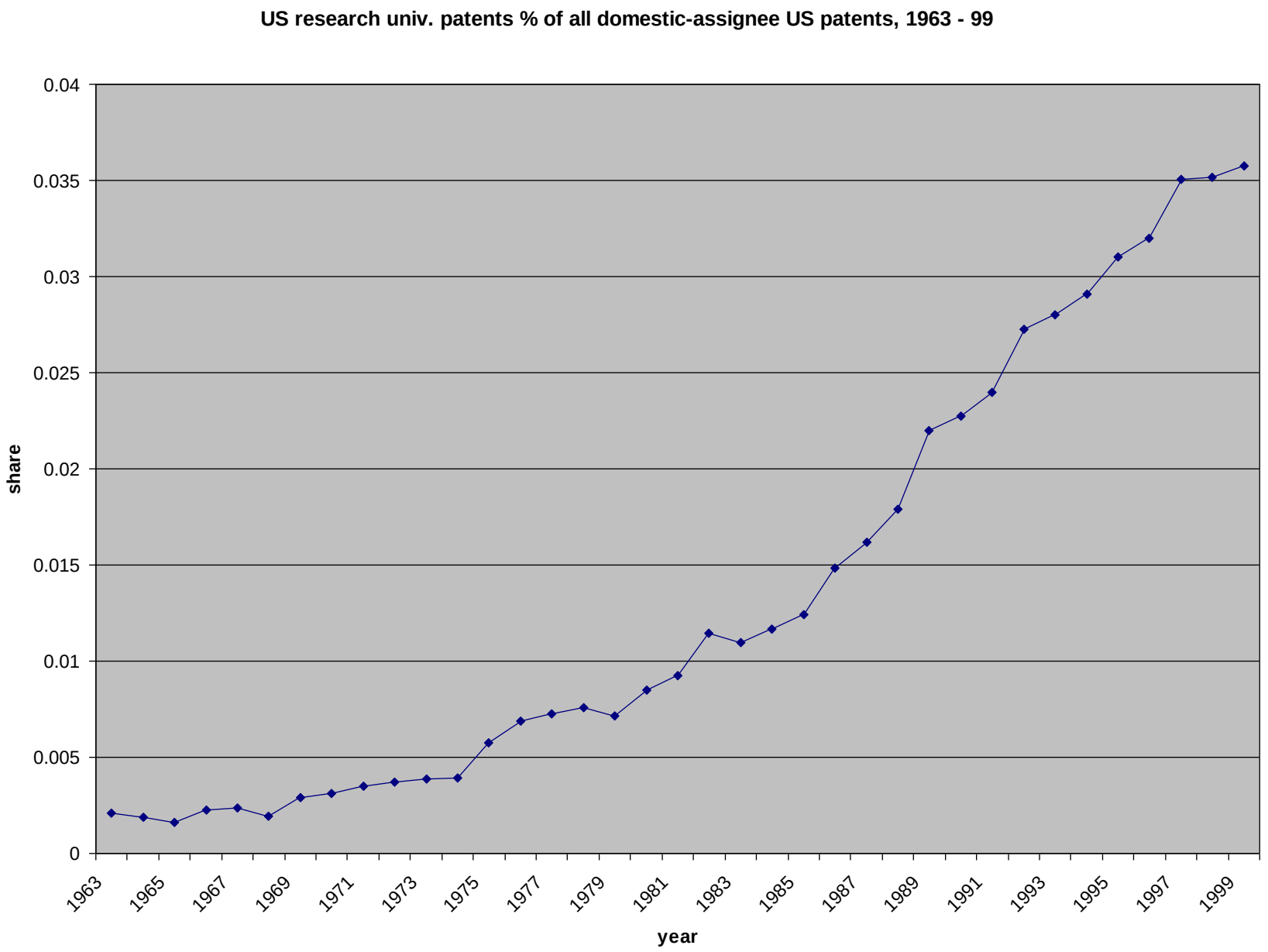
OECD policy experiments in university-industry collaboration: Science parks and patenting

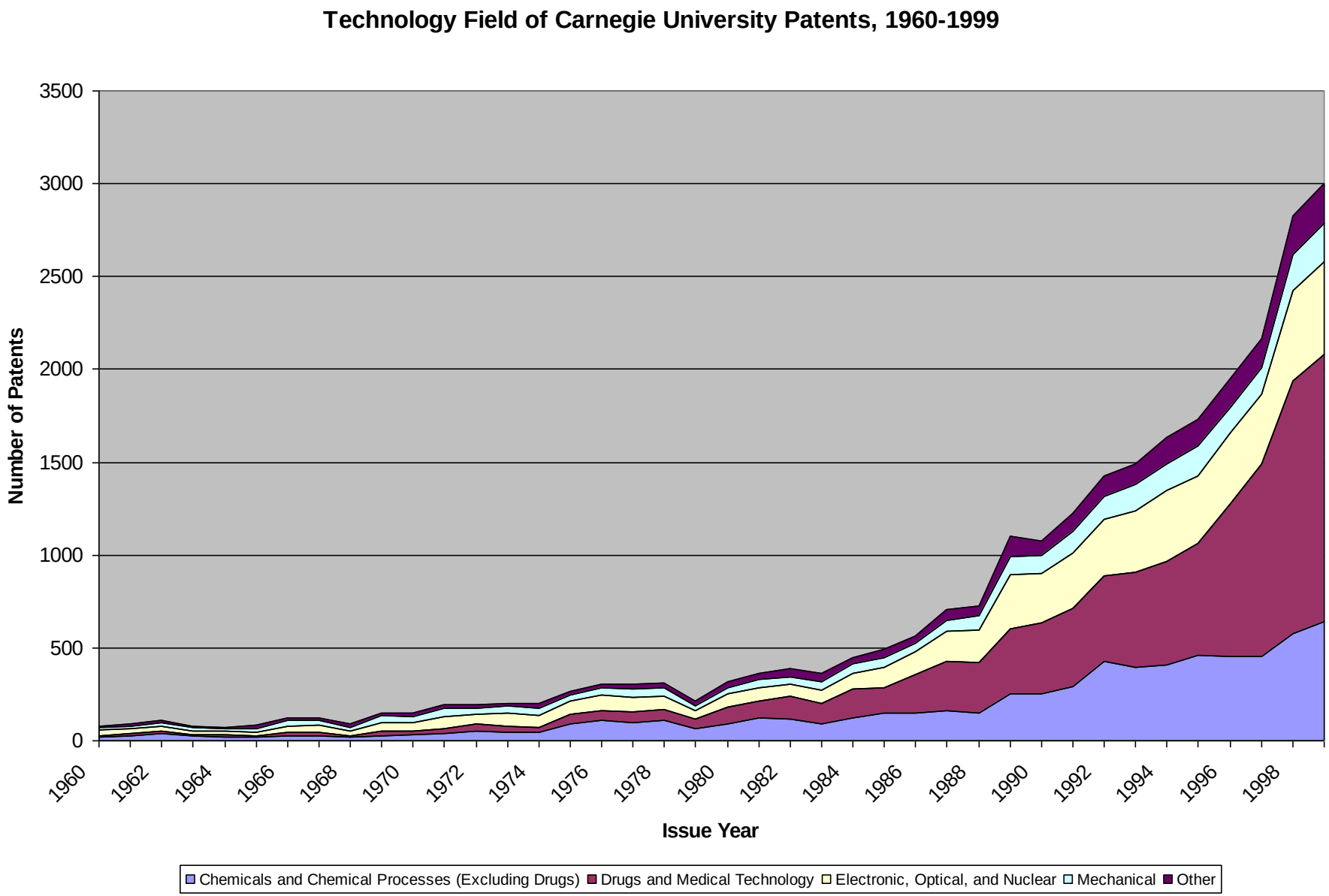
Science parks and incubators: Necessary or inefficient?

- Considerable evidence suggests that knowledge "spillovers" from universities are regionally localized.
- But little evidence supports the argument that universities "cause" high-technology agglomerations.
    - Numerous examples of research universities that have not spawned high-tech clusters.
  - Even less evidence supports the argument that gov't policies are consistently able to create such clusters.
- "Success stories" such as Hsinchu (Taiwan), Silicon Valley (US), or "Research Triangle" (US) differ from one another.
  - Silicon Valley and Research Triangle took decades to become high-tech clusters.
    - Silicon Valley an area of high-tech activity since early 20th century.
  - No single "recipe."
  - "Targeted" policies that seek to favor a single location or industry have a poor track record (Wallsten, 2001).
  - But broader policies supporting liberalization of domestic capital markets, greater labor mobility contribute to cluster formation.
  - As in many other policy areas, the successful cases are widely publicized, and the failures receive too little attention.

Patenting & licensing policies: The Bayh-Dole Act of 1980

- Passed in 1980 to encourage commercial development of federally funded inventions in university and government labs. The Act enabled these institutions to obtain patents on inventions and to license them to private parties, including exclusive licenses.
- Bayh-Dole replaced a complex web of Institutional Patent Agreements (IPAs) between individual federal funding agencies and individual universities.
- The Act constituted a Congressional endorsement of university licensing in the face of federal agencies' concern over exclusive licensing agreements negotiated under IPAs.
- Bayh-Dole has been widely cited (*Economist*, OECD) as an important contributor to US economic growth during the 1990s.


US research univ. patents % of all domestic-assignee US patents, 1963 - 99
0.04
0.035
0.03
0.025
0.02
0.015
0.01
0.005
0
share
1963
1965
1967
1969
1971
1973
1975
1977
1979
1981
1983
1985
1987
1989
1991
1993
1995
1997
1999
year


Technology Field of Carnegie University Patents, 1960-1999
Number of Patents
3500
3000
2500
2000
1500
1000
500
0
1960
1962
1964
1966
1968
1970
1972
1974
1976
1978
1980
1982
1984
1986
1988
1990
1992
1994
1996
1998
Issue Year
Chemicals and Chemical Processes (Excluding Drugs)
Drugs and Medical Technology
Electronic, Optical, and Nuclear
Mechanical
Other

Structural characteristics of US higher education motivated technology transfer long before 1980.

- Large scale of national “system.”
- No centralized (e.g.,federal) control of administrative policies.
- Heterogeneous institutional structure (public; private; secular; religious; large; small) and quality.
- Dependence by many institutions on “local” sources of financial & political support motivated research with “local” benefits, search for links with “local” industry.
- Inter-institutional competition for resources, prestige, faculty.
- These factors created strong incentives for faculty to seek out industry research sponsors and licensees.

US university patenting before Bayh-Dole

- University patenting during 1910-70 period drew on research collaboration with industry.
- Considerable ambivalence within U.S. universities over assumption of a direct role in management of patenting, licensing.
  - Wisconsin Alumni Research Foundation (WARF) was established in 1925 partly to distance University from direct involvement. U. Minnesota, Purdue, Cornell establish similar "agencies" during the late 1920s, 1930s.
  - MIT, Princeton, Columbia, & other research universities relied on the Research Corporation to manage patenting.
- By the late 1950s, most research universities had adopted formal policies.
  - But at least some of these policies, especially in medical schools, discouraged or prohibited patenting.
  - Public universities were more active in direct management of patenting and licensing.

Change in rate and character of US university patenting during the 1970s

- US university patenting accounted for roughly 0.2% of annual US patents during 1949-70, increasing to 0.5% by 1980.
- Biomedical technologies' share of US university patents increased from 11% in 1971 to more than 29% in 1980.
- Private universities' share of US university patenting more than tripled during 1960-80, growing from 14% in 1960 to 45% in 1980.
- Universities became more active managers of patenting & licensing during the 1970s, at the expense of the Research Corporation and other entities.
- Universities active in patenting were among the leading supporters of the Bayh-Dole Act.

Other US policy developments during the 1970s and 1980s influenced growth of university patenting, licensing

- ***Diamond v. Chakrabarty***: Life forms are deemed patentable by the US Supreme Court in 1980.
- Creation of the Court of Appeals for the Federal Circuit in 1982. The Court becomes a strong "pro-patentholder" judicial body.
- Other federal actions strengthen intellectual property protection in domestic, international economy during the 1980s.
- "War on Cancer" spurs research in molecular biology.

“Emulating” Bayh-Dole?

- Much of the growth in patenting & licensing would have occurred without Bayh-Dole:
  - Growth in biomedical research funding and discoveries.
  - Broader strengthening of federal intellectual property rights.
- Long before Bayh-Dole, U.S. university system’s structure (scale, autonomy, institutional diversity) created strong incentives for faculty and administrators to seek collaboration with external sources of research funding.
- Growth in patenting and licensing, licensing revenues are heavily concentrated in biomedical technologies.
- For many universities, these financial returns are modest or negative.
- Universities entering into these activities require considerable time to learn to manage them.
  - Staff and legal expenses for patenting and licensing offices are high.
- Partly because of lack of experience, much of the “post-Bayh-Dole” growth in patenting has affected “marginal” inventions.

“Emulating” Bayh-Dole? (2)

- Increased university patenting & licensing in some fields is changing universities and industrial firms from collaborators into competitors.
- Are patents and licenses necessary to support transfer and commercialization of university inventions? Evidence is mixed.
- Technology transfer and commercialization also rely on other institutions outside of the U.S. university, such as venture capital and equity markets.
- Research collaboration and technology transfer include many channels in addition to patenting and licensing.
  - Industry R&D managers rank these “other channels” more highly than patents, licenses.
- Broader economic policy environment also affected the “success” of Bayh-Dole:
  - Overall improvement in US macroeconomic policies in early 1990s => stronger overall growth, greater abundance of capital for investment in technology commercialization.

Conclusions

- Universities have played an important historic role in innovation and growth within the NSIs of developed, newly-industrialized economies.
  - But the structure of university systems and their historic roles differ considerably.
- The importance of universities' role seems likely to increase.
- An important basis for university contributions to economic & technological growth since the 19th century is their links to the international S&T system.
- Their combined performance of advanced research and training in many NSIs is another important source of university contributions to economic growth.
- Channels for knowledge flow, technology transfer between universities and domestic firms are numerous and involve much more than codified knowledge.
  - Relative importance of different mechanisms, channels for knowledge interaction between universities and industry also differs among technologies.

Conclusions (2)

- Institutions outside the university system play a key role in the effectiveness of university systems in research, training within NSIs.
  - Other tertiary education institutions, as well as “bridging” institutions (extension services; Frauenhofer Institutes, etc.).
  - Public research laboratories.
  - Domestic labor-market flexibility, mobility; industrial finance systems.
- Essential design decisions:
  - Balance between domestic universities, public laboratories in performance of publicly funded R&D.
  - Postgraduate vs. undergraduate training.
  - Differentiation within national “tertiary education” systems.
  - Strengthening links with the international science system, including other developing-economy universities.
- There is no single formula for success; principles for successful policy design include
  - Competition among domestic research performers.
  - Greater labor mobility between university and industry, as well as between universities and the international R&D system.
  - A variety of types of tertiary educational and “bridging” institutions.
  - Improved access (for both entry and completion) for all groups within a nation to tertiary education.

Appendix

Selected Data on University of California, Stanford University, and Columbia University Licensing Income, FY1970-95

UC	FY1970	FY1975	FY1980	FY1985	FY1990	FY1995
Gross income (1992 dollars: 000s)	1140.4	1470.7	2113.9	3914.3	13240.4	58556.0
Gross income from top 5 earners (1992 dollars: 000s)	899.9	1074.8	1083.0	1855.0	7229.8	38665.6
share of gross income from top 5 earners (%)	79	73	51	47	55	66
share of income of top 5 earners associated with biomedical inventions (%)	34	19	54	40	91	100
share of income of top 5 earners associated with agricultural inventions (%)	57	70	46	60	09	0
Stanford		FY76				
Gross income (1992 dollars: 000s)	180.4	842.6	1084.4	4890.9	14757.5	35833.1
Gross income from top 5 earners (1992 dollars: 000s)		579.3	937.7	3360.9	11202.7	30285.4
share of gross income from top 5 earners (%)		69	86	69	76	85
share of income of top 5 earners associated with biomedical inventions (%)		87	40	64	84	97
Columbia						
Gross income (1992 dollars: 000s)				542.0	6903.5	31790.3
Gross income from top 5 earners (1992 dollars: 000s)				535.6	6366.7	29935.8
share of gross income from top 5 earners (%)				99	92	94
share of income of top 5 earners associated with biomedical inventions (%)				81	87	91

Universities in economic "catchup": US and Germany

- German universities grew rapidly, developed close links with emergent electrical-equipment, chemicals industries during late 19th century.
  - Extensive collaboration, consulting between university faculty and industrial firms.
  - German universities were world leaders in scientific research in late 19th century, and trained many leading early 20th-century US scientists.
  - Expanded supply of S&Es from German universities supported growth in industrial R&D.
  - Creation of public research labs, technical institutes in late 19th-century supported applied research.
  - Huge growth in enrollments, little growth in funding after 1970 => serious difficulties.
- The "German model" was widely adopted by public and private US universities after 1870, but US universities remained weaker in research until mid-20th century.
  - But rapid growth, huge scale of US universities => major contributions to S&E workforce training.
  - US universities collaborated with new US ehcmical, electrical-equipment firms in engineering-oriented research during 1900-1940.
  - Federal and state funding supported extensive agricultural research and "extension services," increasing US agricultural productivity.

Universities in economic "catchup": Japan

- Emulation of German model in late 19th century.
  - British, German scientists were important institutional leaders and innovators in the creation of Japan's "Imperial Universities."
  - Highly centralized system emphasized training of engineers.
  - Like US before 1945, strength in training not equaled by research performance.
  - Universities played important role in inward technology transfer by Japanese firms, aided by informal consulting, other links between faculty and industry.
  - Little change in structure through 20th century—centralized control by national government limited autonomy of universities, incentives for faculty to seek industry research funding.
  - Public research institutes in telecommunications, electronics played an important role in post-1945 "catchup."
  - Little competition among universities for faculty, research resources.
  - During the 1980s and 1990s, Japanese universities experienced greater criticism over performance in basic research.
  - New policies in 1990s seek to emulate US Bayh-Dole Act, with limited success.

Universities in economic "catchup": S. Korea

- University enrollment grew from 8000 in 1945 to 90,000 by 1960 (6.4% of population cohort); 25.5% of cohort by 1987.
    - Substantial growth in private universities as well.
- Simultaneous outflow of S. Korean students to foreign universities for undergraduate, postgraduate study.
    - Many of the first returning expatriate S&Es move to public research institutes, rather than universities.
- But S. Korean universities' enrollment growth was not matched by expansion in their research role.
    - Universities perform 5.4% of nat'l R&D in 1971, 10.5% in 1987, vs. 33.1% of national R&D workforce in 1987.
    - Public laboratories are "backbone of advanced R&D" through the 1990s.
    - Weak university research capabilities limit possibilities for collaboration with industry.
- Public laboratories' role may decline in the near future.

Universities in economic "catchup": Taiwan

- Rapid enrollment growth, substantial "brain drain," limited research role for universities through the 1980s.
  - Taiwanese universities remain highly centralized and subject to significant central-gov't control.
  - Like S. Korea, Taiwanese universities' role in performance of publicly funded R&D is outstripped by role of public-sector laboratories.
  - Hsinchu "Science Park" established in 1980 to link universities and industry more closely.
- Like S. Korea, Taiwan faces challenge in upgrading research capacity of domestic university systems, expanding postgraduate training.
  - Like S. Korea, return of foreign-trained scholars, managers played an important role in Taiwan's "catchup" during the 1990s.
- Taiwanese universities seek greater autonomy in order to form closer links with domestic industrial firms.
  - Greater inter-institutional competition for research resources.
- As in S. Korea, public laboratories' future role is likely to decline in importance.

Universities in economic "catchup": the PRC

- Post-1949 NSI modeled on USSR, emphasizing "scientific academies" as major performers of research.
  - Universities' research role limited, primarily sources of trained S&Es.
- Economic reform period shifted R&D funding:
  - Universities forced to develop alternative sources of funding: they remain minor R&D performers (8.9% of total, vs >28% in "R&D institutes," as of 2000).
  - Overall GERD/GDP ratio grew to >1% by 2000.
- University enrollments have increased sharply:
  - Undergraduate enrollment in science, engineering, agriculture & medicine grew from 1.8M in 1995 to 3.3 M in 2000; graduate enrollments increased by 30% during 1999-2000.
- Elite (Beijing-based) universities have been important sources of patented inventions, "spinoff" enterprises.
  - Source of conflicts of interest for faculty, pressure to pursue applied research.
- "Brain drain" remains problematic: approx. 10% of all PRC university students are studying abroad as of 2000, roughly the same share as 1976.
  - Crude estimates suggest that 75% - 80% of the PRC students enrolled in US universities become permanent residents of US.
  - "internal" brain drain also an issue.

Other OECD economies have considered or adopted policies modeled on the Bayh-Dole Act.

- Japan
- United Kingdom
- Italy
- Discussions underway in Canada, France, Sweden, Germany.

Implications for Other Economies

- These “structural” incentives predate and are largely unaffected by Bayh-Dole.
- Absent such structural incentives, reforms affecting IP alone may be unsuccessful or counterproductive.

Implications for Other Economies (2)

- University role in technology transfer/commercialization depends on external institutions, whose absence may limit success of policies modeled on the Bayh-Dole Act.
  - Supportive policies in other spheres also crucial to any revitalization of universities' roles in collaboration, technology transfer.
- In addition to the "feasibility" of a Bayh-Dole Act, many issues about the effects of greater university involvement in patenting, licensing remain unresolved (these "effects" are not solely attributable to the Act):
  - Effects on "research culture" of universities.
  - Effects on research of patenting of inputs to science.
  - Patenting may hinder rather than encourage industry-university collaboration in some industries.

Universities in NSIs

- Universities are among the oldest institutional organizations in most European economies.
  - A key characteristic of 11th & 12th universities was self-governance.
  - "Self-governance" makes universities very conservative, often resistant to structural change.
- The "modern" research university first emerged in 19th-century Germany.
  - "German model" characterized by strong disciplinary, departmental structure, emphasis on graduate education, and classroom & laboratory instruction rather than tutorial coursework.
  - "German model" influenced Japanese, U.S., Nordic university systems.
    - But US system differs significantly from Japanese, German, most Nordic systems in scale, decentralization, institutional autonomy.
- National higher education systems are one of the most "nationally idiosyncratic" elements of NSIs throughout the industrial economies.

Universities, knowledge production, and innovation

- Conceptual frameworks for understanding the role of universities in industrial innovation:
  - "linear model" (V. Bush, 1945; embodied in Bayh-Dole).
  - "Mode 2" (Gibbons, 1994; emphasizes economic motivation, interdisciplinarity and inter-institutional collaboration).
  - The "republic of science" and contrasting norms of disclosure and dissemination of research in industry and academia (Dasgupta and David, 1994).
  - "Pasteur's Quadrant" (Stokes, 1995): Much academic research involves problem-focused basic research, linked to specific societal or industrial challenges (Pasteur and the phylloxera epidemic).
- Each conceptual framework => a different view of the nature of the economic benefits of academic research and the channels through which these benefits are realized:
  - Linear model: Economic benefits flow mainly from basic research.
  - "Mode 2": In the New Economy, universities must collaborate with other actors in networks and teams, focusing on applied and basic research.
  - "Republic of science": University research differs from industrial research because of the strong academic incentives for disclosure of results from basic or applied research.
  - "Pasteur's Quadrant": University research is a complex mix of basic & applied work.

Characteristics of the university-industry technology transfer process

- Most university faculty inventions require substantial development investment and time to approach even prototype status.
- Inventor involvement is essential to transfer, exploitation of licensed inventions.
  - Incentives for faculty-inventor involvement are important (Goldfarb & Henrekson, 2003).
  - The need for inventor involvement helps explain the decentralized structure of US university TLOs, and contributes to the frequency of faculty/inventor-founded startups (Lowe, 2003).
- Technology transfer relies on a two-way flow of knowledge, knowhow, funding, and people.
- Much of the most important "knowledge output" from academic research for industrial innovation involves the research techniques, exposure to frontier science & engineering that graduates obtain.
  - Graduates are an important linkage to industry, other parts of an NSI.
  - Flow of postgraduates (postdoctoral fellows, faculty) between universities and other institutions another important linkage that is lacking in many public research laboratories.
  - Both types of personnel flow aid technology transfer.