The historical evolution of industrial innovation

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Overview

- Central theme: change over time in the boundaries of the firm in R&D (waxing and waning??).
- The historical origins of industrial R&D.
- Public policy and industrial R&D.
- Post-1985 structural change in industrial R&D: Rise or return of open innovation?
- Conclusion and research issues.

Conceptual issues

Key theme: the changing boundaries of the firm & market in innovation

- Schumpeter “Mark I”: Inventors create new technologies, entrepreneurs (a different group) commercialize them, disrupting markets and displacing incumbent firms.
  - Innovation/invention distinction is key.
  - The 19th century? Or the late 20th?
  - Innovation is a force for social change.
- “Mark II”: Incumbent firms manage R&D to sustain market power; innovation becomes a tool of strategy for large firms.
  - Innovation is a force for stabilization and reduction in social mobility, leading (according to Schumpeter) to socialism.

Capitalism, Innovation, and Socialism

"The perfectly bureaucratized giant industrial unit not only ousts the small or medium-sized firm and "expropriates" its owners, but in the end it also ousts the entrepreneur and expropriates the bourgeoisie as a class which in the process stands to lose not only its income but also what is infinitely more important, its function. The true pacemakers of socialism were not the intellectuals or agitators who preached it but the Vanderbilts, Carnegies and Rockefellers." Joseph A. Schumpeter, *Capitalism, Socialism and Democracy* (3rd edn.; New York: Harper & Row, 1950), p. 134.

Evolution of industrial R&D affected by a range of influences

- Development of stronger links between technology and science.
  - These links affect change in the organization of R&D and in turn are strengthened by such change.
    - Formal knowledge (& training) become more important.
    - But technology affects science at least as much as the reverse.
- Public policy (industrial governance, IP policy, R&D investment, competition policy).
- Emergence of new types of firms
  - larger, more diversified, absorbing more functions.
    - Extension of firm boundaries includes management of innovation.
  - But are such firms still innovative or competitive?

What is "Open innovation"? And is it new?

- ". . .Open Innovation is the use of purposive inflows and outflows of knowledge to accelerate internal innovation, and expand the markets for external use of innovation. " (Chesbrough, 2006, 1).
- Widely viewed as a new phenomenon, associated with late 20th, early 21st century innovation management & firm strategy.
- But is "open innovation" in fact new?
  - How do we measure its importance, growth?
  - Markets for technology have operated alongside of in-house R&D for much of the 20th century.
  - Firms have long looked outside their boundaries for new technologies.

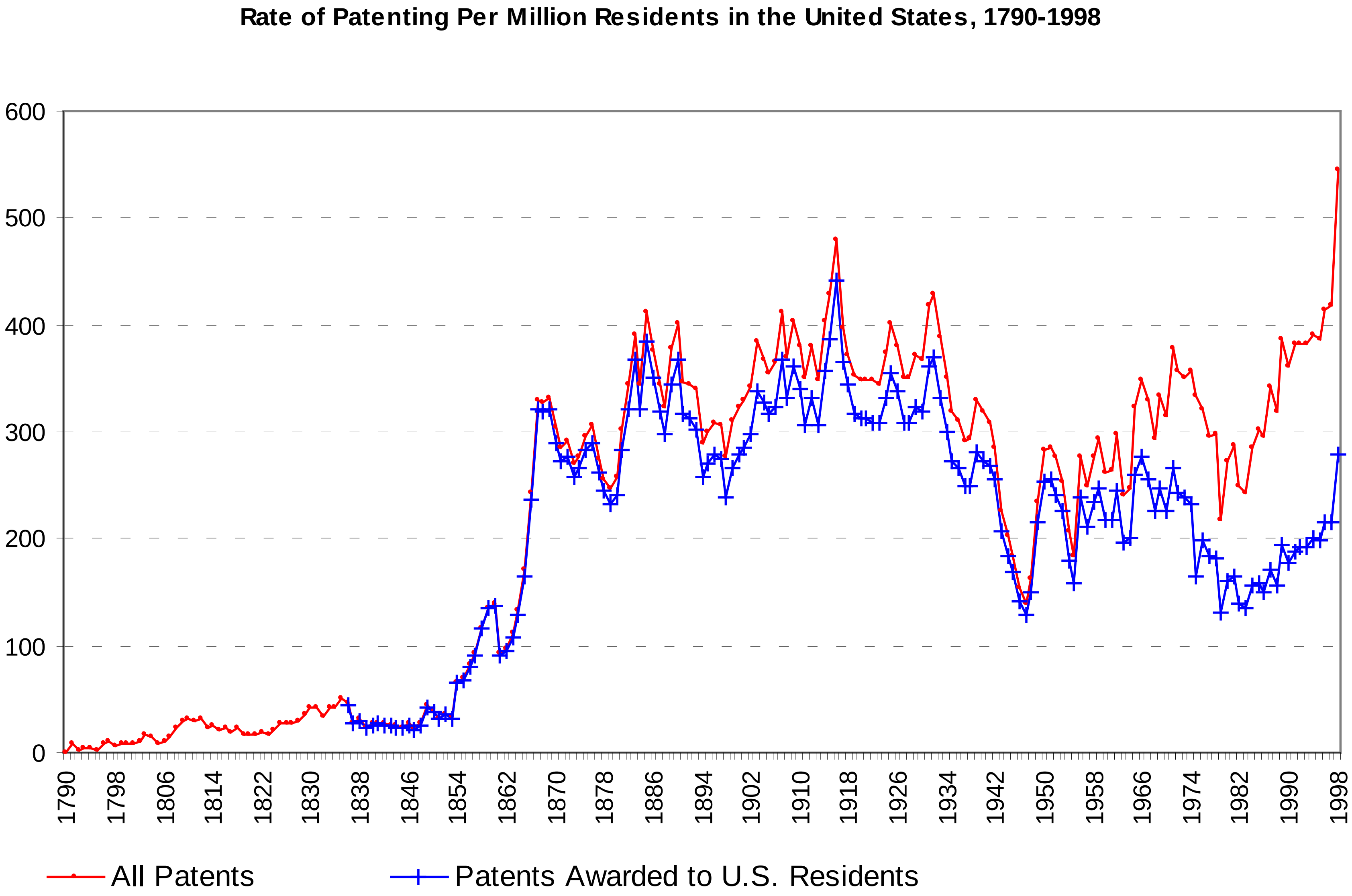
The historical origins of industrial R&D

The 19th-century "golden age" of the independent inventor in US

- Among the famous "independent inventors" of mid-19th century US are McCormick (reaper), Edison (electrical technologies), Sperry (electrical), & Deere (plows).
  - Deere, McCormick, and Edison had little formal scientific training, Edison hired advanced degreeholders for his "invention factory."
- Celebrated as successful "independent inventors," specializing in invention and licensing to other firms, in fact all of them sought to manufacture products based on their inventions.
  - "Markets for technologies" had significant imperfections, especially in international markets.

Decline of the independent inventor

- Reforms in US patent system in 1836 strengthened review, legal validity of patents.
- Lamoreaux & Sokoloff argue that reforms => boom in US patenting, aided by low fees and relatively easy access to patent records.
- By end of 19th century, specialized inventors were productive patenters.
- Growing capital, training, labor costs associated with invention in the "2nd Industrial Revolution" => decline of independent inventor.
  - Invention becomes more costly, difficult for independent inventors to finance.
  - Overall patenting rates in US decline in parallel (during a period of major innovation..


Rate of Patenting Per Million Residents in the United States, 1790-1998
600
500
400
300
200
100
0
1790
1798
1806
1814
1822
1830
1838
1846
1854
1862
1870
1878
1886
1894
1902
1910
1918
1926
1934
1942
1950
1958
1966
1974
1982
1990
1998
All Patents
Patents Awarded to U.S. Residents

Origins of industrial R&D, 1875 - 1930: The "2nd Industrial Revolution"

- Pioneered by German chemicals & electrical equipment firms.
  - Pre-1914 industrial R&D linked with German university researchers.
- Chemicals & electrical equipment firms among the 1st to exploit in-house industrial R&D in US.
- Growth of US industrial R&D was linked with forces (e.g., antitrust policy) that molded the "managerial corporation" analyzed by Chandler.
  - Early US antitrust policy motivated mergers among firms that created many of the large corporations that pioneered industrial R&D.
  - Later court decisions upheld licensing practices that bolstered market power, further increasing value of patents.
  - Industrial R&D supported technology acquisition, diversification, extension of market power through control of intellectual property and licensing.
- US firms with in-house R&D are less likely to be displaced from 200 largest after 1920.

“technology markets” in pre-1945 US

- Firms used industrial R&D to scan their environment for technologies, as well as developing new advances internally.
  - In-house R&D grew alongside of markets for technology that support purchases of inventions from independent inventors, other firms.
- Independent R&D contractors also were significant (Mellon Institute, Battelle, Arthur D. Little).
  - But contract R&D complements, rather than substituting for, in-house R&D.
  - Client firms are those with in-house labs that provide “absorptive capacity. “
- Much of the pre-1945 history of industrial R&D illustrates “open innovation” strategies.
  - Firms use in-house R&D to look to universities, other firms, independent inventors for technologies.

Industrial research during the 1920s & 1930s

- University-industry collaboration expands:
  - US pharma firms' R&D facilities concentrate near research universities during 1927-46 (Furman and MacGarvie, 2005).
  - MIT-Exxon collaboration during 1920s and 1930s lays foundations for chemical engineering.
  - Du Pont – U. of Delaware collaboration builds academic chemistry department.
- The 1930s produce rapid growth in US aggregate productivity, doubling of industry-funded R&D investment, tripling of industry R&D employment.
- Du Pont invention of nylon in 1935 is a rare science-based corporate invention.
  - "linear model" in action (?).

Public policy and industrial R&D

State role in R&D funding grows in 19th, early 20th centuries

- 1st state-funded research labs established in Germany in 1851, focused on agriculture.
  - UK, other European gov’ts follow in developing agricultural research.
  - US establishes what becomes a large state-funded system in 1862.
  - Norwegian gov’t begins to support research in fisheries, agriculture by 1905.
- Late 19th/early 20th century, gov’ts expand investment in development and procurement of weapons (warships, later aircraft).
  - WWI vastly expands role of state in R&D.

World War II expands and makes permanent the state role in R&D

- All major combatant nations vastly expand investment in R&D for military purposes.
- US in particular relies more heavily on industry for R&D, mandates extensive technology-sharing among firms:
  - Aviation fuel.
  - Aluminum production.
  - Penicillin production.
  - Synthetic rubber.
- Development of new policies for gov't support of academic "contract research"

Transformation of the US national innovation system, 1945 – 70s

- Federal R&D investment grows from less than 20% of national R&D spending in 1930s to nearly 65% by 1963, declining to 35% by 2003.
  - Defense-related spending accounted for more than 80% of federal R&D investment in 1950s.
- From late 1930s through the 1970s, US antitrust policy becomes much tougher.
  - Large-firm acquisitions of “related businesses” subject to hostile scrutiny.
  - Patent-based market power also viewed skeptically.
  - DuPont searches for “new nylons,” turning inward and relying on internal R&D for new businesses.
  - RCA, other large firms pursue diversification in unrelated industries.
  - “open innovation” strategies become more difficult for large US firms.

Figure 1: Federal and Nonfederally funded R&D, 1953-2002

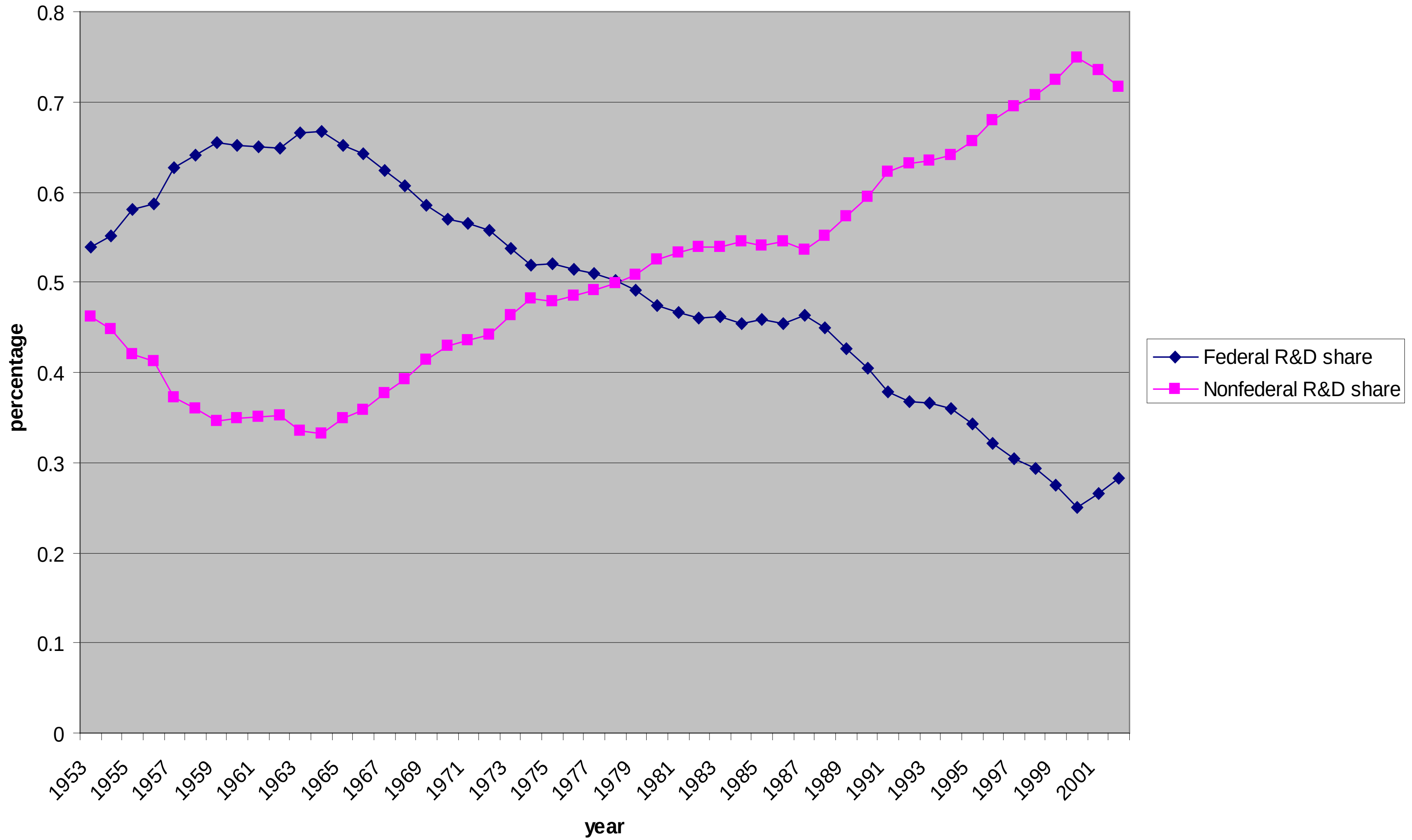
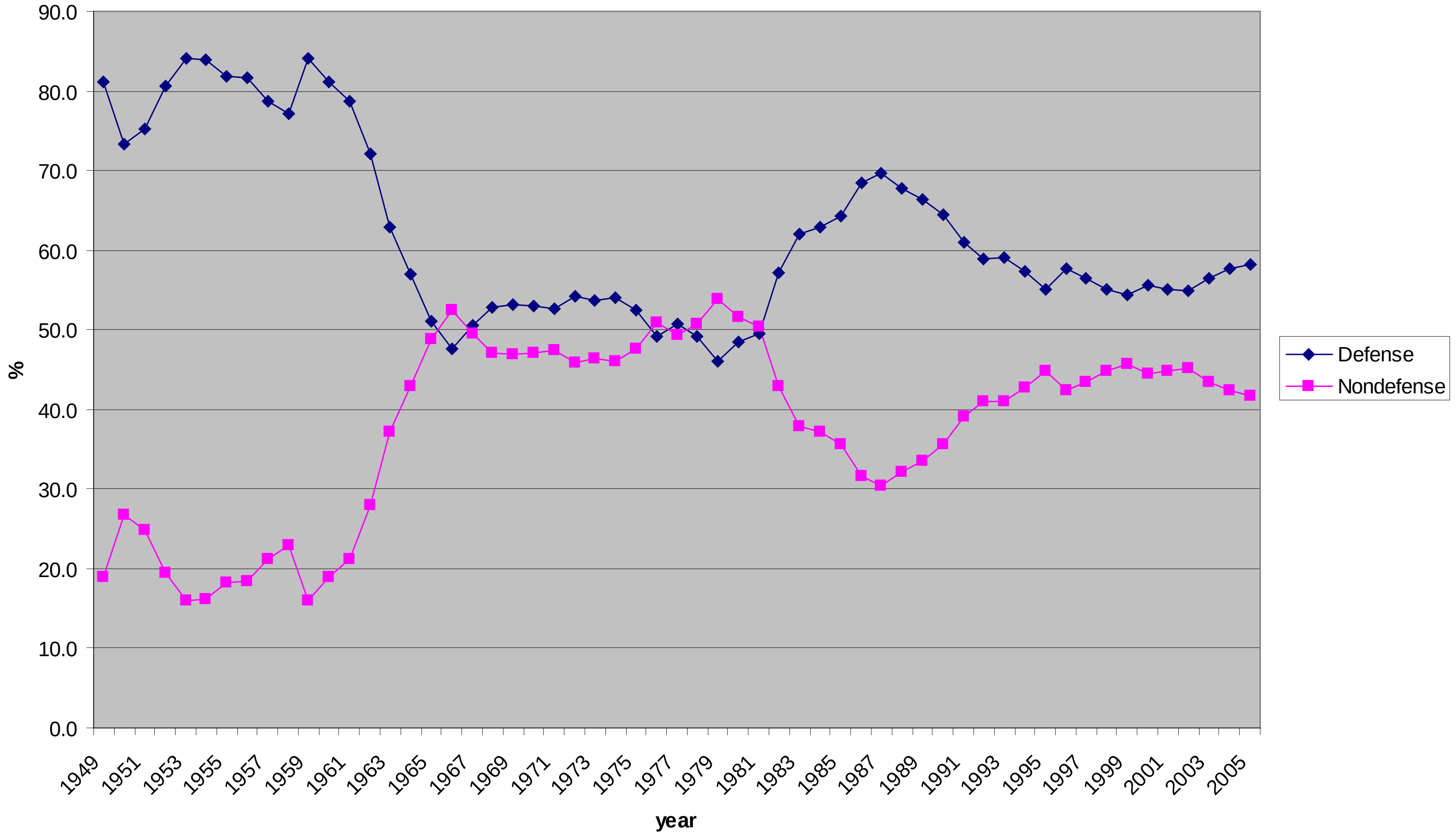


Figure 2: Defense & Nondefense share of total federal gov't R&D outlays, 1949-2005



OECD economies’ public R&D spending dominated by “mission-oriented” R&D

- Economists (notably Nelson, 1959, Arrow, 1962) argued that public funding of R&D should focus on areas of “market failure.”
- But US and other OECD nations focus postwar public funding of R&D on gov’t “missions” (defense, space, nuclear power, agriculture).
  - Based on gov’t mission/program objectives, rather than “market failure.”
  - EU R&D funding is not mission-oriented, and is a tiny share of large member-state public R&D spending.
- Interinstitutional collaboration is common, predating “Mode 2” or “Triple Helix.”
  - R&D program objectives chosen by policymakers, not by “Republic of Science.”

Other characteristics of mission R&D

- "D" accounts for a large share of the "R&D" in military, aerospace, nuclear fields.
- Mission R&D often combined with other policies (procurement) that enhance or offset the effects of funding for innovation.
  - In some cases (early US semiconductor IC development), procurement was more significant than R&D funding.
- Major source of investment in R&D infrastructure (facilities, equipment, etc.) in many OECD economies (including US), and a large university-centered infrastructure in US.
  - WWII: UCB & Manhattan Project; MIT & the Rad Lab=> postwar university-operated gov't research facilities.
  - Creation of US academic computer science research infrastructure supported by postwar DoD investment.

How did “mission-oriented” R&D affect postwar civilian innovation?

- US: Defense-related R&D was a major influence on civilian IT innovation.
  - Effects of R&D investment enhanced by procurement.
  - Huge scale of US defense-related R&D investment =>support of multiple, competing technologies.
  - Defense-civil technology “spinoffs” important, based on similarity in technologies.
    - Spinoffs decline over time, as defense & civilian applications diverge.
- Spinoffs also benefited US aerospace, failed in nuclear power, machine tools.
- Other OECD nations: smaller benefits from defense-related R&D because of smaller scale(?).

Post-1985 structural change in industrial R&D: The rise or return of open innovation?

Post-1985 structural change in industrial R&D

- R&D data arguably convey a less accurate view of innovation strategies and structures during this period:
  - Coverage of new firms, nonmanufacturing firms by NSF R&D investment surveys is problematic.
  - Larger % of firms' innovation-related activities may not be captured by R&D investment data.
- What do we observe in US R&D investment trends?
  - Decline in large firms' share of performance of nonfederally funded R&D.
    - Decline in large-firm role appears to occur after significant declines in share of "long-term" R&D spending.
    - What do we observe in other industrial economies?
  - Nonmanufacturing firms become more important performers of R&D.
- Other elements of structural change include vertical specialization, growth in interfirm alliances, technology licensing.
  - "Open innovation"? Return of Schumpeter Mark I?

Firm size class shares of industry-performed R&D (nonfederally funded), 1984-2008

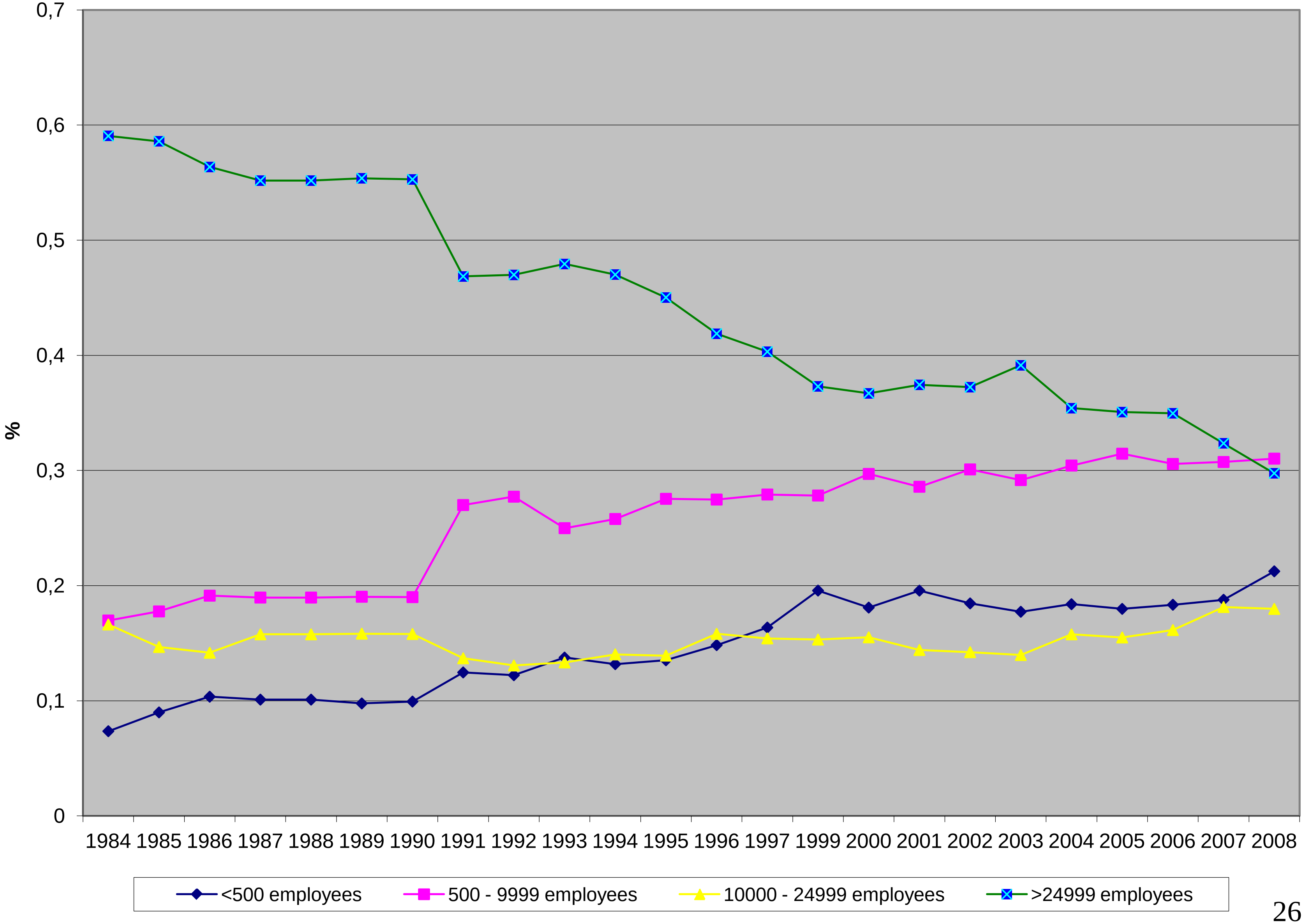
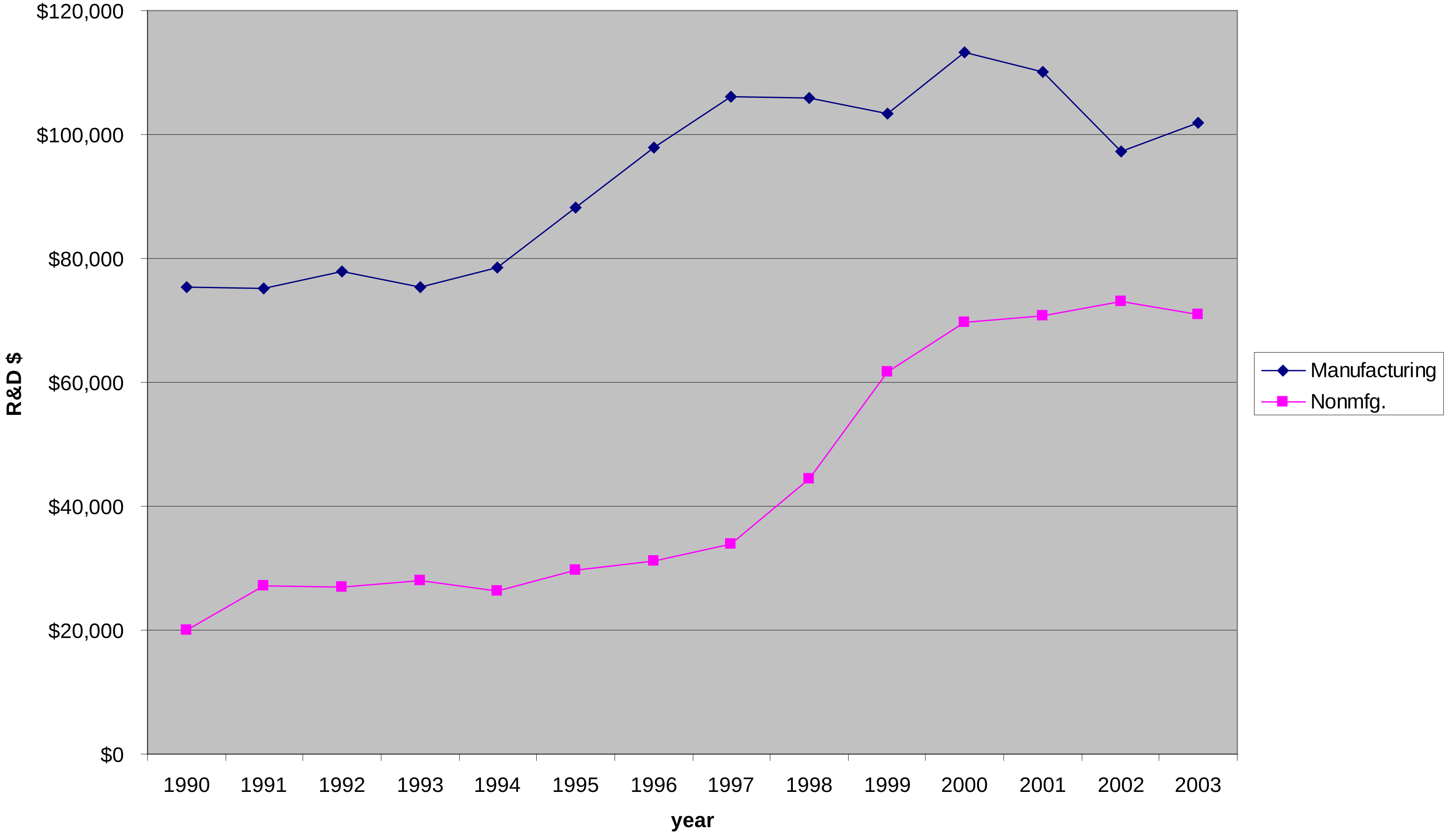


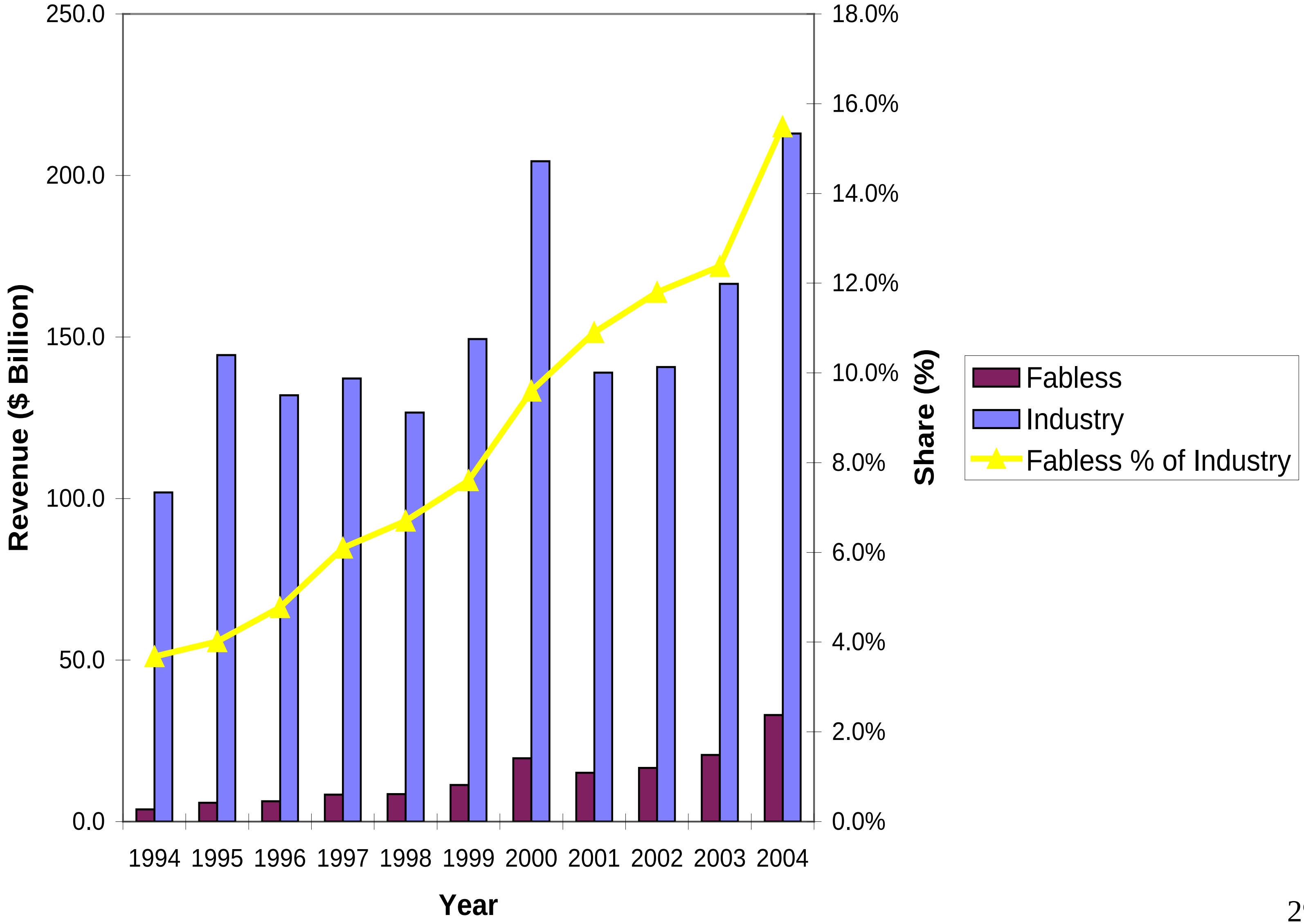
Figure 7: Industry-funded R&D investment, Mfg and nonmfg, 1990-2003 (2000$$)



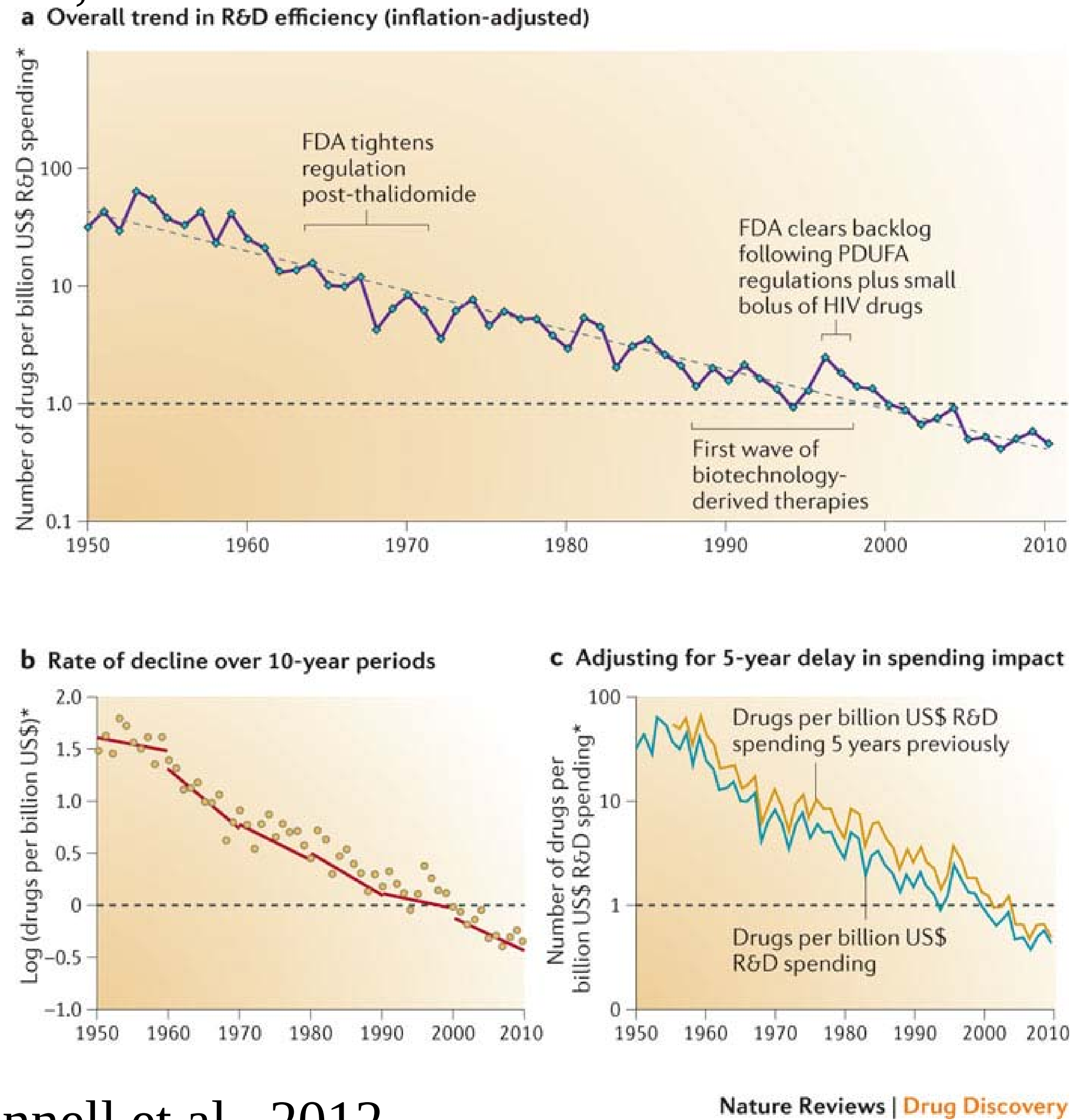
“Vertical specialization” in industrial R&D.

- What is “vertical specialization”?
  - Different steps in innovation & production processes are performed by different firms, in contrast to the large firm integrating R&D and production earlier in the 20^{th} century.
  - Applies to invention/innovation/production.
    - “Fabless firms” in semiconductors.
- Vertical specialization increased in IT and biomedical sectors during 1990s, 00s, especially in US; what of other industrial economies?
- Vertical specialization complements “open innovation,” but in pharmaceuticals, vertical specialization has not accelerated innovation.

Fabless and Overall Semiconductor Industry Revenues, 1994-2004



“Erooms Law,” 1950 - 2010

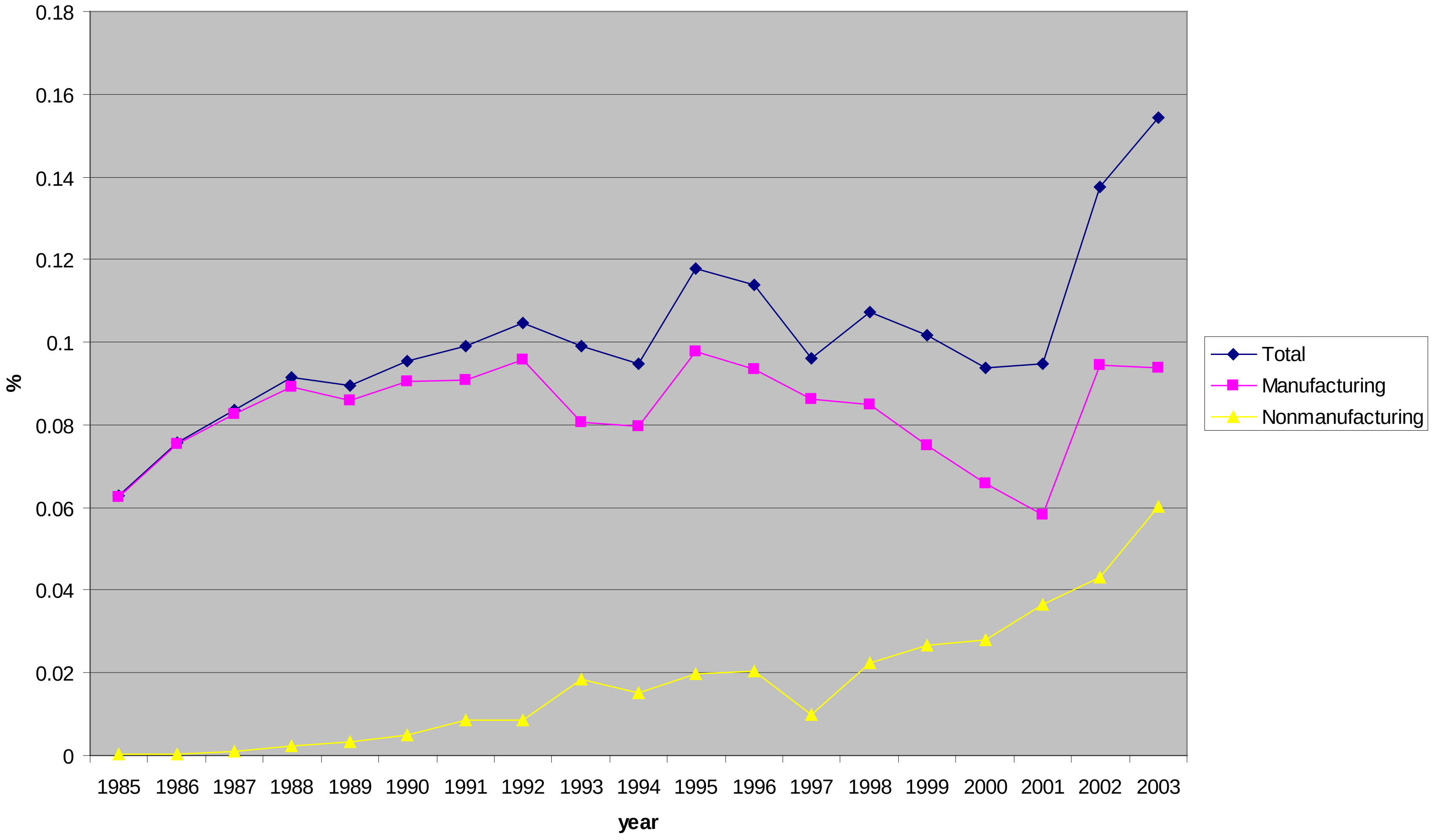


Source: Scannell et al., 2012

R&D “globalization” for US firms after 1985

- Foreign-funded share of total US industry-funded R&D doubles (7% to >15%) during 1987-2002.
- US firms’ 1985-2003 offshore R&D investment grows modestly within mfg., significantly in nonmfg. industry.
- Foreign-firm assignees account for growing share of corporate US patents during 1990-2003.
- But data on site of invention for semiconductor patenting reveal no evidence of growth in “nondomestic” inventive activity for US, European, Asian semiconductor firms. Why?

Figure 12: U.S. ind-funded offshore R&D % of total U.S. ind-funded R&D, 1985-2003



Growth in interfirm R&D, technology development alliances

- "Technology development" alliances (domestic and international) involving US firms increase in number during 1980-2003.
  - Consistent with growth in "open innovation"?
  - But data for semiconductor industry and overall => decline in rate of formation of new alliances. Why?
  - Consistent with growth in open innovation?
- MERIT-CATI alliance data for alliances overall suggest that contractual governance forms dominate. Why?
  - Equity generally recommended as a superior governance mode for dealing with opportunism.
  - Is (apparent) prevalence of contracts linked to vertical specialization in IT and biomedical fields?

Figure 8: Alliances between US & non-US firms, 1980 - 2003

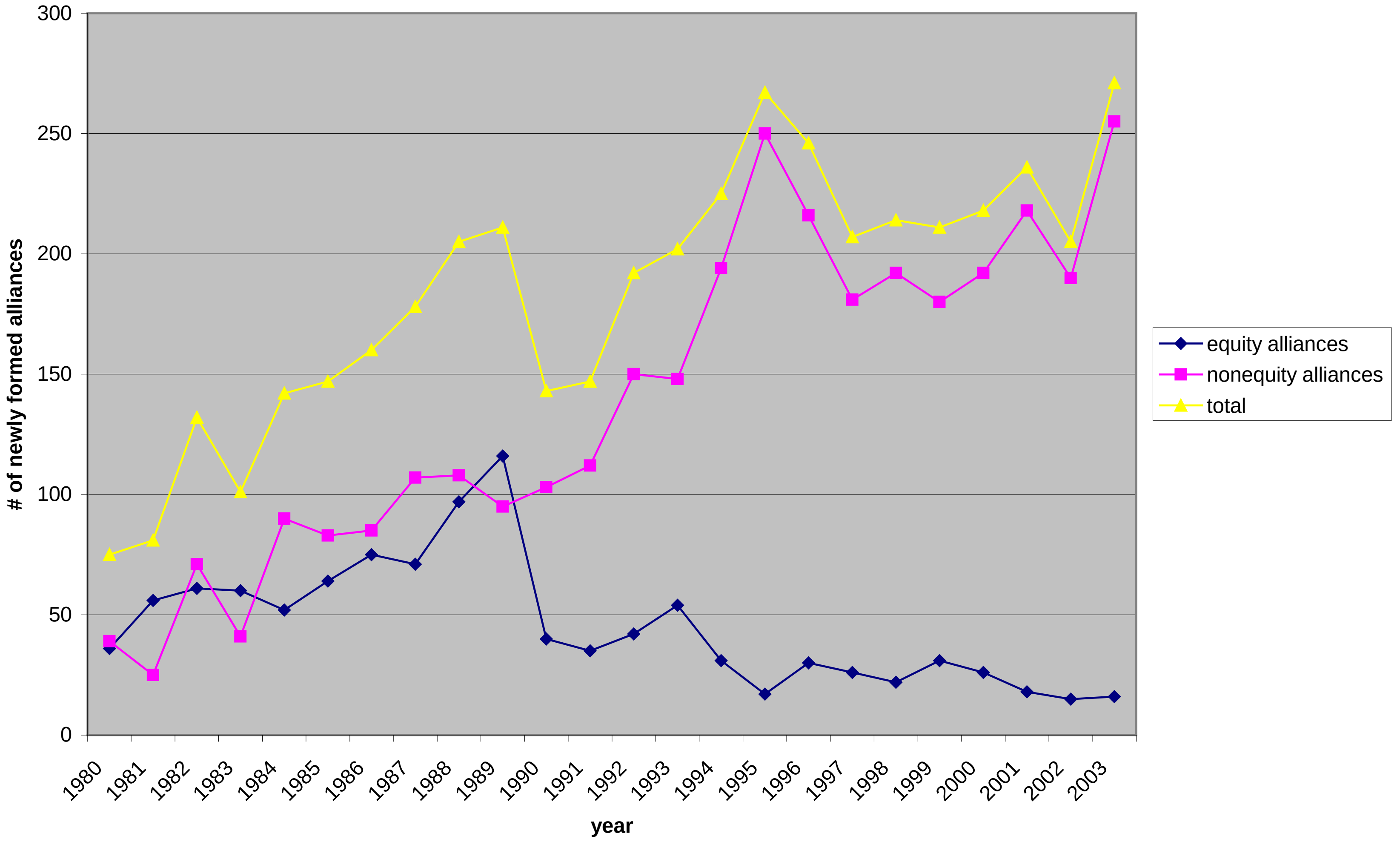
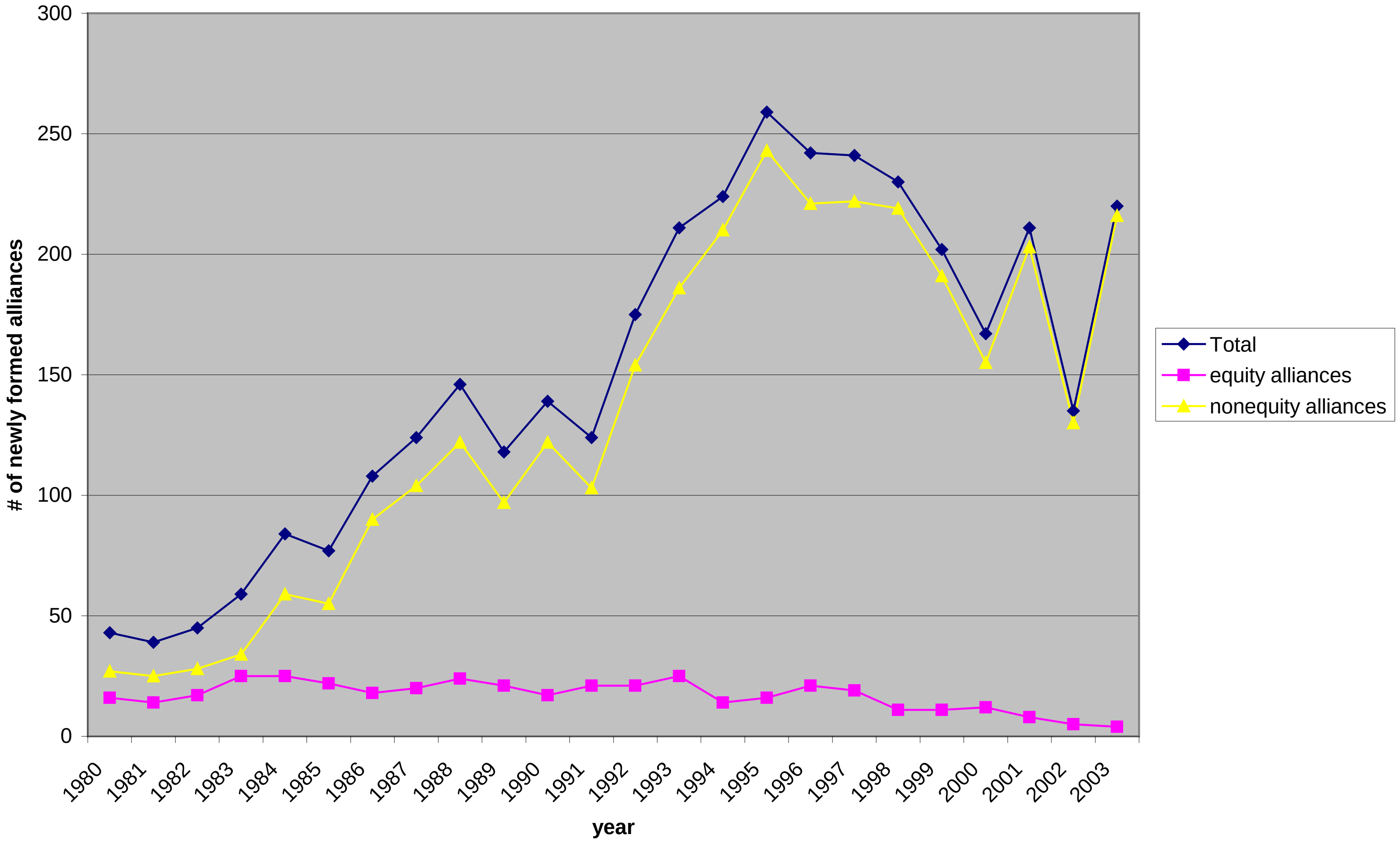
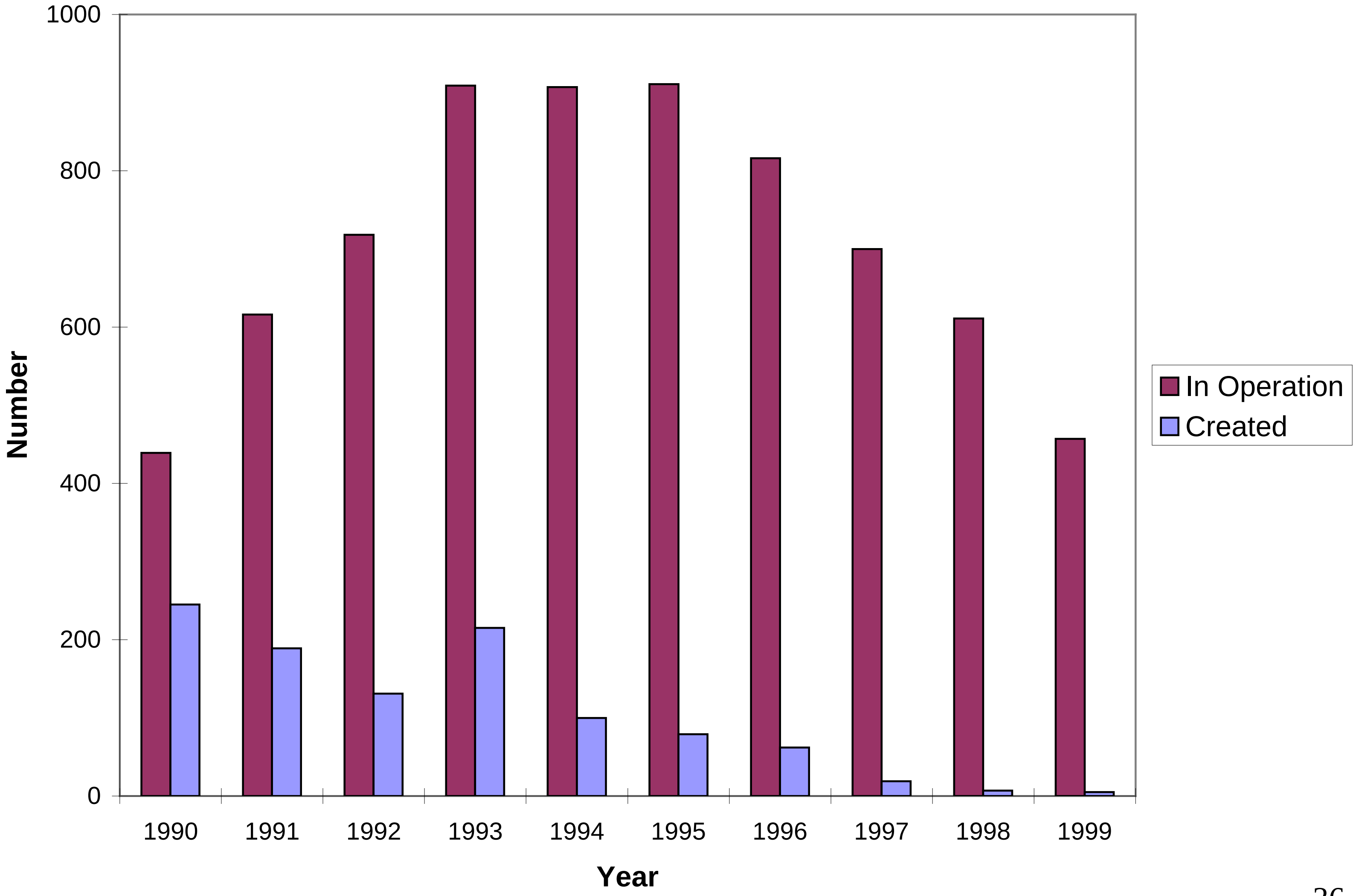


Figure 9: Alliances among US firms, 1980 - 2003



Semiconductor Industry Alliances, 1990-1999



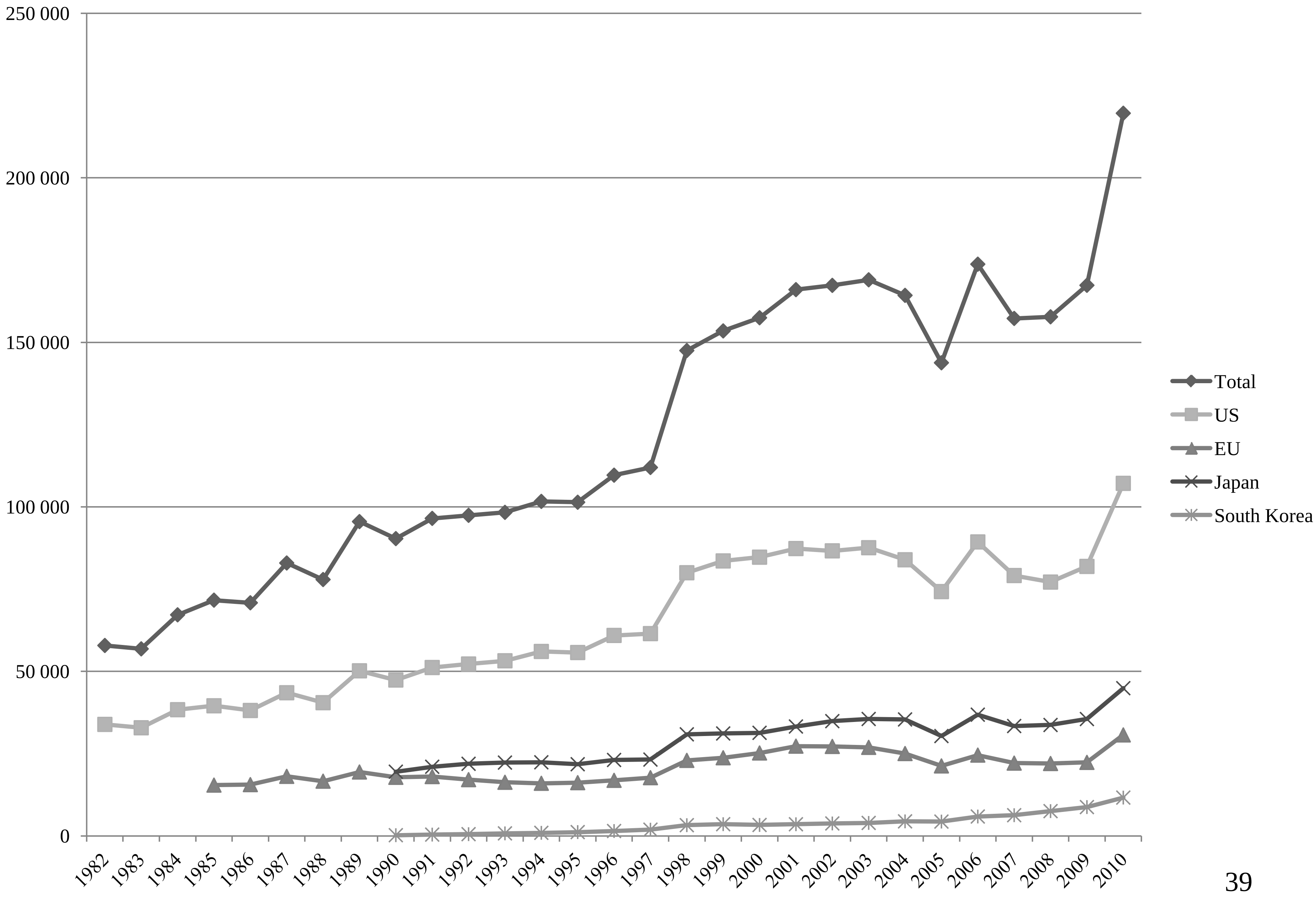
Change in IP policy in the US and other economies

- US intellectual property policy changes radically during the 1980s.
  - Shift away from policy hostility toward strong patents, especially when these conferred or strengthened market power.
  - Change in US IP policy complemented by shift to a weaker competition policy posture.
- The "pro-patent" policy after 1980.
  - US Supreme Court upholds patentability of life forms, software.
  - Congressional actions to strengthen IP rights reflect concern over declining US "competitiveness."
  - US shifts in domestic IP policy lead US to pursue stronger international IP standards, enforcement (TRIPS).

The effects of the shift in US IP policy

- Surge in US patenting during the 1980s, 1990s.
  - Can the US patent office keep up with surge in applications?
  - Surge in patent litigation => greater resort to "defensive" patenting.
  - How do low-quality "defensive patents" affect innovation?
- Controversy over effects of strong patents => "backlash" during 2010-2012:
  - American Invents Act (2011) introduces a stronger administrative procedure for challenging patent validity.
    - Lengthy and difficult negotiations over the Act reflected conflicting views of benefits of IP within US industry.

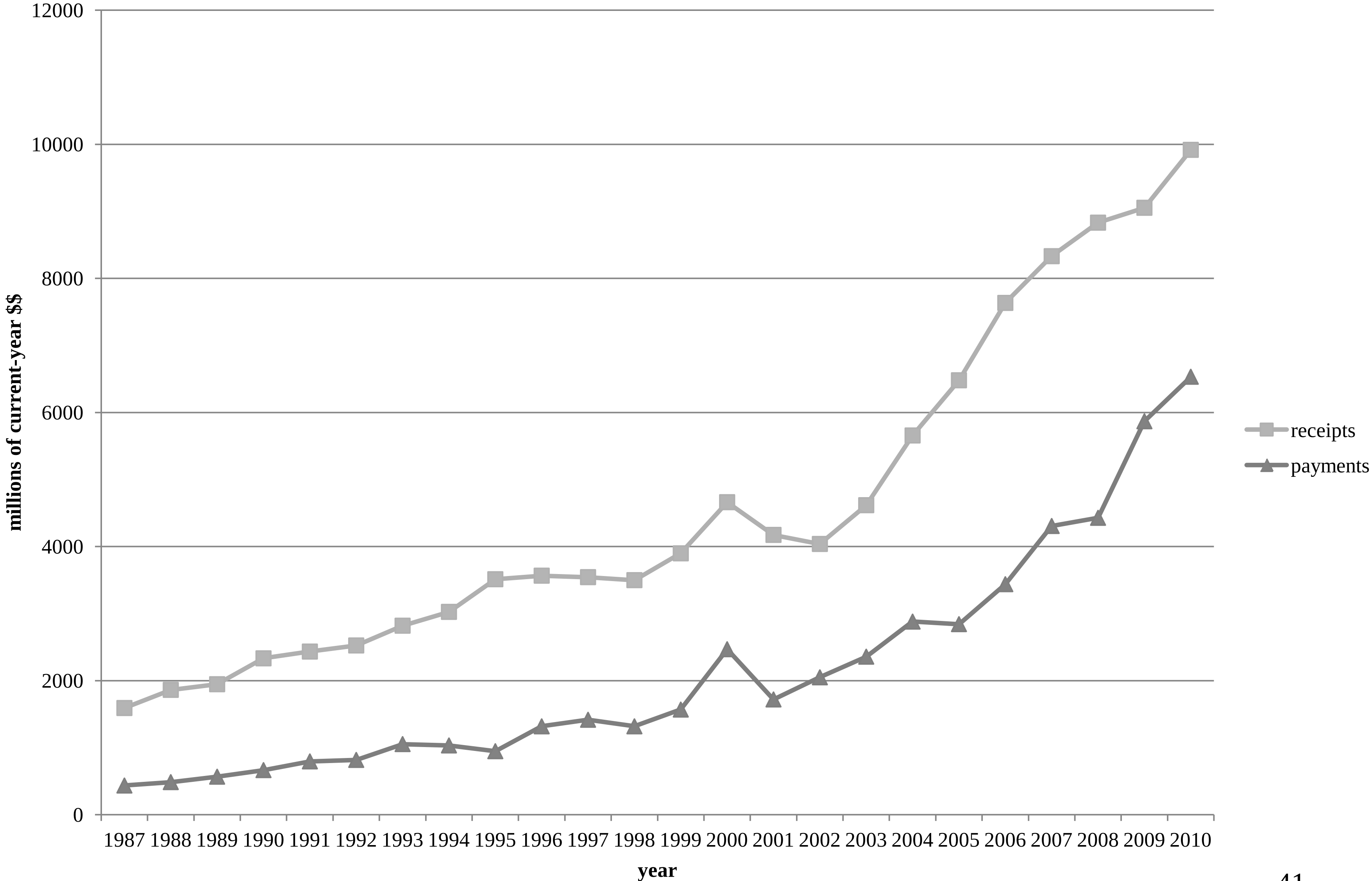
USPTO patents granted, 1982-2010, by residence of 1st inventor



Do stronger IP rights => faster growth in "markets for technology"?

- Growth in "open innovation" => greater reliance on interfirm technology licensing.
- US universities, gov't labs have increased patenting and licensing.
- Data on interfirm licensing activity are incomplete, but suggest that licensing grew at 10-15%/year during late 20th/early 21st centuries.
  - Is this an acceleration or deceleration?

US enterprises' licensing & royalty receipts to/from unaffiliated entities, 1987 - 2010



How does post-1985 structural change vary across OECD economies?

- Scale, composition of US public R&D investment (dominated by biomedical & defense fields) are unique.
  - Mission-oriented R&D in US supported unusual pattern of new-firm commercialization of technologies in semiconductors, other high-tech fields.
- But “pro-patent” IP policy shifts have been widespread among OECD, industrializing economies.
- “Convergence” toward equity-based industrial finance systems varies among OECD economies; gradual at best.

Convergence among national innovation systems?

- Even in an era of "globalization" and significant cross-border flows of capital and technology, key structural indicators for OECD member states display limited convergence during the 1971-2005 period:
  - Little/no convergence for R&D/GDP ratio.
  - Weak evidence of convergence for industry-funded/total R&D investment
- Important elements of "national innovation systems" thus remain nationally unique.
- What mechanisms drive convergence and/or preserve national differences?

Figure 5: R&D/GDP ratios, 1971 - 2005

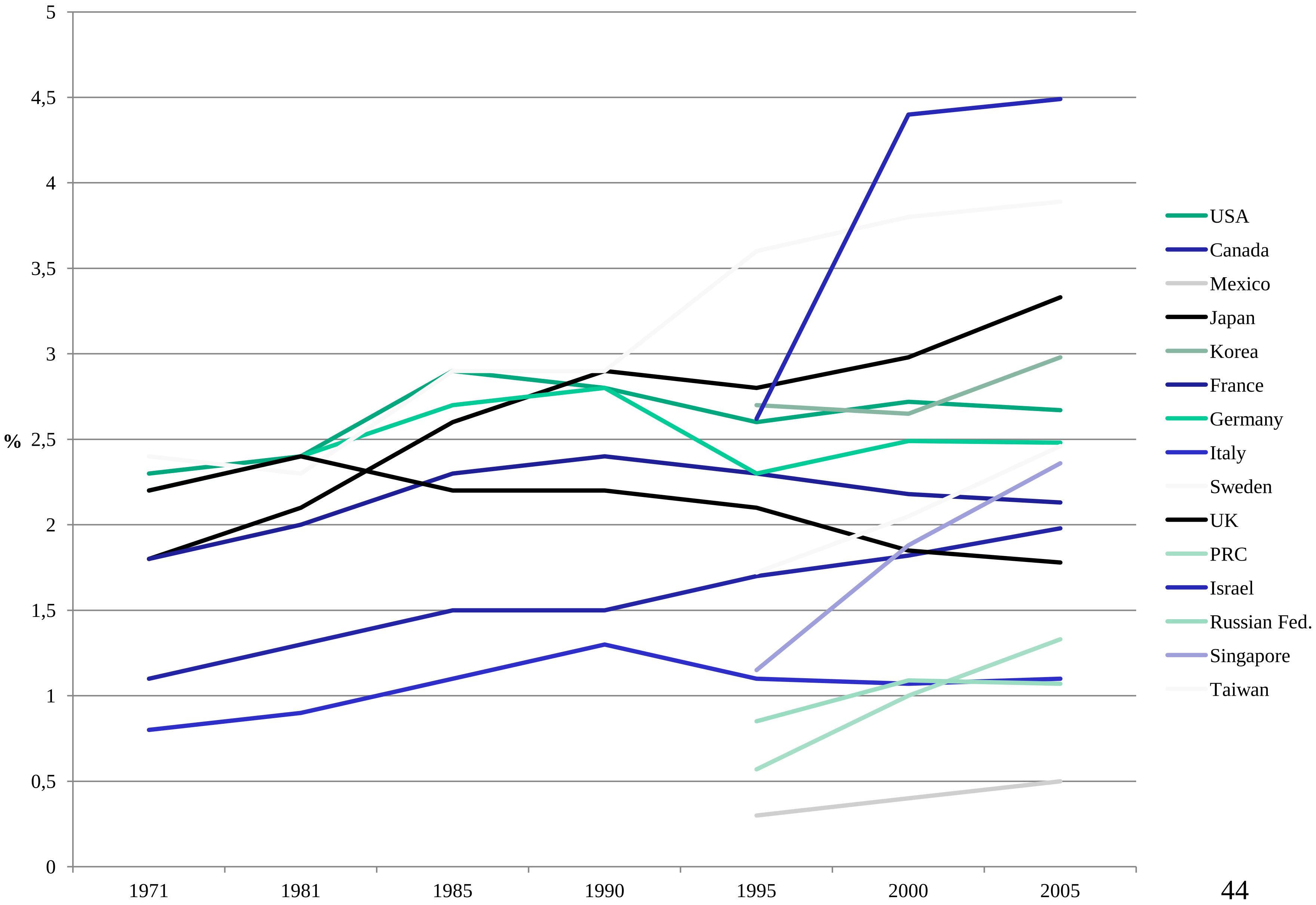
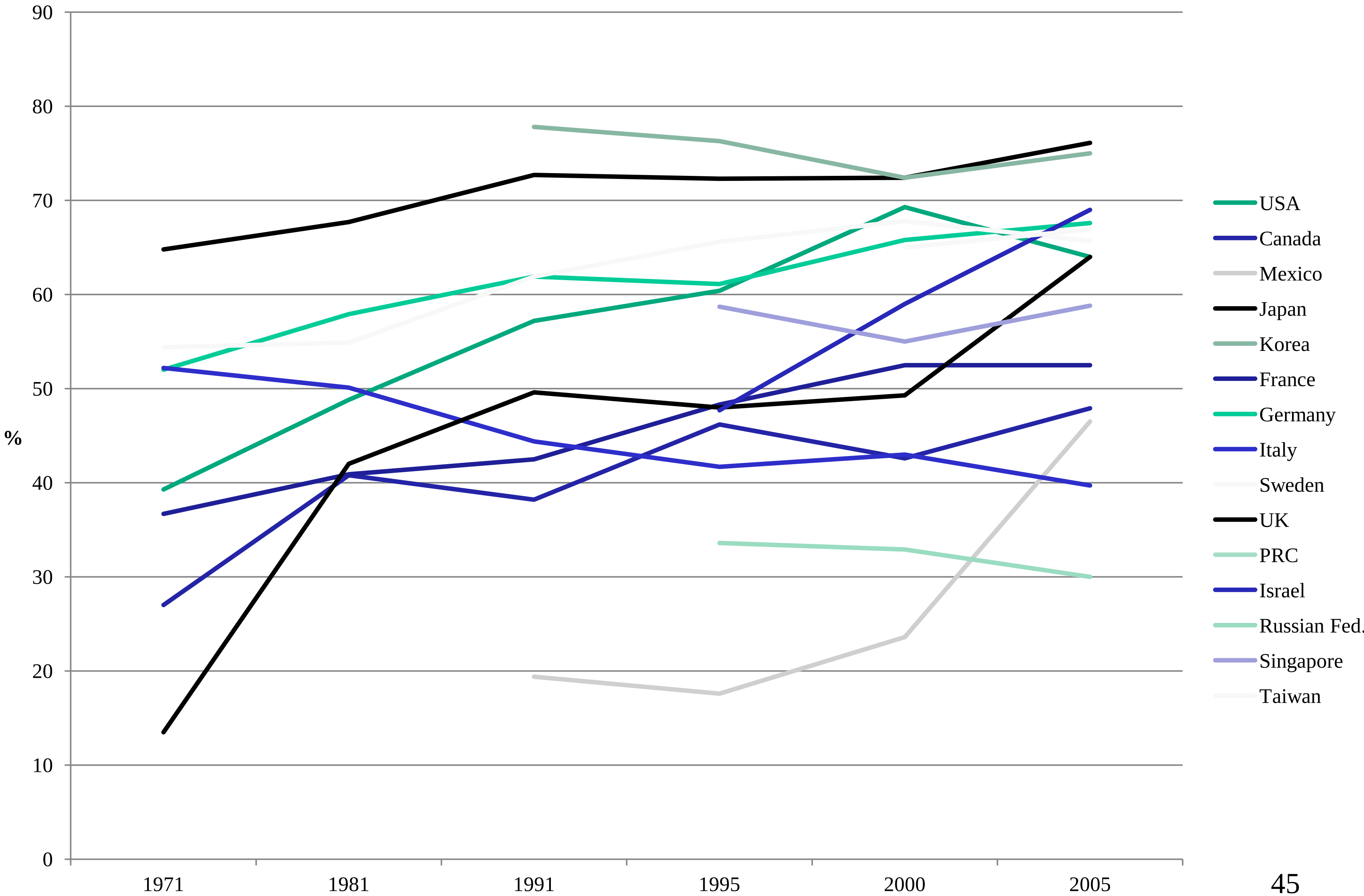


Figure 6: Share of total national R&D financed by industry, 1971 - 2005



Conclusion: What is new & what is old?

- "Open innovation" is not novel, but can be seen in elements of US innovation system of in the early 20th century:
  - Firms' use of internal R&D to exploit external technology sources.
  - "Vertical specialization" in invention, commercialization (independent inventors' "golden age").
  - Judicial deference to patentholder rights.
  - Industry - university collaboration.
- Is the 1945 – 85 period an evolutionary "detour" within the long-term development of US industrial R&D?
- Public policy is an important influence on origins and evolution of US industrial R&D.
  - In US, public policy laid the foundations for IT and biomedical innovations that are widely cited as hallmarks of the "3d Industrial Revolution."

Research issues (partial list)

- Why has the size distribution of R&D performers in US shifted so dramatically? Is this shift unique to US?
- Why do we observe such a modest role for equity-based governance in R&D alliances?
- Why is R&D productivity in pharmaceuticals so abysmal?
- Is open innovation new? Or a return to normal after a 50+-year “deviation”? How can we measure this?
- Huge research agenda in IP:
  - Effects on innovation
  - Effects on international transfer and catchup.
- Convergence in the structure of national innovation systems—how to measure it? What drives it?

QUESTIONS?