Historical Perspectives on National Innovation Systems

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Overview

- Characteristics of the innovation process.
- Three “industrial revolutions”:
  - The British Industrial Revolution (1750-1850)
  - The “second” Industrial Revolution in Germany and the USA (1870-1914)
  - A “third” Industrial Revolution in the USA (1945-2004).
- How has change in the innovation process influenced the role of NSIs and how have NSIs influenced these changes?
- NSIs in economic “catchup.”
- Conclusions and implications.

Characteristics of the innovation process

- Process is rarely one of "scientific breakthrough" leading quickly to commercial application.
  - Instead, complex iteration between knowledge, application.
  - Distinguish between "invention," the initial research advance, and "innovation," the translation of a technical advance into a commercial product.
    - A key distinction in Schumpeter.
    - Inventors frequently are not the innovators.
- Economic importance of "radical breakthroughs" often is overstated.
  - Lengthy period of time required to improve quality, operating costs, "user-friendliness."
  - Incremental improvement is a key source of economic benefit.

Characteristics of innovation (2)

- Characteristics of knowledge influence rate, direction, location of innovation.
  - Knowledge is "sticky" and its transfer is difficult.
  - Knowledge development (in general, but especially in firms or other institutions) is path-dependent and influenced by history.
- Institutions matter.
  - Corporate structure and governance, IPR, labor regulations, competition policy, all are critical influences on innovation and adoption.
- Institutions co-evolve with technologies and one another in a path-dependent fashion.
- Intersectoral technology flows are important.

Characteristics of innovation (3)

- Uncertainty is pervasive.
  - Uncertainty about scientific or technological underpinnings.
  - Uncertainty about markets and demand.
  - Experimentation is important; environments that support exploration of multiple avenues may be more productive sources of innovation.
  - Mechanisms for variety generation and selection (e.g., competition) drive pace and direction of experimentation.
- Users are an important source of innovation in many technology fields.
  - ICT, scientific instruments in the 20th, woodworking or metalworking machinery in the 19th century.
  - Requires sophisticated users and/or technologies that are relatively easy to modify.

Realization of economic benefits of innovation requires its adoption

- Technology adoption typically is a slow process.
- The processes of technology adoption, absorption from external sources are themselves knowledge-intensive activities.
- An innovation undergoes considerable modification during the process of adoption.
- In technologies for which users are important sources of innovation, faster adoption may => more rapid innovation.
  - The Internet in the USA during the 1990s.

The 1st Industrial Revolution: Why NW Europe?

- China, India, & NW Europe in the 15th, 16th centuries were at roughly equivalent levels of development. Why did NW Europe "take off"?
  - Political developments in NW Europe weakened the power of feudal elites, supported overseas expansion, strengthened private property rights.
  - Effects of these changes heightened by technological innovation
  - No similar developments in Asia during this period.
  - Institutional developments are one essential prerequisite.
- 1st Industrial Revolution and its political consequences produced economic divergence between Europe, Asia.
  - Economic divergence => significant disparity in military, economic power and political subjugation.

The 1st Industrial Revolution in Great Britain (1750-1800)

- International technology flows were important to UK.
  - Innovation in British iron industry relied on migration of skilled craftsmen from Continental Europe.
- Although important innovations occurred in steampower and textile machinery, patent records reveal significant increase in overall inventive activity during 1750-1800.
  - Consumer goods; food processing, farm machinery.
- The economic transformation that began in mid-18th century Britain reflected more than technological change.
  - Limited-liability corporations were able to assemble greater capital.
  - New techniques of workforce organization (Josiah Wedgwood) enabled much higher productivity.
  - Investment in canals, roads from public, private sources.
- Infrastructure investment & corporate governance both were influenced by gov't policy.

The innovation process in the 1st Industrial Revolution

- Not a "science-driven" activity.
  - Trial & error, often based on the learning and tinkering of individual craftsmen.
  - Codification of knowhow through manuals for metalworking and woodworking another important influence.
- James Watt and the steam engine.
  - 1st model steam engine appeared in 1691.
  - Newcomen engine (pumping water out of mines) introduced in 1712.
  - Watt's engine, the 1st successful industrial power source that didn't depend on water or wind, introduced in 1775.
    - Lengthy "trial & error" experimentation.
  - Watt depended on a reliable "entrepreneur" partner (Boulton), advanced metalworking technologies (Wilkinson), and intellectual property protection.
  - Adoption was gradual.

A 2nd Industrial Revolution: Germany and the USA, 1880-1914

- New industries (electricity and chemicals) and new leading economies (USA & Germany).
  - Great Britain falls behind in these industries and in overall economic performance, in part because of outmoded institutional framework.
- Science plays a more important role, although much innovation remains “trial & error”-driven.
- The R&D process is formalized and incorporated into corporations of unprecedented size and complexity.
  - Institutional change matters, directly & indirectly.
    - emergence of new German and US corporations is influenced by developments in competition policy, intellectual property rights, and corporate finance.
  - British firms do not undergo a similar restructuring.
- Universities are important sources of research and trained S&Es in both USA, Germany.
  - But USA is not a global leader in science during this period.

US and German chemicals in the 2nd industrial revolution

- Chemicals one of the 1st industries to organize in-house R&D in Germany & USA.
  - DuPont (explosives) in the USA (1902); Bayer (dyestuffs & pharmaceuticals) in Germany (1883).
  - In-house R&D in Bayer developed close links with customers; in-house R&D in DuPont evaluated "external" inventions for possible purchase or licensing.
    - R&D is an important vehicle for DuPont's diversification after 1918.
- German and US chemicals industries pursued different trajectories of development, based on natural resource endowments.
  - Germany: Extensive coal deposits=> focus by firms on coal-tar-based dyestuffs and pharmaceutical "fine chemicals."
  - USA: Development of extensive petroleum deposits=> focus on large-scale production of bulk chemicals, aided by a new discipline, chemical engineering.
    - US chemicals industry and chemical engineering "co-evolve."
- Divergent US & German trajectories persist through 1945.

A 3d Industrial Revolution, 1945-2004

- The state becomes heavily involved as a funder of R&D, purchaser of high-tech products.
  - Military R&D and procurement especially important during 1945-90 (and once again in the USA since 9/11?).
- Science is an important part of the innovation process, although the “linear model” does not dominate.
- USA dominates early development of a number of “new industries,” in which new firms play unprecedented roles in commercializing new products in ICT; semiconductors; biotechnology.
  - Reflects unusual mix of policies spanning military procurement (which often favored new firms); intellectual property protection (which was relatively weak in ICT and semiconductors in the early stages); and very tough competition policy.
- 3d Industrial Revolution also a period of “catch-up” by Asian economies (S. Korea, Taiwan), technology-led reconstruction in Japan.

Innovation in the 3d Industrial Revolution: The Internet

- Originated in R&D supported by US Defense Department in 1960s on computer networking.
  - Networking seen as a valuable technology to enable researchers to exploit limited # of large computers.
  - UK, France also support networking research and innovation.
  - Major innovation in US, TCP/IP "protocol," placed in public domain.
- Unlike UK, France, US defense agencies supported large-scale initial deployment of prototype network.
  - Along with rapid innovation and adoption in desktop computers, network deployment sparks user-led innovation.
- The Internet emerges in the 1990s, as US innovators exploit technical advances from Europe.
  - HTTP, HTML invented at CERN, incorporated into the 1st "browser" by U. of Illinois students in 1994.

How has the innovation process changed over the 1750-2000 period?

- Role of formalized bodies of knowledge (science, engineering) has become more important.
  - But "science base" still is lacking in some areas of high-tech innovation.
  - Greater importance of trained personnel (S&Es) => institutions for formal training of S&Es now are more important.
- Innovation is often more closely linked to economic forces.
  - R&D labs in industry.
  - Startup firms focusing on innovation for profit (markets for IP).
  - "mission-oriented basic research" in many universities, gov't labs.
  - Investment (in R&D, or in plant & equipment) is an important economic influence and one channel through which broader economic policy may affect national innovative performance.
- But sectors still differ considerably in science-dependence, role of formal R&D.

How has the innovation process changed? (2)

- Reflecting increased "formal-knowledge-intensity," as well as other trends, government is a more prominent player in the R&D process today than in 1700s, 1800s.
  - Public funding of R&D in industry, public labs, universities has increased since 1945.
  - Public procurement of knowledge-intensive products in defense, other sectors also has grown.
  - Especially since 1945, formal regulation of many knowledge-intensive sectors (pharmaceuticals) has expanded and influences innovation.
- Higher "formal-knowledge-intensity" of innovation and expansion in international trade since 1945 also => smaller role for domestic natural resource base in national patterns of innovation, performance.
  - E. Asian "catch-up" benefited from indigenous human capital formation and improved access to global natural resources.

The role of NSIs in a changing innovation process

- Industrial, technological leaders shift over time:
  - UK leadership in the 1st Industrial Revolution (1750-1850);
  - US/German leadership in the 2nd Industrial Revolution (1880-1910);
  - US leadership in a 3d Industrial Revolution (1945-1990).
- Reflects (among other things) shift in sources of innovative leadership, comparative advantage.
  - UK: institutional change =>stronger private property rights, which aided UK (and NW Europe generally) in pulling away from India, China..
  - Germany/US: development of national institutions (universities, large, managerially controlled firms) that support the institutionalization of R&D.
  - US: Research leadership in post-1945 era spurred by large-scale public funding, procurement in defense, biomedical research.
  - E. Asia: New institutions (gov't support for specific industries; human capital investment; protection of domestic markets) support inward transfer, improvement, exploitation of industrial technologies from advanced industrial economies.

Dynamics of NSI evolution

- Characteristics of NSI evolution:
  - Considerable intersectoral difference in relevant institutions and their evolution.
  - Change is rarely if ever planned, but instead emerges from complex, co-evolutionary processes.
- Co-evolutionary dynamics:
  - Technological change interacts with industry structure, institutional change.
  - Institutional change influences development of industry, technology.
  - Causal relationships difficult to specify rigorously.
- Examples of failures to adapt:
  - UK in the 19^{th} century transition from "1^{st}" to "2^{nd}" industrial revolution—weak university system, outmoded corp. structure & governance.
  - Japan in the 1990s—corp. governance, gov't macroeconomic policy, public R&D infrastructure, university system all impede a transition from "catch-up" to "frontier" R&D, innovation.

NSIs in the "economic catch-up" process

- Economic "catch-up" has occurred repeatedly:
  - US, Germany in the 19th century.
  - Japan in the late 19th, early 20th centuries.
  - S Korea, Taiwan during the post-1945 period.
  - How will future "catch-up" differ from these episodes?
- Characteristics of the "catch-up" process:
  - Technology absorption, modification, improvement, effective application are important processes.
  - "Followers" often are able to invest more efficiently because the "frontier" is relatively well-defined.
  - Institutional innovation is important (US & German universities; MITI in Japan; ERSO and ITRI in Taiwan).
  - Investment in domestic human capital another theme characterizing German, US, Japanese, E. Asian post-1945 catchup.
  - The processes of technological absorption, improvement are knowledge-intensive, but historically have not required "frontier" scientific knowledge.
  - International flows of people, capital, technology, goods have played a central role.
  - NSI institutions well suited to "catch-up" are not always effective for operating at the scientific frontier.

NSIs and "economic catch-up" (2)

- No single "best practice" path.
- NSIs play an important in inward transfer of technology.
  - Many of the key institutions in NSIs represent an important magnet for return of foreign-educated expatriate S&Es.
- Increasing science-intensity of technology means that the role of NSIs in inward technology transfer, modification, application is likely to become more important.
- But the characteristics of effective high-income NSIs are equally relevant to developing economies.
  - Strength of interinstitutional linkages within an NSI, as well as linkages to foreign sources of knowledge, people, expertise.
  - Breadth of policies that influence their effectiveness.
  - Importance of competition in supporting indigenous demand from industry and elsewhere for innovation.

“Lessons” of history for assessing NSIs

- Interinstitutional linkages remain important throughout the succession of “industrial revolutions.”
  - Linkages operate through collaborative R&D, labor mobility, co-financing.
  - S&E labor markets an important, overlooked dimension of NSI.
- Competition within NSIs among research performers, would-be commercializers of technology enhances performance and heightens pressure for adaptation and change.
  - Especially in public R&D programs, their structure may be at least as important as their scale for performance.
- The importance of institutions => a broad view of “what matters & what doesn’t” in assessing NSIs.
  - Corporate governance & finance, labor markets for S&Es, competition policy, all are at least as important as formal gov’t “R&D policy.”
  - Intersectoral differences are important.
- Technology adoption a key element of NSI performance.
- Adaptive and evaluative capabilities may be as important as planning, “foresight” exercises for policymakers.
  - Uncertainty => sources of change are difficult to predict.

"Lessons" of history (2)

- Emulation of "best practice" from other NSIs is potentially valuable, but must be undertaken with care and caution.
- In the face of uncertainty over direction of technical change, commercialization, the ability of NSIs to support greater diversity (variety generation) is important to performance.
  - Source of scale-related advantage.
- How (if at all) should policy differ between small- and large-country NSIs?
  - Both large- and small-country NSIs benefit from good domestic linkages, as well as strong capabilities in inward transfer.
  - Equally important distinction is between the frontier of S&T vs. catch-up.
  - Small-country NSIs may benefit from developing stronger, more formal linkages with external sources of innovation, R&D.
    - Strategies to benefit from "scale effects" in research, innovation, adoption, competition may require stronger international links.

Conclusions

- Competition and innovation have produced change in the economic & technology leaders (Great Britain; Germany; US; Japan) and laggards.
- The science-technology “interface” has changed over time and has become more complex.
  - Science now more important, but a “linear model” remains inaccurate portrayal of innovation in all but a few sectors.
- The structure of the innovation process itself has changed.
  - Schumpeter: “heroic entrepreneurs” would be replaced by “routinized innovation,” dominated by large firms.
    - This generalization also does not characterize a number of NSIs, technologies.
  - But the nature of the key institutions and actors in the innovation process has changed over the past 250 years.

Conclusions (2)

- Development of NSIs in the 3d Industrial Revolution has been heavily influenced by post-1945 revival of international flows of goods, technology, & capital.
  - An important factor in Asian economies' "catch-up."
  - Also has transformed the "resource base" available to many NSIs.
    - Natural resources now far less important to economic development (Norway, Canada, and Australia may be exceptions), because of robust international trade.
    - Human capital now arguably the most important "endowment" for national innovative and economic performance.
- Will globalization produce "convergence" in the structure of industrial, industrializing nations' NSIs?
  - Convergence in some areas is far more advanced than in others (corporate finance & governance, university systems).
  - Challenges for "catch-up" today differ from those faced by previous "followers."