Economics of Science & Technology Leadership

Jeffrey L. Furman
Boston University & NBER

Chapter 3 in
Leadership in Science and Technology: A Reference Handbook
William Sims Bainbridge, Editor,
Sage Publications

I. Introduction

This chapter examines the economics of science and technology leadership. The chapter takes a broad perspective on economics, considering research in the economics of innovation and productivity as well as macroeconomics, labor economics, and industrial organization, as well as less orthodox areas, including evolutionary economics and political economy, as they relate to innovation. The chapter is based primarily on the research in the economics of science and innovation; however, it draws on work in macroeconomics (on ideas-driven economic growth), as well as work on clustering and agglomeration, national industrial competitive advantage, and even the role of institutions and the perspectives of the national innovation systems literature. The chapter focuses on the inputs and outputs associated with the literature (e.g., business R&D expenditure levels and patenting) rather than the interrelated structure of those institutions and the role of policy-making in structuring them.

After describing research on the role of science and technology in economic leadership, the chapter examines four principal perspectives on the economics of leadership in science and technology (a) ideas-driven economic growth; (b) the 'systems' approach to country-level innovation embodied in the "national innovation systems" literature; (c) perspectives that focus on national industrial competitive advantage, and (d) the national innovative capacity framework. After discussing these economic perspectives on S&T leadership, the chapter notes that the most salient fact about country-level innovative leadership its decline – i.e., that the set of firms that regularly innovate at the global frontier has expanded and that the differences between the most innovative and least innovative of these countries has diminished over time. The chapter concludes with two forms of discussion: First, the concluding discussions the many omitted topics that could have been addressed were the chapter to have been longer. Second, it identifies some limitations of current literature on the economics of S&T leadership and points the way towards some potentially fruitful research topics.

II. The Role of Science & Technology in Economic Leadership

While early economic models of growth focused on the roles of capital, labor, and productivity rather than ideas, the seminal research of Solow and Abramovitz set in motion a literature that has led to the near-universal consensus among academics and policymakers that scientific and technical knowledge play a central role in economic growth and social welfare (Solow, 1956; Abramovitz, 1956). Economic research lagged behind public policy in this regard, as Vannevar Bush laid out the arguments in favor of public support for a scientific and technical infrastructure in his report to President Roosevelt, *Science: The Endless Frontier* (1945), upon the close of the Second World War. Bush. Subsequently, numerous economists, including Nelson (1959) and Arrow (1962), characterized science (and to a lesser extent technology) as a public, non-rivalrous, non-excludable good for which private returns were expected to be lower than overall social returns. Non-rivalrousness refers to the fact that there are essentially zero marginal costs associated with units of that good being transmitted to and consumed by additional actors in the economy, while non-excludability refers to the fact that, inherently, potential users cannot be excluded from employing certain goods for the creation of products or services or for their own consumption. Knowledge is not a *pure* perfect good because may require investments to obtain and apply (which limit, in practice, the extent to which it is non-rivalrous) and because particular forms of knowledge (e.g., those that can be effectively protected via trade secrecy) are characterized by some excludability. As a consequence of the fact that non-rivalrousness and non-excludability lower the expected returns from investments in knowledge creation, markets for science and technology are likely to lead to underinvestment in research and underprovision of scientific outputs – as well as inventions and innovations – relative to the social ideal. Considering the demonstrated importance of knowledge generation and diffusion for economic growth, the public good nature of science and technology goods make a strong case for making knowledge generation and diffusion central goals of public policy.

Although there is now a consensus that supporting science and technology is a key aim of government, at least in the United States, it remains an open question whether the returns to scientific and technical *leadership* actually justify the costs. While extant research makes the case that ideas play a fundamental role in economic growth and that ideas are likely to be underprovided by the market, it remains to be proven whether average (or marginal) rates of return on investments in knowledge generation yield higher rates of return than would investments in knowledge assimilation. Indeed, the fact that scientific and technical knowledge can diffuse (often quite quickly) across countries yields a potential free-riding problem in which fast-follower countries may wish to exploit the more expensive investments in S&T made by leader countries. Thus, an important question is whether ideas are local or global public goods. If they are global public goods, then national governments will have incentives to free-ride on the investments of other nations.

Arguments in favor of scientific and technical leadership depend on increasing returns and local diffusion of knowledge (i.e., the idea that knowledge is a local public good). Specifically, in order for locally-generated knowledge to be translated into scientific and/or technical leadership, researchers in close proximity to an original discovery must be able to exploit that discovery more rapidly and more intensively than more distant researchers. That is, local researchers and firms must be able to take advantage of a discovery more quickly than competitive researchers and firms are able to catch up. There, however, are at least some reasons to believe that investments in scientific and technical leadership may yield high rates of return than investments encouraging fast-follower approaches. Indeed, evidence suggests that investments in science and technology at the world's frontier yield spillovers that are constrained to geographically proximate regions (Jaffe, Trajtenberg, & Henderson, 1993) and that even small barriers to diffusion can explain large differences in productivity levels among the most advanced nations (Eaton & Kortum, 1999). Nonetheless, there is a relative paucity of theoretical and empirical evidence adjudicating whether country-level investments in scientific and technical leadership have higher average and marginal rates of return than investments in diffusion, imitation, and catch-up.

III. Perspectives on the Economics of Science & Technology Leadership[1]

Four principal perspectives inform our understanding of the economics of scientific and technical leadership: (a) ideas-driven endogenous growth theory (Romer, 1990; Aghion and Howitt, 1992); (b) research on national innovation systems (Freeman, 1987; Nelson, 1993; Lundvall, 1992; Edquist, 1997); and (c) cluster and agglomeration-oriented perspectives that

[1] Note that this section builds on Furman, Porter, Stern (2002), Furman and Hayes (2004), and associated papers.

focus on sectoral and industrial competitive advantage (Porter, 1990), and (d) the national innovative capacity framework (Furman, Porter, Stern, 2002, Furman and Hayes, 2004). Each of these perspectives identifies country-specific factors that affect the creation of knowledge and its impact on national economies. Although these perspectives emphasize a number of common elements, each takes a different approach to considering the inputs and outputs associated with science and technology and each highlights distinct drivers of the knowledge-generating process at the national level. Moreover, these perspectives differ in the levels on which their concepts operate and with respect to the drivers they emphasize most highly. For example, endogenous growth theory is developed at a high level of abstraction and is built upon the pillars of an economywide "knowledge stock" and pool of "ideas workers," while the other perspectives emphasize subtle institutions and cross-sector interactions. For example, the national innovation systems literature focuses on sets of national policies and the specific configuration of research-oriented actors in an economy, while the clusters-oriented perspective highlights the particular microeconomic relationships within and across specific industries. The national innovative capacity framework explicitly incorporate many of the elements of the prior three frameworks, with the aim of quantifying the extent of country-level innovation inputs and outputs.

III.A. Ideas-Driven Endogenous Growth

Ideas-driven (or endogenous) growth theory, operates at an aggregate level, emphasizing quantifiable relationships among a fundamental set of drivers that determine the flow of new ideas in a national economy. These models represented a breakthrough in macroeconomics: Although Solow (1956) and Abramovitz (1956) had demonstrated the centrality of technological innovation in economic growth, it was not until in the late 1980s that technological change was treated *endogenously* – i.e., that it was not regarded as a choice variable in models of macroeconomic growth. A number of authors, including Romer (1990) and Aghion and Howitt (1992), developed models based on increasing returns to ideas in which investments in knowledge generation constituted the engines of economic growth. A particularly popular variant, the Romer growth model (1990), articulates the economic foundations for a sustainable rate of technological progress ($\dot{A}$) by introducing an ideas sector for the economy, which operates according the national ideas production function:

(1) $\dot{A}_t = \delta H_{A,t}^{\lambda} A_t^{\phi}$

The implication of this structure is that new ideas are produced as a function of the extent of the ideas-generating workers (H_A) and the available stock of ideas (A_t). The rate of technical change is, thus, endogenous in two different ways: On one hand, the extent to which the economy is devoted to generating new ideas is a function of the R&D labor market, which drives H_A. (In turn, the allocation of resources to the ideas sector – i.e., which determines H_A – depends on R&D productivity and the private economic return to new ideas.) On the other hand, the productivity of new ideas generation depends on the stock of ideas discovered in the past. In the Romer model, $\phi > 0$, implies that the creation of new ideas is *easier* when the stock of ideas is larger and, thus, prior research increases current R&D productivity. This "standing on shoulders" effect is an example of a circumstance in which the stock of knowledge yields increasing returns to the knowledge stock. When $\phi < 0$, the model implies that prior research has discovered the ideas that are easiest to find, thus inhibiting the discovery of subsequent ideas (a negative rather than positive knowledge externality). Rather than standing on the shoulders of prior ideas, the associated metaphor is that of a fishing hole that has been "fished out."

The values of the parameters of these types of models are a matter of active debate (Jones, 1995; Porter and Stern, 2000), as are the particular forms of the model and equilibrium logic that relates the production of knowledge to the extent of economic growth and productivity growth (Grossman and Helpman, 1991; Kortum, 1997). Romer's model of sustainable long-term growth posits proportional returns ($\phi = \lambda = 1$), i.e., that an increase in the stock of ideas results in a proportionally equivalent increase in the productivity of the ideas sector. This assumption implies that the growth rate in ideas is a function of the effort dedicated to ideas production, ($\frac{\dot{A}}{A} = \delta H_A$), which ensures that productivity growth will not be abated by diminishing returns. A less optimistic view is that of Jones (1995), which suggests that ϕ and λ may be less than one, which implies the possibility that long-term productivity growth may not be sustainable. While debates remain about the specific forms and parameters of ideas-driven models of economic and productivity growth, there is broad consensus that the factors emphasized by ideas-driven growth models are, indeed, crucial to explaining the extent of innovation in an economy and the levels of productivity and economic growth (Jones and Romer, 2010)

III.B. National Innovation Systems

Whereas endogenous growth theories operate at a relatively high level of abstraction and describe general principles associated with science and technology leadership, the "national innovation systems" approach (sometimes referred to as the "national systems of innovation" approach, particularly by European authors), focuses on the specific configuration of actors and policies that affect a country's science and technology leadership. This perspective is emerges from a series of articles in the 1980s, particularly those of Chris Freeman (e.g., Freeman, 1987), and is fully articulated in the papers by Nelson, Lundvall, and Freeman in Part V of Dosi, et al., (1988). Important, though often subtle, differences exist among authors within the national innovation systems literature (Schmoch et al, 2006); however, the overall approach involves the identification of the actors, policies, and institutions that play an essential role in affecting the rate and direction of innovative input and output in individual countries (Nelson, 1993, provides an overview of the approach as well as comprehensive, country-by-country analyses; see, also, Dosi, 1988, and Edquist, 1997). The national systems approach can also be usefully applied to understand a nation's scientific inputs and outputs separately from its innovation inputs and outputs (Pavitt, 1998). A separate literature on "national science systems" is less well-developed, however; typically, the national innovation systems literature considers the configuration of institutions and policies affecting science as among the many interrelated factors affecting country-level innovation.

While other economic perspectives on science and technology leadership acknowledge the role of public policies in shaping the rate of innovation (at least to some degree), the national innovation systems literature emphasizes the active role played by government policy and public institutions in shaping the nature of innovation in a national economy. These include the structure, organization, and incentives faced by national university systems (Nelson and Rosenberg, 1994), national policies regarding the commercialization of scientific and technical breakthroughs (Mowery and Sampat, 2005), the extent of intellectual policy protection (Merges and Nelson, 1990), the historical evolution of the organization of industrial R&D (Mowery, 1984) and the nature of R&D-related undertaken by private industry, universities and federal and state agencies (Mowery and Rosenberg, 1998).

In developing its perspective, research on national innovation systems draws on research in economic history and evolutionary economics. With respect to economic history, it builds upon ideas initially articulated to understand the economic development and industrialization of the United States, Europe, and Great Britain and the roles played by resource endowments and geography in the evolution of national institutions and national industries (Rosenberg, 1969; Nelson and Wright, 1992). Consistent with research in evolutionary economics (Nelson and Winter, 1982), the national innovation systems view highlights that processes leading to technical advance involve detailed search efforts, iterative learning, and complex interactions among the actors described above (Lundvall, 1992).

One important feature elucidated by this literature is the substantial heterogeneity across successful innovator countries in the nature of their national innovation systems. For example, the United States innovation system is characterized by substantial government investment in basic research in the life sciences and in technological innovations with military applications; in addition, it provides high incentives for universities to engage in commercially-relevant scientific and technical research. The Federal Republic of Germany provides lesser incentives for university commercialization but supports intermediate institutions, such as the Fraunhofer Society, that conduct applied research based on Federal and state (*Bundesländer*) support and contract research from industry.

This approach's aim of articulating the processes and relationships affecting a country's (or within-country region's or cross-country region's) innovation system requires a broad-based understanding of the relationships among R&D-related actors in that region. As a consequence, much of the research in this perspective is case-based. Indeed, many of the signature publications in this line of research are edited volumes that combine case studies (e.g., Nelson, 1993) to yield broad insights about the configurations of actors and policies that support leading-edge innovation. Thus, there was relatively little quantitative research among the early work in the national innovation systems tradition, a fact which prompted Patel and Pavitt (1994) to issue a call for research dedicated to measuring the characteristics, inputs, and outputs associated with national innovation systems. Responding to this request, some quantitative analyses in the NIS tradition have focused on aspects of national innovation systems, such as particular policies supporting commercialization (e.g., Mowery and Sampat, 2005 and related evaluations of the Bayh-Dole Act). Other recent research has focused on scientific and technical indicators, many of which are staples in research on Scientometrics and others of which appear regularly in national science and engineering indicators (Schmoch et al., 2006). One of the potentially promising, but relatively underexplored aspects of this literature would involve quantifying specific features of national innovation systems and measuring the statistical relationship between those measures and heterogeneity in the nature of scientific and technical outputs.

III.C. Industry clusters and Agglomeration

Whereas the previous two perspectives emphasize macroeconomic factors and national policies and institutions in considering the nature and extent of realized country-level scientific and innovative output, other perspectives highlight the importance of the microeconomic environment of industries and industrial clusters in mediating the relationship between competition, knowledge generation and diffusion, and country-level science and innovation. These views have their origins in important studies such as Rosenberg (1963), which identifies interdependencies between aspects of the microeconomic environment and the realized rate of technological innovation and economic growth and on research on agglomeration that emphasize the local nature of knowledge spillovers (Marshall, 1890). These views generally refer to the extent of innovation in a country and in the country's collection of industries and clusters, rather than the extent of science in that country.

Building on the ideas of Rosenberg, Marshall, and related authors, Porter (1990) developed a framework describing the characteristics of the environment in a nation's industrial clusters that affect its leadership in private sector innovation. This framework categorizes the influences on innovation in a national industry cluster into four areas. One determinant regards the factor conditions associated with innovation in an industrial cluster, principally, the availability of high-quality and specialized innovation inputs. These would include both the availability of a well-trained scientific and engineering workforce and the provision of relevant intermediate inputs, such as lab facilities and infrastructure. In addition to supply considerations, a second driver of cluster-level innovation is the nature of domestic demand for cluster producers and services. Stimulating innovation at the global frontier requires local demand for advanced goods and the presence of a sophisticated, quality-sensitive local customer base. In the absence of demanding customers, there would be little incentive for domestic firms to pursue new-to-the-world technologies; the presence of such sophisticated customers would raise the incentives to develop innovations at the world's technological frontier.

A third determinant of innovation in a nation's industrial clusters regards the nature of the competition in a national cluster, specifically, the extent to which the competitive context is intense and provides rewards for successful innovation. The idea underlying this determinant is that industrial clusters in which firms are exposed to consistent pressure from intense domestic and international rivalry face the highest incentives to invest in and achieve innovation. This relies upon a Red Queen logic in which firms that do not continuously upgrade their innovative capabilities will fail in particularly intense competitive environments. The extent of local rivalry depends, in turn, on policies that are specific to the cluster (e.g., policies regarding the efficacy and safety of national pharmaceutical products) and to country-level policies, such as the openness of the economy to international competition, its extent of anti-trust enforcement, and intellectual property protection. The fourth determinant in the Porter framework regards the extent to which vertically- and horizontally-related industries provide support for innovation in a national industrial cluster. These related industries can generate positive externalities both from knowledge spillovers and cluster-level scale economies, each of which is enhanced when clusters are concentrated geographically. For example, the existence of a vibrant industry supporting funding for new ventures in the United States is perceived as contributing positively to the rate of new start-ups in many industries, including biotechnology and information and communication technologies, which helps ensure that their competitive environments reward investments in innovation.

While the Porter framework is one of the most well-known of the microeconomic approaches to analyzing country-level innovative leadership, complementary accounts of the importance of clusters as well as the interaction between clusters and institutions in leading to national innovative output are described in Niosi (1991), Carlsson and Stankiewicz (1991) and Mowery and Nelson (1999). These accounts often incorporate elements of the systems approach of the national innovation systems literature. Specifically, these accounts often examine the path-dependent evolution of industries and particular interactions of policies and cluster-specific actors in leading certain national industries to be leaders and others to be followers. Overall, these perspectives emphasize that a country's innovation profile can be usefully considered to be a composite of multiple industry- and sector-specific innovation profiles.

Each of the perspectives noting the importance of microeconomic conditions in affecting industry and sectoral innovation outcomes incorporates some degree of recognition of the role of localized knowledge spillovers. For example, the Porterian perspective on national industrial clusters highlights the role of within- and across-industry spillovers in its consideration of factor and demand conditions affecting innovation and in its consideration of the importance of related industries. Rather than focusing on industries or industrial sectors as the microeconomic environment from which national innovation performance arises, perspectives rooted more deeply in economic geography, including Saxenian (1994), focus on the importance of geographic concentrations of industries in driving productivity and innovation in an economy. These ideas note that innovation is more concentrated geographically than economic production or human population (Audretsch and Feldman, 1996). Building on work that demonstrates that knowledge flows disproportionately within geographically proximate areas (Jaffe, Trajtenberg, and Henderson, 1993), this line of research acknowledges that positive externalities from knowledge spillovers and cluster-level scale economies are enhanced when clusters are concentrated geographically. Authors in this line of research often point to innovation-driven successes of regions such as Silicon Valley (in California) and Research Triangle Park (in the Raleigh-Durham area of North Carolina) and some policy-makers have inferred from this literature that one path to regional (and, perhaps, even national) innovative success is to emulate the cluster conditions that lead to such successes. The full range of ideas and policy recommendations associated with geographically-concentrated innovative clusters is too broad to be fully discussed in this chapter, but it is worth noting that the successes of such regions seems far easier to analyze *ex post* than they are to create *ex ante*.

III.D. Country-level ideas production functions and the national innovative capacity framework

Blending insights from each of the three approaches described above, Furman, Porter, and Stern (2002) develop a perspective focused on measuring the potential for each country to achieve frontier levels of commercializable innovation, which they refer to as national innovative capacity.[2] Consistent with models of ideas-driven growth, this framework notes that the ability of a country to generate commercializable innovations depends, fundamentally, on its technical sophistication and labor force; consistent with the national innovation systems and clusters perspectives, the framework also acknowledges the influence on private sector investments, policies, and behaviors and the role of government in setting incentives to engage in R&D and the affecting the overall productivity of national R&D. The framework classifies the factors affecting national innovative capacity into three principal categories: (a) a common pool of institutions, resource commitments, and policies that support innovation, which the authors describe as the *common innovation infrastructure*; (2) the extent to which interrelated national industrial clusters yield an intense orientation towards innovation; and (3) the effectiveness of linkages between the two.

While acknowledging that a country's innovative performance ultimately depends on the investments and organization of individual firms and industrial clusters, the frameworks also recognizes that the ability of firms to innovate successfully depends upon critical investments that support innovation across all segments of an economy. The set of policies and investments that affect all firms in the economy are considered by the framework as the "common innovation

[2] The term "innovative capacity" has been used by a broad range of researchers in literature in economics, geography and innovation policy. For example, Keith Pavitt, employed the term in a manner similar to that in this paper in his broad-based research in innovation policy and economics (see, e.g., Pavitt, 1980). Suarez-Villa (1990, 1993) applies the concept within the geography literature, emphasizing the linkage between invention and innovation. Neely and Hii (1998) provide a detailed discussion of the origins and definition of innovative capacity in the academic literature.

infrastructure." Drawing on ideas-driven models growth models, the frameworks suggests that the ability of the common innovation infrastructure to contribute to overall national innovation depends on a country's accumulated knowledge stock (which could be proxied by a number of measures, including GDP per capita) and upon the scope of the workforce dedicated to the production of science and technology (which could be measured via counts of scientists and engineers). In addition, a nation's common innovation infrastructure depends on national investments and policy choices, represented by expenditures on higher education, the nature of intellectual property protection and anti-trust enforcement, and openness to international competition, each of which can have a broad-ranging impact on innovative activity throughout a country's economy.

Within the context of the overall conditions for innovation established by the common innovation infrastructure, individual firms and groups of firms in industry and geographically-proximate clusters make the investments and organizational choices that develop and commercialize innovation. The national innovative capacity framework, thus, also acknowledges the importance of the extent to which a nation's firms compete on the basis of science and innovation. It does so by drawing on the Porterian "diamond" framework of national industrial competitive advantage, which is one of the cluster-based approaches to thinking about national technological leadership described above. Thus, the national innovative capacity framework suggests that four features of the microeconomic environment fundamentally influence the rate of innovation in a given national industrial cluster: factor conditions that ensure the availability of specialized, high-quality inputs; inducements for innovation derived from sophisticated local demand; an intense local competitive environment that encourages innovation-oriented investment; and the presence of sets of related industries whose outputs usefully support innovative investments.

The third element of the national innovative capacity framework acknowledges that the extent to which the potential for innovation provided by the common innovation infrastructure can be rendered into commercialized innovations by firms in national industrial clusters depends upon the effectiveness with which these areas are linked. In the absence of successful mechanisms linking a nation's common innovation infrastructure with firms in its industrial clusters, the resources for and outputs of the common innovation infrastructure may end up being exploited more effectively by firms in other countries than by domestic firms. As an example of this, Furman and co-authors cite the case of the chemical dye industry. Though generated by the insights of the English chemist William Henry Perkin, the chemical dye industry developed more quickly and more successfully in Germany, in large part as a result of that country's more effective university-industry interactions and greater availability of capital for technology-intensive ventures (Murmann, 2003). Consistent with this story, researchers in the national innovative capacity tradition often use measures of the availability of venture funding and indicators of university-industry interaction or university involvement in commercializing technology as indicators of thee strength of linkages between the common innovation infrastructure and national industrial clusters.

Although the national innovative capacity framework does include a conceptual component, its most novel contributions to the study of the economics of scientific and technical leadership are empirical. Specifically, a chief goal of the conceptual framework is to guide empirical exploration into the drivers of country-level differences in innovation productivity. Employing a panel dataset of 17 OECD countries over 20 years, Furman, Porter, Stern (2002) investigate the relationship between patenting by foreign countries in United States (international patenting) and variables associated with the national innovative capacity framework. The authors use patents not as direct measures of innovation output, but as indicators that are correlated with the overall potential for innovation in a country. Although it is important to acknowledge the limitations associated with using patent data, the results suggest that the production function for international patents can be effectively characterized by a small but nuanced set of observables associated with their conceptual framework. Specifically, the authors find that a substantial fraction of cross-country variation in innovation derives from differences in factors associated with the common innovation infrastructure (e.g., the extent of R&D human capital and the stock of knowledge in the economy, and policy choices such as the extent of IP protection and the average degree of openness to international trade), with factors associated with the strength of a nation's industrial clusters (e.g., the degree of technological specialization in a country), and the strength of linkages across these two elements (e.g., the share of research performed by the academic sector and funded by the private sector). Further, the authors find that national innovative capacity influences downstream commercialization, such as achieving a high market share of high-technology export markets and is related to economic indicators of broader interest, including the extent of science in an economy, a country's total factor productivity, economic growth. It seems as if this, the provision of a useful empirical framework in which to consider a factors affecting country-level outputs of new-to-the-world technology, is the most valuable contribution of the national innovative capacity framework to the study of innovative leadership.

IV. Catch-Up

IV.A. Perspectives on Catch-Up

While the economic determinants of scientific and technological leadership are important in their own right, they are also of importance for thinking about the ability of countries behind the world's frontier to catch-up. This question is of particular importance as technological catch-up may be a pre-cursor (or just a correlate) to improving the overall social welfare of developing countries.

Veblen (1915) and Gerschenkron (1962) are among the first and most prominent authors to consider whether laggard countries' wealth and technological progress increase at a higher rate than that of leader countries; each did so by considering the influence of national institutions on industrial innovation. Veblen (1915) compared countries' relative economic standing and identified penalties associated with initial industrial disadvantages. Gerschenkron (1962) built upon these ideas by suggesting that later-industrializing countries may be to leapfrog leader countries by adopting leading technologies and developing institutions that deal with contemporaneous challenges more effectively than those developed in previous periods.

Approaches to catch-up in technical innovation involve both institutional and evolutionary arguments and formal economic modeling.

Institutional traditions reject strict simplifying assumptions about technology and focuses on more fine-grained factors that affect the rate and direction of technical change, while approaches rooted in economic modeling generally abstract away from such characteristics and employ simplifying assumptions about the nature of technology. Consistent with a view of technology as non-rivalrous and non-excludable, early neoclassical growth models assumed technology to be communicated costlessly across countries, leaving only "transitional dynamics" and difficulties associated with capital mobility (Fagerberg, 1994, p. 1149) to explain differences in innovative performance across countries,. Although some models in the 1960s incorporate learning-by-doing into formal models, the importance of a country's stock of knowledge and the parameters affecting the mobility of knowledge across borders are not fully incorporated in economic models until the work on ideas-driven growth in the 1990s. In these models, the ability to apply existing technology and generate new innovations differs systematically across economies and convergence in economic wealth is not inevitable. Complementing models, an extensive empirical literature assesses the extent of economic convergence among sets of countries and various periods of time (see, e.g., Barro and Sala-i-Martin, 1992, and Baumol, 1986).

Building upon, though often contrasting, formal models and large scale empirical analysis of convergence in economic performance, innovation studies scholars and economic historians have developed a perspective on the role of technology in economic advance in which a more nuanced understanding of innovation is central. Fagerberg (1994) describes this perspective the "technology gap" approach. Specifically, he notes that this view (including Rosenberg, 1969; Nelson and Winter, 1982; and Nelson and Wright; 1992) emphasize that the creation and application of innovation are sufficiently embedded in particular firms, clusters, and economic institutions that innovations diffuses with lags and difficulties across economic actors and distances. Thus, the ability of laggard nations to achieve convergence with leader nations depends on scientific and technological investments as well as the development of additional institutions for catch-up. Consistent with the argument that specific investments in innovative capabilities are essential for assimilating new-to-the-country innovation, Abramovitz (1986) proposes that countries whose economic environments more closely match that of the leader country will have better "technological congruence" and will, thus, be more successful in incorporating advances made elsewhere. For related reasons, Bell and Pavitt (1993) argue that investments in innovative capacity are essential for catch-up in developing countries, as investments in production equipment alone are insufficient for incorporating technical advances made elsewhere.

IV.B. Evidence regarding catch-up

In the early 1980s, British economist Keith Pavitt called attention to his country's need to make substantial investments in its innovative capacity in order to avoid the dimming of its prospects for economic growth (Pavitt, 1980). Since that time, his country has increased R&D expenditures and international patenting (patents granted by the USPTO) by approximately 30 percent each. During the same period, Ireland increased its count of R&D personnel by nearly tenfold and more than tripled its international patenting. Not surprisingly, while England's innovative performance and economic prospects improved by modest amounts during this time, Ireland's performance on similar metrics improved substantially. This comparison is emblematic of the two most salient facts regarding national innovative capacity during the past three decades: First, differences in relative innovative productivity among the most innovative national economies have declined. Second, the world has experienced an expansion in the set of countries consistently producing innovations at the global frontier (Furman and Hayes, 2004; Hayes, 2010).

The first fact regards convergence in innovative productivity among the set of nations that regularly innovate at the global frontier. While historical leaders in country-level innovation, such as the United States, Germany, and Japan, have persisted in increasing their investments in innovation, other historically innovative economics have ratcheted up their investments in innovation to an even greater degree. As a consequence, the gap in innovative productivity between the world most innovative economies and other innovator countries persists but has shrunk relative to its levels in the first three-quarters of the 20th century.

The second fact notes that the set of countries that generate innovations at the global frontier has expanded as a set of previously industrializing countries have sufficiently increased their commitments to innovation that they have begun to generate frontier-level innovations with regularity. These countries include a set of recently-industrialized economies that had been primarily imitators (and consumers) of innovations at the world's technological frontier. Ireland, Israel, Singapore, South Korea, Taiwan are among the nations that have achieved remarkable increases in innovative output per capita, suggesting that their innovative capacities have overtaken those of some countries whose economic conditions were more favorable as recently as the 1980s.

Furman and Hayes (2004) document both forms of catch-up – i.e., convergence among the world's most innovative nations and entrants by prior imitator countries into the set of innovator countries. Hu and Mathews (2005) focus to a greater degree on emerging East Asian economies, including Korea, Hong Kong, Singapore, China, and Taiwan. Specifically, they examine how these five countries may differ in the factors that affect innovative productivity in these countries relative to historically industrialized economies outside of Asia. These authors note that while the core findings of prior work apply to the East Asia context, these countries differ in the sense that specialization (industrial concentration) and public R&D funding have a tighter association with international patenting than is the case outside of Asia. In recent research, including Fagerberg and Srholec (2008), variations of the national innovative capacity framework are emerging that retain the perpective's emphasis on linking country-level concepts associated with innovation with country-level measures of innovation-oriented policies and innovation inputs and outputs. Specifically, Fagerberg and Srholec (2008) innovate by postulating four different types of national "capabilities" based on a factor analysis of numerous country-level innovation measures – these include the development of a country's *innovation system*, (b) the effectiveness of *governance* in the country, (c) the nature of the national *political system* and (d) the degree of *openness* of the economy.

V. Discussion

This chapter has introduced a number of perspectives on the economics of science and technology leadership. The discussion has focused disproportionately on the economics of technology (rather than science) leadership since a greater amount of work has been done in this area. By focusing on overarching perspectives, the chapter has neglected a number of important topics that are acknowledged to be of great importance to overall science and technology leadership and that are studied to varying degrees. There are at least four topics that are worth substantial additional consideration: (a) the role of human capital in science and technology leadership, including the importance of training, immigration, and diaspora effects (e.g., Freeman, 2010; Kerr and Lincoln, 2011; and Agrawal et al., 2011); (b) the role of intellectual property policy (e.g., Merges and Nelson, 1990; Moser and Rhode, 2011), which may affect scientific and leadership and catch-up among imitator countries; (c) the role of anti-trust policy in innovative leadership (Aghion et al., 2001); (d) university-industry technology transfer (e.g., Mowery and Sampat, 2005); and the role of institutions in affecting scientific and technical output (e.g., Furman, Murray, Stern, 2010).

Although important progress has been made in studying the economics of science and technology leadership, vast ranges of topics remain ripe for analysis. For example, despite the empirical advances of the national innovative capacity framework, relatively little is understood about drivers of country-level innovation inputs. Indeed, one substantial omission of the national innovative capacity framework is the fact that the drivers of inputs and outputs are endogenously determined; thus, extant analysis can offer only limited prescriptions for public policy as it cannot isolate the causal influence of various policies and national investments on innovative outputs. As well, empirical research has focused on understanding differences in aggregate innovative outputs rather explicating the dispersion of innovative inputs and outputs across country's economic sectors. Vast case research is dedicated to describing the path-dependent histories of various national industries; however, this research considers only a partial equilibrium (i.e., the inputs and outputs associated with specific countries and industries). More wide-ranging approaches to the economics of S&T leadership could consider these choices in a general equilibrium framework (i.e., considering the incentives and outcomes associated with the full set of country-level decisions regarding innovative inputs and outputs). Moreover, by taking advances in econometric techniques in the policy evaluation research (Imbens and Wooldridge, 2009), it should be possible to evaluate and make recommendations regarding policies affecting science and technology leadership.

References

Abramovitz ,Moses (1956) "Resource and Output Trends in the United States Since 1870," *American Economic Review*, 46, 5-23.

Abramovitz, M. (1986) "Catching Up, Forging Ahead and Falling Behind," *Journal of Economic History*, 46, 385-406.

Aghion, Philippe and Peter Howitt (1992) "A Model of Growth Through Creative Destruction," *Econometrica*, 60(2): 323-351.

Aghion, Philippe, Christopher Harris, Peter Howitt, John Vickers (2001) "Competition, Imitation and Growth with Step-by-Step Innovation," *Review of Economic Studies*, 68(3), 467–492.

Ajay Agrawal, Devesh Kapur, John McHalec, and Alexander Oettl, "Brain drain or brain bank? The impact of skilled emigration on poor-country innovation," *Journal of Urban Economics*, 69(1), 43-55.

Audretsch, David B. and Maryann P. Feldman (1996) "R&D Spillovers and the Geography of Innovation and Production," *American Economic Review*, 630-640.

Barro, R. and X. Sala-i-Martin (1992) "Convergence," *Journal of Political Economy*, 100(2), 223-251.

Baumol, W. (1986) "Productivity Growth, Convergence, and Welfare: What the Long-Run Data Show," American Economic Review, 76(5), 1072-1085.

Bell, M. and K. Pavitt (1993), "Technological accumulation and industrial growth: contrasts between developed and developing countries," *Industrial and Corporate Change*, 2, 157-210.

Bush, Vannevar (1945) *Science: The Endless Frontier*. Washington, DC: United States Government Printing Office.

Dosi, Giovanni, ed. (1988) Technical Change and Economic Theory. London (UK): Pinter Publishers.

Eaton, J. and S. Kortum (1999) "International Technology Diffusion: Theory and Measurement," *International Economic Review*, 40(3), 537-70

Edquist, Charles, ed. (1997) *Systems of Innovation: Technologies, Institutions and Organizations*. London, UK: Pinter/Cassell Academic.

Freeman, Chris (1987), *Technology policy and economic performance*, Pinter: London, UK.

Freeman, Richard B. (2011) "Does globalization of the scientific/engineering workforce threaten U.S. economic leadership?" NBER Working Paper #11457.

Furman, Jeffrey L. and Richard Hayes (2004) "Catching up or standing still? National innovative productivity among 'follower' countries, 1978-1999," *Research Policy*, 33, 1329-1354.

Furman, Jeffrey L., Michael E. Porter, and Scott Stern (2002) "The Determinants of National Innovative Capacity," *Research Policy*, 31, 899-933.

Furman, Jeffrey L., Fiona Murray, and Scott Stern (2010) "More for the research dollar," *Nature*, 468, 757–758.

Gerschenkron, Alexander (1962) *Economic Backwardness in Historical Perspective*. Cambridge, MA: Belknap Press of Harvard University Press.

Hayes, Richard (2010) "Convergence in national innovation intensity," working paper, University of Melbourne.

Hu, Mei-Chih and John A. Mathews (2005) “National innovative capacity in East Asia,” *Research Policy*, 34(9), 1322-1349.

Imbens, Guido W. and Wooldridge, Jeffrey M. (2009) “Recent Developments in the Econometrics of Program Evaluation,” *Journal of Economic Literature*, 47(1), 5-86.

Jaffe, Adam, Manuel Trajtenberg, and Rebecca M. Henderson (1993) “Geographic Localization of Knowledge Spillovers as Evidenced by Patent Citations,” *Quarterly Journal of Economics*, 108(3), 577-598.

Jones, Charles I. and Paul Romer (2010) “The New Kaldor Facts: Ideas, Institutions, Population, and Human Capital,” *American Economic Journal: Macroeconomics* 2(1), 224–245.

Kerr, William R., and William F. Lincoln (2010) “The Supply Side of Innovation: H-1B Visa Reforms and U.S. Ethnic Invention,” *Journal of Labor Economics* 28(3), 473-508.

Lundvall, Bengt.-Ake, ed. (1992) *National Systems of Innovation: Towards a Theory of Innovation and Interactive Learning*. London, UK: Pinter.

Marshall, Alfred (1890) *Principles in Economics*. Macmillan: London, UK.

Merges, Robert P. and Richard R. Nelson, R. (1990) “On the complex economics of patent scope,” *Columbia Law Review* 90, 839–916.

Moser, Petra and Paul Rhode (2011) “Did plant patents create the American rose?” Stanford University working paper.

Mowery, David C. (1984) “Firm structure, government policy, and the organization of industrial research: Great Britain and the United States, 1900–1950,” *Business History Review* 58, 504–531.

Mowery, David C. and Bhaven N. Sampat (2005), “The Bayh-Dole Act of 1980 and University–Industry Technology Transfer: A Model for Other OECD Governments?” *The Journal of Technology Transfer*, 30, 115-127.

Mowery, David C. and Nathan Rosenberg, ed. (1998) *Paths to Innovation*. Cambridge University Press: Cambridge, MA.

Mowery, David C. and Richard R. Nelson, ed. (1999) *Sources of Industrial Leadership: Studies of Seven Industries*. Cambridge University Press: Cambridge, MA.

Murmann, J. P. (2003) *Knowledge and Competitive Advantage The Coevolution of Firms, Technology, and National Institutions* . Cambridge University Press.

Neely, Andy and Jasper Hii (1998). “Innovation and Business Performance: A Literature Review,” working paper, Judge Institute of Management Studies, University of Cambridge.

Nelson, Richard R. (1959) “The Simple Economics of Basic Scientific Research,” *Journal of Political Economy*, 67, 297-306.

Nelson, Richard R., ed. (1993) *National Innovation Systems: A Comparative Analysis*. New York (NY): Oxford University Press.

Nelson Richard R. and Gavin Wright (1992) “The Rise and Fall of American Technological Leadership: The Postwar Era in Historical Perspective,” *Journal of Economic Literature* 30 (4), 1931-64.

Nelson, Richard. R. and Sidney Winter (1982) *An Evolutionary Theory of Economic Change.* Cambridge, MA: Harvard University Press.

Pavitt, K. (1980) “Industrial R&D and the British Economic Problem,” *R&D Management*, 10, 149.

Pavitt, Keith (1998) "The social shaping of the national science base," *Research Policy*, 27 (8) 793-805.

Romer, Paul (1990) "Endogenous Technological Change," *Journal of Political Economy*, 98, S71-S102.

Rosenberg, Nathan (1969) *The American System of Manufactures*. Edinburgh University Press: Edinburgh, UK.

Saxenian, Annalee (1994) *Regional Advantage: Culture and Competition in Silicon Valley and Route 128.* Harvard University Press: Cambridge, MA.

Schmoch, Ulrich Christian Rammer, and Harald Legler, eds. (2006) *National Systems of Innovation in Comparison: Structure and Performance Indicators for Knowledge Societies*. Springer: Dordrecht, NL.

Solow, Robert M. (1956) "A Contribution to the Theory of Economic Growth," *Quarterly Journal of Economics*, 70, 65-94.