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Catching up or standing still? National innovative productivity among 'follower' countries, 1978–1999

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Abstract

Over the final two decades of the 20th century, a number of formerly industrializing economies and historical imitator countries achieved levels of innovative capacity commensurate with or greater than those of some economies that were historically more innovative. We investigate the factors that enabled such *emerging innovator* economies to achieve successful catch-up while some historically more innovative countries experienced relative declines in innovative productivity. We focus our analysis on the estimation of a production function for innovations at the world's technical frontier. Based on the results of this analysis, we classify countries into categories reflecting their historical levels of innovative capacities and develop counterfactual indices that identify the factors that correspond to long-run improvements in innovative roductivity. These exercises suggest that the development of innovation-enhancing policies and infrastructures are necessary for achieving innovative leadership, but that these are insufficient unless coupled with ever-increasing financial and human capital investments in innovation.

Keywords: R&D productivity; Technology catch-up; National innovative capacity; National innovation systems; Patents

1. Introduction

Examining the state of British industrial performance in 1980, Keith Pavitt cautioned that unless the nation made substantial improvements in its innovative capacity, both through additional industrial R&D and improved linkages between R&D and product development, its prospects for long-run economic growth would dim (Pavitt, 1980). This sentiment resonates with those of economists and policymakers, who have focused increasing attention in the years since World War II on the centrality of scientific and technological advance in driving economic progress and who have argued that increasing national investments to

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innovation are essential to ensure countries' economic growth (Schumpeter, 1942; Bush, 1945; Solow, 1956; Abramovitz, 1956; Romer, 1990; Jones, 1995).

In the near quarter-century since Pavitt's initial appeal, Great Britain has made investments in its innovative capacity; its level of R&D expenditures and its realized level of USPTO patenting have increased by approximately 30% each. At the same time, neighboring Ireland, whose standard of living in the early 1980s was substantially lower than Britain's, has vastly increased its economic and policy commitments to innovation, boosting its count of R&D personnel nearly tenfold and achieving a 350% increase in USPTO patents, thus achieving a rate of per capita patenting comparable with that of a number of the more innovative countries in the world. The experience of these countries is illustrative of two striking facts about country-level innovative output over the last few decades.

First, among the set of countries that have historically generated significant numbers of innovations at the world's technological frontier, the difference in the relative innovative productivity of the most innovative countries and other innovative countries has declined. While the world's leading innovator economies, including the United States, Switzerland, and Japan, have continued to increase investments in innovative capacity, other members of the group of innovator countries have increased their commitments to innovation at an even greater rate. Thus, although the absolute gap in innovative productivity between the world's most innovative economies and other innovator countries remains, this gap is relatively smaller at the end of the 20th century than it was 20 years before.

Second, the set of countries that generate numerous new-to-the-world innovations has expanded over the past quarter-century, as a number of formerly industrializing countries have sufficiently increased their levels of innovative productivity to begin introducing new-to-the-world innovations with regularity. These countries include a number of late industrializing countries 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.

The fact that some countries have increased their innovative capacities so substantially while others have not presents a puzzle for the study of national systems of innovation (Freeman, 1987; Dosi, 1988; Lundvall, 1992; Nelson, 1993), a literature which does not issue strong predictions about the emergence of innovative leaders among former follower countries. In this paper, we investigate developments in national innovative capacities, focusing on the country-level investments, institutional configurations, and national policy decisions that shape the success of follower nations in catching up to the world's leading innovator countries in terms of per capita innovative output. By studying the emergence of innovative capacity in former industrializing and imitator countries and examining the relative leveling of investments in innovation in some historical innovator countries, we build directly on set of issues central to Keith Pavitt's work (Pavitt, 1979, 1980; Patel and Pavitt, 1987, 1989; Bell and Pavitt, 1992, 1993). Further, in adopting an approach that focuses on statistical analysis, we contribute to research that addresses Patel and Pavitt's (1994) appeal for quantitative analysis clarifying the properties of national innovation systems.

We base our analysis on the conceptual framework for understanding national innovative capacity outlined in Furman et al. (2002), which builds in particular on literature in macroeconomic growth (Romer, 1990), national industrial competitive advantage (Porter, 1990) and national innovation systems (Nelson, 1993).[1] The core of our empirical analysis involves the estimation of a production function for economically significant technological innovations. The framework on which we based our estimation suggests that an economy's innovative productivity depends on (a) investments in

[1] We employ the term "innovative capacity" to describe a country's potential – as both an economic and political entity – to produce a stream of commercially relevant innovations. The term "innovative capacity" has been used by a broad range of researchers in literature in economics, geography and innovation policy. For example, Pavitt (1980), employed the term in a manner similar to that in this paper in his broad-based research in innovation policy and economics. 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. The framework presented here builds directly on research reported in Porter and Stern (1999) and Furman et al. (2002) and the references cited therein.

broadly available resources for innovation, which we refer to as the common innovation infrastructure, (b) the environment for innovation in its industrial clusters, and (c) linkages between these components.

To evaluate this empirically, we employ a panel dataset of 23 countries between 1978 and 1999. Consistent with prior research, these regressions show a tight fit between predictors of national innovative capacity and economically significant innovations. These models also bear out the striking result that a number of former follower countries are becoming increasingly productive in their innovative output. To more fully explore the factors driving this phenomenon, we categorize countries into four groups based on historical patterns in their levels of innovative capacity: (1) leading innovator countries; (2) middle tier innovator countries; (3) third tier innovator countries; and (4) emerging innovator countries. Over the course of the sample, the leading innovator countries have the highest levels of innovative capacity, followed by the middle tier countries, and the third tier countries. Average innovative capacity in emerging innovator grows substantially over the course of the sample, from levels slightly higher than those of third tier innovators to levels that exceed those of the average middle tier economies. Although not quite catching up to the world's most innovative countries, emerging innovator countries as a group do surpass a number of countries whose historical levels of wealth and innovation had vastly exceeded their own.

The improvements in national innovative capacity in emerging innovator countries do not arise from any single factor alone but rather from increased investment and commitment across a number of the drivers of national innovative capacity. Moreover, emerging innovator countries differ from each other with respect to their geographic region of origin and their national systems of innovation. Just as alternative institutional arrangements can support continuous innovation, there appears to be no single dictate prescribing the ideal institutional configuration necessary for catch-up in innovative productivity and output.

Commonality does, however, exist across emerging innovator countries: They exhibit ever-deepening investments in the drivers of national innovative capacity, both by committing to innovation-enhancing policies and investing in physical and human capital. We examine the drivers of catch-up more precisely by creating indices that decompose a country's commitments to innovative capacity into components associated with (a) its policies and infrastructure and (b) its investments in innovation. This descriptive counterfactual exercise exposes critical differences between groups of innovator countries. It demonstrates that leading innovator countries, middle tier innovator countries, and emerging innovator countries have committed in relatively similar ways to innovation-enhancing policies. Middle tier innovator countries and emerging innovators are, however, distinguished by the extent to which each has increased investments in R&D and human capital. By contrast, third tier innovator countries have neither substantially increased their investments in R&D expenditures and human capital nor have they increased their commitments to innovation-enhancing policies. We explore both the public policy and theoretical implications of these results in greater detail in our discussion.

The remainder of the paper is structured as follows: Section 2 reviews the historical background for this study and discusses prior research on catch-up and the determinants of national innovative productivity. Section 3 introduces the conceptual framework that drives our analysis. Section 4 outlines our empirical approach. Our empirical results appear in Section 5. Section 6 concludes, discussing the findings of the paper in greater generality.

2. Leadership and catch-up in national innovative productivity

2.1. Historical background

In the years since World War II, the set of countries contributing regularly to innovation at the world's technological frontier has expanded, raising a number of questions for conceptual and empirical study. The "economic miracles" of post-war Germany and Japan involved vast improvements in physical and human capital and culminated in the 1970s and 1980s with remarkable increases in innovative productivity. It is curious that, despite the destruction of their economies in the wake of World War II, Germany and Japan accomplished such leaps in national innovative productivity while countries such as England and France did not. Although the United States played a critical role in rebuilding innovative capabilities in Germany and Japan in the years after World War II, their most significant gains in innovative capacity occurred in the 1970s and 1980s, when national choices rather than US edicts drove commitments to innovation.

This experience recurs in a different form in the final two decades of the 20th century, as a set of countries nearly joins the group of elite innovator countries although their economic and political circumstances at the start of the 1980s are similar to or less favorable than a set of countries whose innovative productivity does not increase substantially over this period. These emerging innovators do not appear to have the same historical advantages that benefited Germany and Japan. For example, emerging innovator countries such as South Korea, Singapore, Ireland, and Finland, were not rebuilding shattered economies that had historical legacies of innovative leadership. Instead, these countries developed imitator economies and transformed them into innovative leaders by systematically and continuously increasing their commitments to innovation over time.

We focus our empirical analysis in this paper on this most recent time period, from 1979 to 1999, for which international data availability enables statistical analysis on the country-level determinants of innovative output. This proves to be an empirically interesting time frame: during this period, the set of countries listed above, as well as some other Scandinavian and Asian countries, vastly increased their innovative productivity. At the same time, a number of other countries with similar initial economic conditions and similarly low initial levels of new-to-the-world innovation, including, for example, numerous Latin American and southern European countries, did not improve their capacities for innovation as substantially (Furman et al., 2000; Furman and Stern, 2000). For example, between 1976 and 1980 a sample of emerging Latin American and Asian countries received similar number of USPTO patents; by the second half of the 1990s, however, patenting in the Asian economies dwarfs Latin American countries' output (Appendix Table A.1) (for more detailed studies of country-specific innovative development, see Amsden, 1989; Kim, 1997; O'Sullivan, 2000; Trajtenberg, 2001). In some cases, innovative productivity increases concomitant with economic development. However, the example of Great Britain and Ireland presented in Section 1 demonstrates that initial economic wealth alone does not fully explain levels of or increases in innovative productivity.

2.2. Perspectives on innovation in economic growth and catch-up

The factors that affect economic progress across countries have been of primary interest to political scientists, economic historians, economists, and policymakers – and the role of technology has been principal in the debates. Veblen (1915) was pioneering in comparing countries' relative economic standing and identifying penalties associated with initial industrial advantages. Gerschenkron's (1962) view of catch-up expands on Veblen, suggesting that later-industrializing countries may be able to accelerate their growth rates by adopting technology developed by leader countries and, although considerable obstacles exist, may be able to leapfrog leader countries by developing institutions that deal with contemporaneous challenges more effectively than those developed in previous periods. These authors identify a fundamental question regarding whether laggard countries' wealth and technological progress increase at a higher rate than that of leader countries.

Debate about the factors affecting catch-up and the extent of convergence in economic conditions across countries has intensified since World War II. Since Solow (1956) and Abramovitz (1956) identified the importance of technological progress in economic growth, questions about the role of innovation have been a central feature of this debate.[2] A number of distinct research traditions have emerged around these issues, each of which conceives of and incorporates technology in a different way. On one hand, most formal models of economic growth conceive of technology as a key input (along with labor and capital) in determining economic output and long-run growth. Such modeling efforts often require simplifying assumptions about the nature of technology and do not incorporate its more nuanced characteristics. By contrast, research in more historical, descriptive, or evolutionary (e.g., Nelson and Winter, 1982) traditions, rejects strict simplifying assumptions about technology and focuses on more fine-grained factors that affect the rate and direction of technical change. For example, while some formal models make the simplifying assumption

[2] Similarly, Vannevar Bush's report, *Science: The Endless Frontier*(1945) identified scientific and technological progress as a key element of national policy debates, particularly in the United States.

that technology flows freely across place and time, economic historians and evolutionary theorists document the limitations of such assumptions.[3]

Within the tradition of formal economic models, this distinction is quite important. In early neoclassical growth models, technology is viewed as spilling over freely across countries, leading to certain convergence in levels of economic progress, leaving only "transitional dynamics" (Fagerberg, 1994, p. 1149) to explain differences across countries, subject to constraints associated with capital mobility.[4] Follow-on efforts in the in the 1960s incorporate learning-by-doing into formal models, but these ideas do not have an immediate impact on mainstream economics. The importance of a country's stock of knowledge and the parameters affecting the mobility of knowledge across borders is more fully incorporated in the early 1990s, in models of ideas-driven, endogenous growth (Romer, 1990; Grossman and Helpman, 1991). 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.

Empirical literature assessing drivers of economic growth and the extent of convergence across countries is deep and varied (Barro and Sala-i-Martin, 1992, 1995; Islam, 1995; Sala-i-Martin, 1996; Quah, 1997). Several authors in a primary strand of this literature conclude that conditional convergence has occurred among industrialized economies (Baumol, 1986), but that this result does not hold if one selects countries based on economic leadership in the late 1800s rather than selecting from among the economic leaders in more recent periods (DeLong, 1988; Baumol et al., 1989). Convergence appears to apply to a greater set of countries in the 1990s, as formerly industrializing economies in Asia experience total factor productivity and economic growth. Young (1995) documents this experience in Hong Kong, Singapore, South Korea, and Taiwan, concluding that vast improvements in these countries' levels of per capita income result from substantial growth in labor and capital over the period.

Complementing formal models and large scale empirical analysis, economic historians and technology scholars have developed a perspective on the role of technology in economic advance in which a nuanced understanding of innovation is central.[5] Fagerberg (1994) describes this perspective as the "technology gap" approach, and identifies a number of its central tenets. Specifically, he notes that authors in this view (including Ames and Rosenberg, 1963; Nelson, 1981; Nelson and Winter, 1982; Nelson and Wright, 1992) emphasize that technological innovation does not flow freely across economic actors or distances because its creation and use are so closely tied to specific firms, networks, and economic institutions. In this view, the ability of economically lagging countries to catch-up to leader countries depends on the investments in technology, as incorporating advances made elsewhere is essential to the process of catch-up. Ohkawa and Rosovsky (1973) note this explicitly, and characterize the ability to assimilate external technologies as "social capability." 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 (1992, 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.

The natural progeny of the technology gap perspective, the literature on national innovation systems (Freeman, 1987; Dosi et al., 1988; Lundvall, 1992; Nelson, 1993; Edquist, 1997),[6] focuses on the particular

[3] It is important to note that these literatures are not necessarily at odds, and that some authors have made important contributions to both streams. For example, Romer's (1990) model of endogenous technical change employs a concept of technology that is more abstract than that of his historical essay examining the causes of the United States' technical leadership in manufacturing (1996). Likewise, Abramovitz's early growth accounting research (1956) was a keystone for early formal models, though his later research on catch-up (1986) adopts a more phenomenon-driven approach, e.g., proposing "technical congruence" as a notion to explain why knowledge flows imperfectly across countries.

[4] For additional elaboration, see also, Fagerberg (1987, 1988) and Fagerberg and Verspagen (2002).

[5] Keller and Gong (2003) also provide a recent review of the evolution of economic growth and the role of technology.

[6] This perspective is first articulated fully in the papers by Nelson, Lundvall (1988), and Freeman (1988) in Part V of Dosi et al. (1988).

configurations of firms, networks, and institutions that affect innovative outcomes in different countries.[7] Unlike the technology gap or economic growth literatures, research in the national innovation systems tradition is not focused explicitly on relative levels of economic or technological development. Instead, this research has emphasized rich, descriptive accounts of the constellations of organizations and policies that contribute to patterns of innovative behavior in particular countries, highlighting the institutions and actors whose roles in important industries are particularly decisive and emphasizing the diversity in national approaches to innovation. Such actors include private firms, universities, public and quasi-public research organizations, governmental departments and ministries (e.g., military, aeronautics and health) as well as the institutions, legal authorities, budget-setting agencies, and norms that influence the nature and extent of innovative efforts in an economy.[8] Consistent with evolutionary theorizing (Nelson and Winter, 1982), this perspective also emphasizes that processes leading to technical advance involve detailed search efforts, iterative learning, and complex interactions among the actors described above (Lundvall, 1992). Understanding the processes operating in a country's (or region's) innovative system requires far-reaching examinations of the relationships among its actors and technological infrastructure. As a consequence, research in this tradition has been predominantly qualitative, prompting Patel and Pavitt's (1994) call for follow-on research quantifying the characteristics, inputs, and outputs of national innovation systems.

Although the national innovation systems tradition has not yet generated a great deal of large-scale empirical analysis, the nuanced national innovation systems and technology gap literatures have helped focus research efforts on exploring the determinants of national innovative output as well as overall economic output. This development occurred parallel to and complementary with advances in the literature on macroeconomic growth that model the ideas-generating sector (innovation-generating sector) of the economy as an endogenous determinant of economic growth (Romer, 1990; Jones, 1995; Porter and Stern, 2000). In investigating the drivers of innovative outputs in the OECD, Furman et al. (2002) is among a number of recent papers that build on both of these research streams to evaluate the determinants of innovation and innovative productivity at the country level. For example, Hu and Mathews (2004) investigate developments in innovative capacity in a sample of five East Asian countries, concluding that public financing played a key role in fostering the growth of their innovative capacities (see, also Gans and Stern, 2003). We design this paper to contribute to that emerging line of research, focusing on the factors that have allowed a number of former follower countries to achieve substantial improvements in their ability to generate new-to-the-world innovations.

3. Conceptual approach

3.1. Overview and introduction

Informed by the research traditions described in the previous section, we pursue a conceptual and empirical approach with the aim of acknowledging the subtleties of the national innovation systems and technology gap literatures and incorporating its lessons in a way that also allows us to assess the drivers of national innovative output. In order to measure key constructs in a way that is comparable across a broad range of countries, we trade off some of the rich detail of the national innovation systems literature; at the same time, we are able to incorporate a greater degree of sensitivity for institutional variation than is characteristic of more formal economic approaches. We interpret our approach as complementary to, rather than a substitute for, both case-based research in innovation studies and more formal modeling efforts.

Accordingly, the framework we employ for understanding the drivers of national innovative productivity is fairly eclectic. It builds on recent models of ideas-driven economic growth (Romer, 1990; Jones, 1998), in which economic growth depends in great measure on the production of the ideas-generating sector of

[7] These authors echo Gerschenkron (1962) and North (1990), who are among the numerous economic historians who have pointed out the importance of national institutions in affecting the structure and nature of competition across countries and described how these institutions have a long-run impact on national economic fortunes.

[8] It is important to note that important though subtle differences exist among authors within the national innovation systems literature. McKelvey (1991) reviews some of these perspectives.

the economy. The rate at which new ideas are produced depends, in turn, on the stock of knowledge (previously generated ideas) and the extent of efforts (human and financial capital) devoted to the ideas-generating portion of the economy. The notion of an ideas production function forms the core of our empirical approach to understanding catch-up in innovative productivity.

We build, as well, on ideas developed by Rosenberg (1963) and Porter (1990) regarding the manner in which microeconomic processes interact with the macroenvironment and national institutions to affect the overall level of innovative activity in an economy. We incorporate this understanding of the importance of the microstructure of competition in our view of national innovative productivity and catch-up.

The final pillar of our approach to understanding the drivers of innovative output comes from the national innovation systems literature, which emphasizes the array of national policies, institutions, and relationships that drive the nature and extent of country-specific innovative output.

3.2. Determinants of national innovative capacity

To explain the sources of differences among countries in the production of innovations at the world's technical frontier, we employ the framework introduced by Furman et al. (2002). According to this framework, national innovative capacity is understood as an economy's potential for producing a stream of commercially relevant innovations. In part, this capacity depends on the technical sophistication and labor force in a given economy; however, it also reflects the investments, policies, and behaviors of the private sector and the government that affect the incentives to engage in R&D and the productivity of the country's R&D enterprise. The framework organizes the determinants of national innovative capacity into three main elements (see Fig. 1): (1) a common pool of institutions, resource commitments, and policies that support innovation, referred to as the common innovation infrastructure; (2) the particular innovation orientation of groups of interconnected national industrial clusters; and (3) the quality of linkages between the two.

The innovative performance of a country's economy ultimately depends upon the activities of individual firms and industrial clusters. Some of the most critical investments that support innovative activity affect all innovation-oriented sectors in an economy. These cross-cutting factors comprise the *common innovation infrastructure* (represented by the left-hand portion of Fig. 1). Consistent with models of ideas-based growth

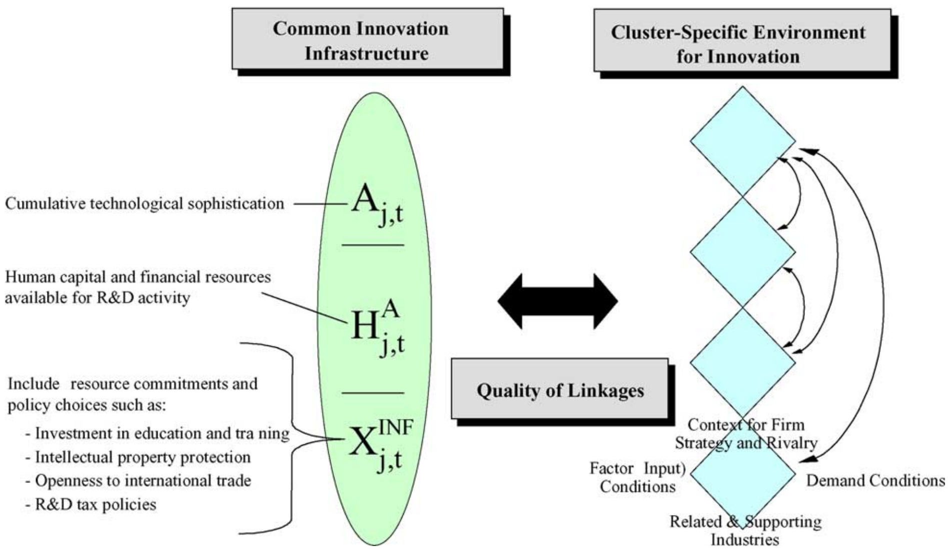


Fig. 1. National innovative capacity.

(Romer, 1990), the framework suggests that a country's R&D productivity depends upon its historical stock of knowledge (denoted A_t) as well as the amount of scientific and technical talent dedicated to the production of new technologies (denoted $H_{A,t}$). Innovative productivity also depends on national investments and policy choices (denoted as X^{INF}), including factors such as expenditures on higher education, intellectual property protection, and openness to international competition, which will exert an over-arching impact on innovativeness across the range of a country's economic sectors (Nelson, 1993).

While the common innovation infrastructure provides resources for innovation throughout an economy, it is the firms in specific industrial clusters that introduce and commercialize those innovations. The innovative capacity of an economy, then, depends upon the extent to which a county's industrial clusters support and compete on the basis of technological innovation. Drawing on the "diamond" framework developed in Porter (1990), we emphasize four key elements of the microeconomic environment – the presence of high-quality and specialized inputs; a context that encourages investment and intense local rivalry; pressure and insight gleaned from sophisticated local demand; and the presence of a cluster of related and supporting industries – that have a central influence on the rate of innovation in a given national industrial cluster (these are the diamonds on the right-hand side of Fig. 1). The potential also exists for productivity-enhancing knowledge to spill over across industrial clusters (this is represented by the lines connecting the diamonds on the right-hand side of Fig. 1).

Finally, the extent to which the potential for innovation supported by the common innovation infrastructure is translated into specific innovative outputs in a nation's industrial clusters will be determined by the quality of linkages between these two areas. In the absence of strong linking mechanisms, upstream scientific and technical activity may spill over to other countries more quickly than opportunities can be exploited by domestic industries. For example, while the underlying technology for creating the chemical dye industry was the result of the discoveries of the British chemist Perkin, the sector quickly developed and became a major exporting industry for Germany, not Britain. At least in part, this migration of the fruits of scientific discovery to Germany was due to that country's stronger university–industry relationships and the greater availability of capital for technology-intensive ventures (Arora et al., 1998; Murmann, 2003).

4. Empirical approach and data

4.1. Empirical approach – estimating national innovative productivity

We base our approach to assessing national innovative productivity on the ideas production function articulated by Romer (1990), Jones (1995), Porter and Stern (2000). We use the national innovative capacity framework described above as a guide to direct our model and analysis. Specifically, we describe a production function for economically significant technological innovations, choosing a specification in which innovations are produced as a function of the factors underlying national innovative productivity:

$$\dot{A}_{j,t} = \delta(X^{\mathrm{INF}}_{j,t}, Y^{\mathrm{CLUS}}_{j,t}, Z^{\mathrm{LINK}}_{j,t}) H^{A\lambda}_{j,t} A^{\phi}_{j,t} \quad (1)$$

where for each country j in year t, $\dot{A}_{j,t}$ represents the flow of new-to-the-world innovations, $H^{A}_{j,t}$ reflects the total level of capital and labor resources devoted to the ideas sector of the economy, and $A_{j,t}$ symbolizes the stock of useful knowledge available to drive future ideas production. In addition, X^{INF} refers to the level of cross-cutting resource commitments and policy choices which constitute the common innovation infrastructure, Y^{CLUS} refers to the particular environments for innovation in a country's industrial clusters, and Z^{LINK} captures the strength of linkages between the common infrastructure and the nation's industrial clusters.

The reasoning we apply to arrive at an empirical model to estimate (1) follows the logic of Furman et al. (2002) and reflects our principal aim of allowing the data to illustrate the phenomenon to the greatest possible extent. As the source of statistical identification, we employ a panel dataset over a time period of more than 20 years. We can, therefore, take advantage of both cross-sectional and time series variation in estimating the parameters associated with (1). Recognizing the benefits (and pitfalls) associated with each identification strategy, our analysis explicitly compares how estimates vary depending on the source of identification.[9] We are careful in our analysis to include year dummies to account for the evolving differences across time in the overall level of innovative output. We also include either country dummies or other measures to control for aggregate differences in technological sophistication (e.g., as reflected in GDP per capita). By controlling for year and country effects in most of our analysis, we address some of the principal endogeneity and autocorrelation concerns.[10]

We base our specification of the innovation production function on the assumption that each of the terms of (1) are complementary with one another, in the sense that the marginal productivity associated with increasing one factor is increasing in the levels of each of the other factors. (More precisely, this simplification is based on the assumption that the factors X^{INF}, Y^{CLUS}, and Z^{LINK} enter (1) exponentially. Thus (1) becomes $\dot{A}_{j,t} = \delta X_{j,t}^{\delta_{\text{INF}}}, Y_{j,t}^{\delta_{\text{CLUS}}}, Z_{j,t}^{\delta_{\text{LINK}}} H_{j,t}^{A\lambda} A_{j,t}^{\phi}$ and simplifies to (2) after logarithmic transformation.) Denoting the natural logarithm of X as LX, our main specification reduces to the following form:

$$L\dot{A}_{j,t} = \delta + \delta_{\text{INF}} LX_{j,t}^{\text{INF}} + \delta_{\text{CLUS}} LY_{j,t}^{\text{CLUS}} + \delta_{\text{LINK}} LZ_{j,t}^{\text{LINK}} + \lambda LH_{j,t}^{A} + \phi LA_{j,t} + \varepsilon_{j,t} \quad (2)$$

The log–log form of this specification allows many of the variables to be interpreted in a straightforward way in terms of elasticities, is less sensitive to outliers, and is consistent with prior research in this area (Jones, 1998).

4.2. Measuring innovative output across countries and time

To perform our proposed analysis, we must identify observable measures that characterize new-to-the-world innovation and the concepts underlying national innovative capacity and develop a dataset that tracks these measures across countries and over time. Constructing a measure of commercializable innovations that is comparable and available across countries over the course of our dataset and is indicative of national innovative output is a difficult task. Consistent with Furman et al. (2002), we focus our analysis of visible commercializable innovations on "international patents" (PATENTS), which we define as the number of patents granted by the U.S. Patent & Trademark Office to inventors from foreign countries.[11]

We recognize that no measure is perfect in characterizing the precise extent of innovation in an economy and readily acknowledge the well-understood hazards of using patenting as an indicator of innovative activity (Schmookler, 1966; Pavitt, 1982, 1985, 1988; Griliches, 1984, 1990; Trajtenberg, 1990). As Griliches notes succinctly, "not all inventions are patentable, not all inventions are patented, and the inventions that are patented differ greatly in 'quality', in the magnitude of inventive output associated with them (1990, p. 1669)". Such difficulties are exacerbated when comparing innovation across countries because the propensity to patent also differs across country (Eaton and Kortum, 1996, 1999; Kortum and Lerner, 1999).

At the same time, we focus on international patenting rates as "the only observable manifestation of inventive activity with a well-grounded claim for universality" (Trajtenberg, 1990, p. 183) and, thus, the most useful measure available for comparing innovative output across countries and over time. Though we believe that the advantages of international patent data suggest it as the best measure for our purposes, we exercise caution in our use and interpretation of the data. For example, we construct PATENTS to include only commercially significant innovations at the world's technical frontier.[12] Moreover, in using realized international

[9] Cross-sectional variation allows inter-country comparisons that can reveal the importance of specific determinants of national innovative capacity, yet it may be subject to unobserved heterogeneity. On the other hand, time series variation yields insight into how national choices manifest themselves in terms of observed innovative output, but may be subject to its own sources of endogeneity (e.g., changes in a country's fundamental characteristics may reflect idiosyncratic changes in its environment).

[10] Porter and Stern (2000) have investigated potential problems with endogeneity in an innovation production function specification similar to the one used here.

[11] Furman et al. (2002) discusses the use of international patenting as a proxy for national innovative output in greater detail.

[12] Focusing on international patents helps satisfy this criteria. First, obtaining a patent in a foreign country is a costly undertaking that is only worthwhile for organizations anticipating a return in excess of these substantial costs. Second, USPTO-granted "international" patenting (PATENTS) constitutes a measure of technologically and economically significant innovations at the world's commercial technology frontier that should be consistent across countries. Third, we are careful to accommodate the potential for differences in the

Table 1
Variables and definitions

Variable		Full variable name	Definition	Source
Innovative output				
$Patents_{jt+2}$		International patents granted in year $t+2$	For non-US countries, patents granted by the USPTO. For the US, patents granted by the USPTO to corporations or governments. To ensure this asymmetry does not affect the results we include a US dummy variable in the regressions	USPTO patent database
Quality of the common innovation infrastructure				
A	GDP PER $CAPITA_{j,t}$	GDP Per Capita	Gross Domestic Product per capita, constant price, chain series, US$	Penn World Tables, OECD Science & Technology Indicators
A	$GDP78_{j,t}$	GDP 1978	1978 Gross Domestic Product constant price, chain series, billions of 2000 US$	Penn World Tables
H^A	FTE R&D $PERS_{j,t}$	Aggregate Personnel Employed in R&D	Full time equivalent R&D personnel in all sectors	OECD Science & Technology Indicators
H^A	R&D$\$_{j,t}$	Aggregate Expenditure on R&D	Total R&D expenditures in Year 2000 millions of US$	OECD Science & Technology Indicators
X^{INF}	$OPENNESS_{j,t}$	Openness to international trade and investment	Exports plus imports, in constant dollar prices, divided by GDP, expressed as a percent	Penn World Tables
X^{INF}	$IP_{j,t}$	Strength of protection for intellectual property	Average survey response by executives on a 1–10 scale regarding relative strength of IP (available beginning in 1989)	IMD World Competitiveness Report
X^{INF}	ED $SHARE_{j,t}$	Share of GDP spent on secondary and tertiary education	Public spending on secondary and tertiary education divided by GDP	World Bank, OECD Education at a Glance
Quality of the cluster-specific innovation environment				
Y^{CLUS}	PRIVATE R&D $FUNDING_{j,t}$	Percentage of R&D funded by private industry	R&D expenditures funded by industry divided by total R&D expenditures	OECD Science and Technology Indicators
Quality of linkages				
Z^{LINK}	UNIV R&D $PERF_{j,t}$	Percentage of R&D performed by universities	R&D expenditures performed by universities divided by total R&D expenditures	OECD Science and Technology Indicators

patents as an indicator of national innovative activity, we draw on a wide-range of research in economics and innovation studies, including Soete and Wyatt (1983), Evenson (1984), Patel and Pavitt (1987, 1989), Dosi et al. (1990), Eaton and Kortum (1996, 1999), Kortum (1997), Vertova (1999) and Furman et al. (2002).[13]

While we acknowledge that the "true" rate of technological innovation is unobservable and that PATENTS is an imperfect proxy, our decision to use

propensity to apply for patent protection across countries and over time (as highlighted by Scherer, 1983) by evaluating robustness of our results to year and country-specific fixed effects.

[13] For example, Patel and Pavitt (1987, 1989) compare the relative innovativeness of European countries using USPTO-approved patents as a benchmark.

Table 2
Sample countries

Australia	Finland	Ireland	Norway	Sweden
Austria	France	Italy	Poland[a]	Switzerland
Belgium	Germany[b]	Japan	Portugal[a]	Turkey[a]
Canada	Greece[a]	Mexico	Slovak Republic[a]	United Kingdom
Czech Republic[a]	Hungary	Netherlands	South Korea	United States
Denmark	Iceland	New Zealand	Spain	

[a] These countries are included in supplemental analyses, but are omitted from the core regression analyses because of data limitations.
[b] Prior to 1990, data are for West Germany only; after 1990, results include all German Federal states.

Table 3
Means and standard deviations

Variable		*N*	Mean	Standard deviation
Innovation output				
Patents		473	3550.20	9193.53
Quality of the common innovation infrastructure				
A	GDP PER CAPITA	473	18324.53	4582.88
A	GDP78	473	578.57	1000.85
H^A	FTE R&D PERS	473	199797.80	383363.60
H^A	R&D $	473	15941.54	35650.40
X^{INF}	OPENNESS	473	63.57	28.63
X^{INF}	IP	245	6.72	1.09
X^{INF}	ED SHARE	473	3.23	1.01
Cluster-specific innovation environment				
Y^{CLUS}	Private R&D funding	473	50.64	14.31
Quality of linkages				
Z^{LINK}	UNIV R&D PERF	473	22.25	6.55

this variable rests on the belief that PATENTS is positively correlated with the true level of new-to-the-world innovative output in our panel dataset and that it represents the best available indicator that allow us to compare national innovative output across a broad set of countries over time. We remain aware of the limitations of this measure, test it carefully for robustness, and bear these limitations in mind when interpreting our results.[14]

A list of our variables, definitions, and sources appears in Table 1; the set of countries included in our analysis is listed in Table 2; and summary statistics appear in Table 3. For all countries except the United States, we define PATENTS as the number of patents granted in year $t+2$ in the United States. This accounts for the average lag between patent application and approval. For the United States, we use the number of patents granted to government and corporations (non-individuals), in the United States in year $t+2$.[15]

Across all years, the average country in our sample obtains approximately 3550 PATENTS. Reflecting the skewness in the data, the standard deviation in international patenting is substantially higher than the mean (nearly 9200). At the country level, these data evidence an increase in PATENTS in countries such as Japan, Finland, and South Korea, a solid increase in PATENTS in many western European countries, and only modest increases in PATENTS in countries such as Italy, Spain, and New Zealand.

[14] In previous work (Furman et al., 2002), we explored several alternative measures to PATENTS, including the rate of publication in scientific journals (JOURNALS), the realized market share of a country in "high-technology" industries (MARKET SHARE), and total factor productivity (TFP) and discuss the relative advantages and disadvantages of using these measures.

[15] To ensure that this asymmetry between US and non-US patents does not affect our results we include a US dummy variable in all regressions that include US data. Note that the key results are also robust to the use of PATENTS based on date of application, and are also robust to the use of alternative lag structures.

4.3. Measuring the drivers of innovative output

Limitations in the quality and extent of available data constitute the principal challenge in developing a dataset that allows us to measure the drivers of innovative productivity in emerging innovator countries. We obtain the majority of our data from series published by the OECD Science and Technology Indicators, the World Bank, the USPTO and the Penn World Tables. Prior to the 1990s, few countries outside of the OECD kept regular, reliable records on science and engineering or R&D-related activities. Thus, our ability to compile a comprehensive historical dataset for a large sample of countries remains limited.[16] As economists and policy-makers have focused increasing attention on innovation as a source of economic growth, national statistical agencies and international bodies have undertaken more concerted efforts at gathering these data. As a consequence, we are able to expand on previous data collection efforts to develop a dataset that reflects investments in the drivers of national innovative productivity for 29 countries between 1978 and 1999. Our core dataset, on which we run our regressions, includes 23 countries for which consistent data series are available over the course of the sample period. In additional analyses, we are able to include six additional countries for which consistent data are available for a subset of years.[17]

We measure the strength of the common innovation infrastructure using variables that reflect the extent of a country's accumulated knowledge stock (A), country-level investments in R&D and human capital (H^A), and national policies (X^{INF}). GDP78 and GDP PER CAPITA measure the knowledge stock indirectly, reflecting the extent to which ideas are embodied in goods and services. GDP78 equals the gross domestic product in 1978, the initial year of our sample. GDP78 is a fixed measure, which reflects the initial stock of knowledge in the economy, while GDP PER CAPITA constitutes a variable measure. Measured in year 2000 US$, GDP78 averages nearly 580 billion dollars across countries. GDP PER CAPITA averages US$ 18,324 over the sample.

Measures of R&D human capital and country-level investments in R&D (FTE R&D PERS and R&D$) reflect the extent of R&D effort in the economy. Countries in the dataset employ an average of nearly 200,000 full-time equivalent R&D workers and invest nearly 16 billion dollars annually on R&D over the sample period. Fig. 2A depicts the substantial dispersion in per capita R&D investment in 1999 and Fig. 2B the growth of R&D expenditures over the sample period. While leading innovator countries like Japan, Sweden, and Switzerland invest more than US$ 900 in R&D per capita, countries with lower levels of innovative capacity, such as Mexico, Poland, and Portugal report fewer than US$ 100 in per capita R&D expenditures in 1999. Consistent with the observation that countries' levels of visible innovative output become more similar over time, many of the countries with the lowest levels of R&D investment are among those with the greatest relative increases in R&D investment over the period. For example, although South Korea invests less than the median amount of R&D per capita in 1999, its level of investment represents a staggering increase of 5570% relative to its expenditures in 1978. Likewise, Portugal, whose per capita R&D expenditures are among the lowest in the sample, had increased its R&D investment by more than 1600% between 1978 and 1999.

We measure the final component of the common innovation infrastructure X^{INF}, using indicators of national policies regarding openness to international trade (OPENNESS), the strength of intellectual property protection (IP), and the share of GDP allocated to expenditures for secondary and tertiary education (ED SHARE). In this paper, we employ a direct measure of the OPENNESS.[18] Specifically, we use data from the Penn World Tables to compute total trade (equal

[16] Some additional data are available from country-specific publications and offices. These are often available only in local languages and for recent year and questions exist about their comparability across countries and over time. Hu and Mathews (2004) address these issues in compiling innovation statistics for their sample of East Asian economics. The ability to analyze a complete set of historical data for a wider array of countries – including both those that have achieved apparent innovative success (e.g., Israel, Singapore, Taiwan) as well as currently industrializing countries – would greatly enhance research in this area.

[17] For the countries in the core dataset, we interpolated data from existing years to obtain occasional missing values. For example, several countries only report educational expenditure data every second year. For these we used an average of the immediately preceding and following years.

[18] Note that this differs from Furman et al. (2002), in which OPENNESS is based on data from the World Competitiveness Report, an

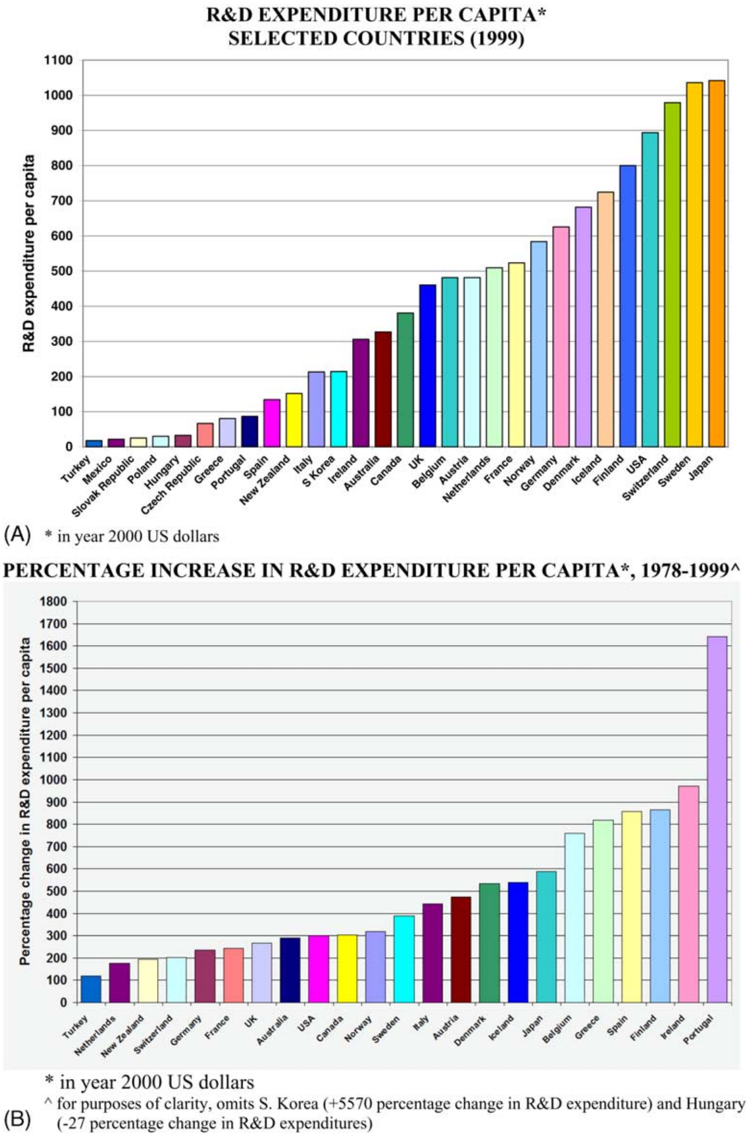


Fig. 2.

to exports plus imports) as a proportion of GDP. This measure correlates with the ability of firms in an economy to target larger international markets and with the ability of foreign firms to exploit their innovations in the local economy. Across the sample, the mean level of trade openness is 63.6%; not surprisingly, this figure is higher in EU countries. IP is measured using executives' responses in the World Competitiveness Report. On a Likert scale between 1 and 10 (where 10 represent the strongest degree of protection), sample countries earn an IP average of 6.7. The average country in the sample devotes 3.2% of GDP to secondary and tertiary education.

To gauge the innovation orientation of industrial clusters and the strength of linkages, we employ compositional variables that reflect the relative sources of

annual survey in which leading executives ranked their perceptions of their country's openness to trade. Although the measure we use here differs, the results are qualitatively similar.

R&D funding between the public and private sector (PRIVATE R&D FUNDING) and the degree to which R&D performance takes place in the university sector (UNIV R&D PERFORMANCE).[19] For our sample countries, industry sources fund slightly more than 50% of all R&D expenditures. As demonstrated in Fig. 3A, this measure varies substantially across countries. In 1999, private sources contribute less than 30% of R&D funds in countries such as Portugal, Mexico, and Greece, although they account for approximately 70% of funding in South Korea and Japan. There is also substantial variation in changes in PRIVATE R&D FUNDING over the sample period (Fig. 3B). While private sources in Iceland and Ireland increased their fraction of R&D funding by more than 30%, PRIVATE R&D FUNDING declined in Austria, Portugal, and Switzerland. Note that declines in PRIVATE R&D FUNDING in Austria and Portugal are, in a sense, more meaningful than those in Switzerland, as private sources fund a substantially higher fraction of national R&D in Switzerland. UNIV R&D PERF averages 22.2% across the sample and evidences similar variation across countries.

5. Empirical results

5.1. Econometric analysis

Our econometric analysis applies the specification in (2) to the core dataset of 473 observations. The results appear in Tables 4 and 5. This specification yields a number of advantages from the perspective of interpretation. First, most of the variables in the specification enter in log form; consequently, their coefficients have a natural interpretation as elasticities. Variables expressed as ratios are included as levels, allowing us to also use an elasticity interpretation for their coefficients. Second, the log–log specification minimizes the leverage of outliers on the results. In all models, R-squared is greater than 0.94; for models including year dummy variables, it is greater than 0.997.

Table 4 reports the primary national innovative capacity results. Eqs. (4-1) estimates a specification that reproduces the Romer–Jones ideas production function model. The results show that GDP PER CAPITA and FTE R&D PERS have a significant and economically important impact on PATENTS. The coefficient on FTE R&D PERS implies that a 10% increase in science and engineering employment is associated with an 11.6% increase in PATENTS. Eqs. (4-2) and (4-3) incorporate the elements of the common innovation infrastructure and the complete national innovative capacity model, respectively. Consistent with prior work, the key measures of the common innovation infrastructure, the environment for innovation in national clusters, and the extent of linkages between the two enter in a statistically and economically significant manner. Coefficients on variables expressed as a share (including as ED SHARE and OPENNESS) can be interpreted as the percentage increase in PATENTS resulting from a 1% point increase in those variables. Eq. (4-4) presents the preferred national innovative capacity regression. In this model, elements of the common innovation infrastructure, the environment for innovation in industrial clusters, and the linkages between the two enter in a statistically and economically significant manner.

Table 5 explores the robustness of the model to a number of modifications. In order to isolate the extent to which the results are driven by time-series rather than cross-sectional variation, we add country fixed effects to the model in (5-1), with all country fixed effects entering significantly. (We omit GDP78 from this model; since its value is fixed over time, it is effectively incorporated into the country fixed effect.) Key measures of the extent of ideas in the economy and the commitment to R&D financial and human capital remain significant and of the expected valence in this equation; many of the more nuanced measures of national innovative capacity become insignificant, however. The positive and significant coefficient on PRIVATE R&D FUNDING is robust to this modification, although ED SHARE and UNIV R&D PERFORMANCE lose their significance, suggesting that cross-sectional variation is what drives significance in these variables. OPENNESS becomes negative and significant in this formulation, suggesting that countries that have, over time, increased their

[19] We have also examined alternative drivers in our background analysis, including policy variables such as ANTITRUST and measures of the extent to which venture funding is available (VC). These variables do not enter our models in a consistently statistically significant manner, and thus do not appear in the preferred model (4-4). In prior work, we have also modeled SPECIALIZATION as a factor reflecting the cluster-specific environment for innovation. The core results in this paper are also robust to the inclusion of SPECIALIZATION.

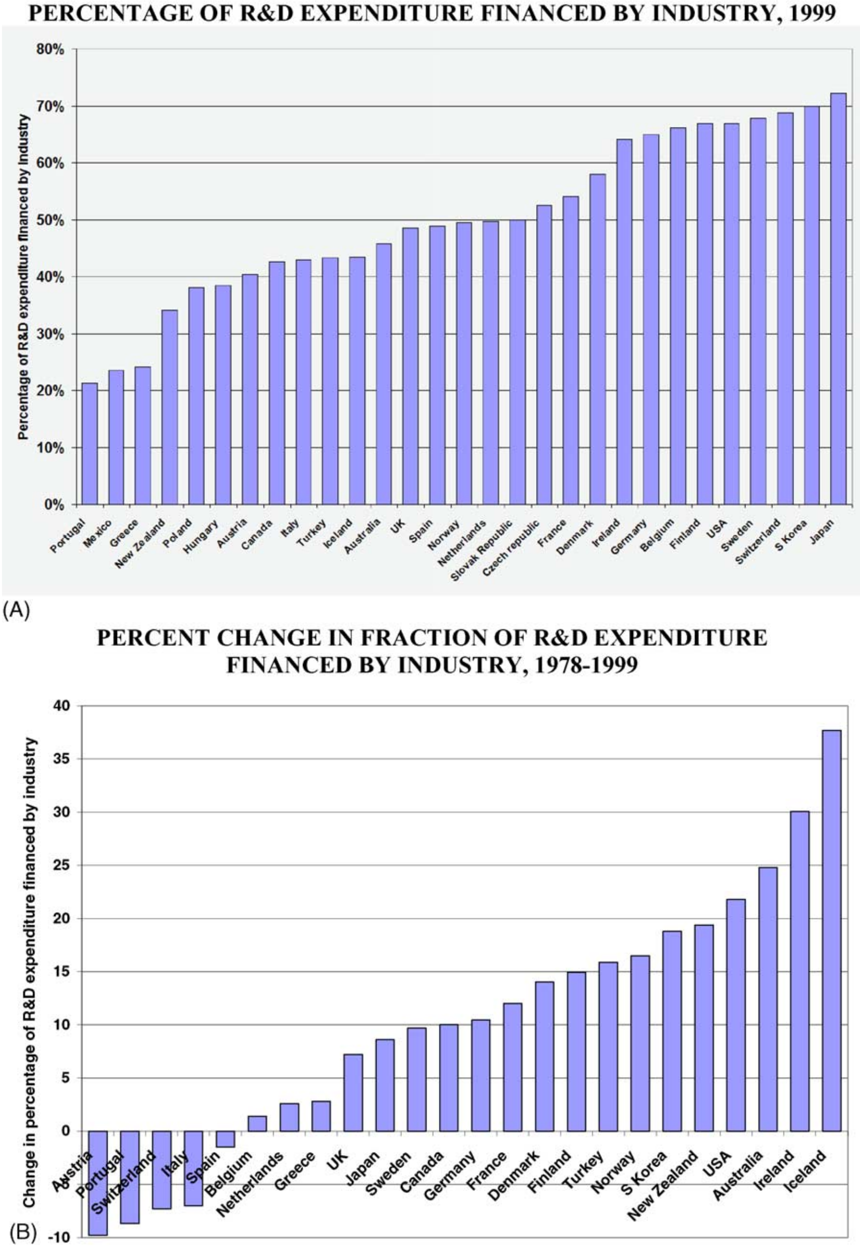


Fig. 3.

openness to international trade have generated fewer PATENTS. This may be an artifact of EU integration. The magnitude of the coefficient on GDP PER CAPITA changes substantially when country fixed effects are added, suggesting that the impact of within-country changes in GDP PER CAPITA over time is different from their impact across the cross-section.

Eqs. (5-2) and (5-3) reproduce key results from Table 4, substituting PATENT STOCK for GDP PER CAPITA as a measure of the stock of knowledge in

Table 4
Determinants of the production of new-to-the-world technologies

		Dependent Variable = ln(PATENTS)$_{j,t+2}$			
		(4-1) Baseline ideas production function	(4-2) Common innovation infrastructure	(4-3) National innovative capacity: including all variables	(4-4) National innovative capacity: preferred model
Quality of the common innovation infrastructure					
A	L GDP PER CAPITA	1.584(0.069)	0.697 (0.130)	0.870 (0.138)	0.836 (0.134)
H_A	L FT R&D PERS	1.161(0.013)	0.737 (0.101)	0.865 (0.097)	0.850 (0.099)
A	L GDP78		−0.355 (0.055)	−0.299 (0.062)	−0.289 0.063
H^A	L R&D $		0.757 (0.076)	0.556 (0.077)	0.556 (0.078)
X^{INF}	ED SHARE		0.069 (0.018)	0.091 (0.018)	0.089 (0.018)
X^{INF}	IP		0.027 (0.042)	0.018 (0.040)	
X^{INF}	OPENNESS		0.004 (0.001)	0.0023 (0.0008)	0.0018 (0.0008)
X^{INF}	ANTI-TRUST		−0.044 (0.033)	0.002 (0.031)	
Cluster-specific innovation environment					
Y^{CLUS}	PRIVATE R&D FUNDING			0.011 (0.002)	0.012 (0.002)
Quality of the linkages					
Z^{LINK}	UNIV R&D PERFORMANCE			0.011 (0.004)	0.011 (0.004)
Z^{LINK}	VENTURE CAPITAL			−0.047 (0.018)	
Controls					
	Year fixed effects		Significant	Significant	Significant
	US dummy		0.136 (0.086)	0.246 (0.085)	0.185 (0.076)
	Constant	−21.931 (0.687)			
R-squared		0.9470	0.9971	0.9974	0.9973
Observations		473	473	473	473

the economy. The results of these equations echo those of the core national innovative capacity equations presented in Table 4.

In addition to the robustness of the results, stationarity is a potential concern given the way we model international patenting. To test for stationarity in our ln(PATENTS) data series, we followed the panel data unit root tests of Levin et al. (2002) and Im et al. (2003), which rely on pooled Augmented Dickey Fuller testing for unit roots. In the case of ln(PATENTS), each test rejected the null hypothesis of nonstationarity, demonstrating that the series is not $I(1)$.

5.2. Categorizing innovator countries

To more deeply understand differences and changes in the level of innovative productivity across countries, we undertake a counterfactual analysis in which we predict per capita international patenting as a function of countries' realized levels of investments in innovation and their policies towards innovation. Essentially, this exercise consists of predicting a country's expected international patenting rate by applying its observed levels of the drivers of national innovative capacity to the regression coefficients obtained in (4-4) and then normalizing by national population. In Fig. 4A, we plot the results of this exercise for all of the countries in our core and expanded samples.

Several notable results emerge from this counterfactual analysis. The first is consistent with a catch-up phenomenon. While the United States and Switzerland have the highest levels of predicted per capita international patenting across the period, the relative difference in predicted per capita international patenting between these countries and others has declined over time as other countries have begun to invest more substantially in the drivers of national innovative capacity. For example, Japan dramatically improved its predicted international patenting between the early 1970s and the present and a number of Scandinavian economies,

Table 5
Exploring robustness

		Dependent variable = ln(PATENTS)$_{j,t+2}$		
		(5-1) Core NIC model, with country fixed effects	(5-2) Baseline ideas production function (w/PAT STOCK)	(5-3) National innovative capacity model (w/PAT STOCK)
Quality of the common innovation infrastructure				
A	L GDP PER CAPITA	2.121	(0.307)	
A	L PATENT STOCK		0.807(0.049)	0.557 (0.034)
H^A	L FT R&D PERS	0.954 (0.129)	0.616(0.118)	0.422 (0.040)
H^A	L R&D$	0.218 (0.093)		0.289 (0.057)
X^{INF}	ED SHARE	0.024 (0.023)		0.047 (0.018)
X^{INF}	OPENNESS	−0.006 (0.002)		0.0003 (0.0007)
Cluster-specific innovation environment				
Y^{CLUS}	PRIVATE R&D FUNDING	0.006 (0.003)		0.006 (0.002)
Quality of the linkages				
Z^{LINK}	UNIV R&D PERFORMANCE	0.002 (0.003)		0.001 (0.003)
Controls				
	Country fixed effects	Significant	Significant	
	Year fixed effects	Significant	Significant	
	YEAR			−0.045 (0.003)
	L GDP 1978			−0.255 (0.045)
	US dummy			0.213 (0.071)
R-squared		0.9991	0.9994	0.9979
Observations		473	473	473

including Denmark and Finland, have made investments that led to increased expected international patenting since the mid-1980s. This catch-up phenomenon has not, however, occurred uniformly across all countries. For example, the estimates associated with several western European economies, including the UK, France, and Italy do not evidence marked increases in relative levels of innovative capacity.

While initial levels of innovative productivity are, at least in part, the legacies of historical conditions, differential rates of catch-up constitute a separate empirical puzzle. As a descriptive exercise that helps us to understand the factors driving differential rates of catch-up in innovative productivity, we classify the countries in our dataset into categories based on the historical evolution of their innovative capacity (Table 6). We designate four categories: leading innovators, middle tier innovators, third tier innovator, and emerging innovator countries.

Leading innovator countries, including the United States, Switzerland, Germany, Japan, and Sweden, maintain high levels of innovative capacity throughout the sample period, with Germany, Japan, and Sweden experiencing particular growth in their innovative capacities in the early 1980s. Average expected per capita patenting rates for this group range from a minimum of 80 PATENTS per million persons to a maximum of over 170 over the sample period.

Middle tier innovator countries, which include a number of the western European countries, as well as Australia, Canada, and Norway, maintain relatively stable levels or slowly increasing level of innovative capacity for much of the sample period. From 1978 to 1995, middle tier innovator countries average patenting rates increase from approximately 38 to slightly more than 50 PATENTS per million persons. Predicted patenting rates rose somewhat more rapidly starting in 1995, and reached nearly 80 PATENTS per million by 1999. Even by 1999, however, middle tier countries have not reached an average level of innovative capacity equal to that of the leading innovators in 1978.

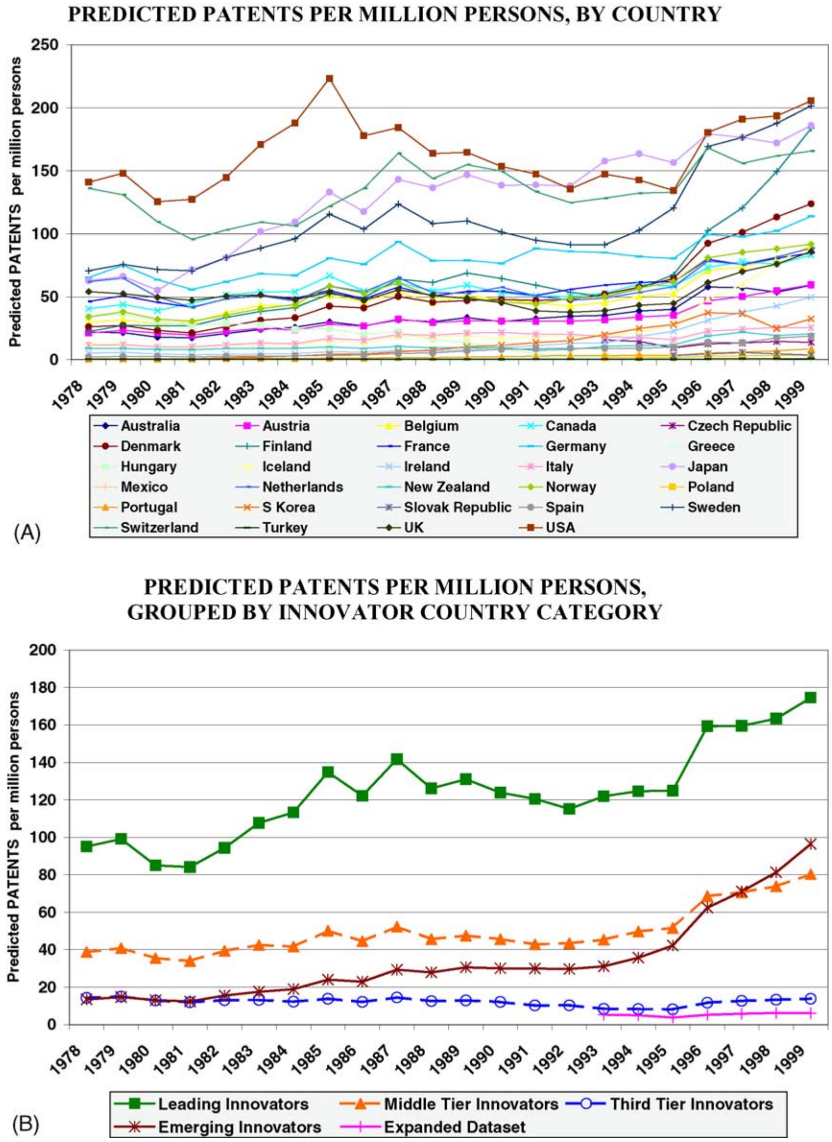


Fig. 4.

Third tier innovator countries, which include Italy, New Zealand and Spain, experience relatively low levels of innovative capacity throughout the sample period, although their investments in innovation drivers also increase in the final few years of the 1990s. Expected international patenting rates in these countries are generally less than 30 PATENTS per million persons throughout the sample period.

Emerging innovator countries, Denmark, Finland, Iceland, Ireland, and South Korea, evidence a dramatically different pattern. Beginning with comparatively low expected patenting rates, these countries have increased their commitments to innovation by a relatively greater fraction than other countries in the sample. As a consequence, by 1999, their average expected patenting rates have exceeded those of the middle tier countries. Denmark and South Korea constitute

Table 6
Categorizing innovator countries

Leading innovator	Middle tier	Third tier	Emerging innovator
Germany	Australia	Hungary	Denmark
Japan	Austria	Italy	Finland
Sweden	Belgium	Mexico	Iceland
Switzerland	Canada	New Zealand	Ireland
USA	France	Spain	South Korea
	Netherlands		
	Norway		
	United Kingdom		

striking examples. In 1978, the predicted international patenting rate was approximately 26 for Denmark and less than 1 for South Korea. Over the subsequent two decades, these countries invested substantially their financial and human capital in innovation and raised their commitments to innovation-supporting policies. By the end of the 1990s, Denmark and South Korea had surpassed many countries whose historical levels of innovative capacity had exceeded their own.

Fig. 4B traces the historical average innovative capacity levels of these groups.[20] The figure also reports averages for countries in the *expanded dataset*.[21] Data for these countries are not sufficiently complete to enable including these countries in our historical regressions, but do enables us to compute predicted patenting rates in the late 1990s. Levels of innovative capacity in these countries are less than half those of third tier innovators over the course of the few years for which reliable data are available.

5.3. Examining the drivers of catch-up

The unpredictable pattern according to which some countries increased their innovative productivity dramatically over the past quarter century while others lagged behind constitutes an empirical puzzle. Our counterfactual exercise in the previous section demonstrates that part of the resolution to this puzzle lies in the extent to which these countries increased their commitments to the drivers of innovative capacity. In this section we decompose the factors that drive innovative capacity, in order to shed more light on the extent to which investments and policy commitments have contributed to the rapid and substantial increases in innovative capacity in emerging innovator countries and the more modest increases achieved by middle and third tier countries. In order to do this, we develop two indices, which incorporate realized levels of the drivers of innovative capacity along with the weights derived in model (4-4 in the econometric analysis).

The first index, which we call the Investment Index, reflects the contribution of country-level investments in R&D and human capital, and growth in the stock of ideas. Essentially, it is a population-adjusted measure of A and H^A. Specifically, it is calculated as the linear combination of the realized levels of FTE R&D PERS, R&D EXPENDITURES, and GDP PER CAPITA, multiplied by their matching coefficient estimates from (4-4), exponentiated, and normalized by population. The second, index, which we call the Policy Index for the purposes of discussion, is based on values of X^{INF}, Y^{CLUS}, Z^{LINK}. It is constructed in the same manner as the Investment Index, using ED SHARE, OPENNESS, PRIVATE R&D FUNDING, and UNIV R&D PERFORMANCE. As these measures are not subject to scaling, we do not adjust this index for population.

We plot the historical Investment and Policy indices for each group of innovator countries in Fig. 5A and B. A number of interesting observations emerge. First, important differences in Investment Index levels are apparent across the categories. The initial Investment Index for leading innovator countries is more than twice that of the middle tier innovators and approximately 10 times that of third tier innovator countries and substantial differences among these groups remain at the end of the sample period. By contrast, the percentage difference among innovator country categories in the Policy Index is substantially smaller, and even third tier innovator countries have Policy Index values that are comparable to (though nonetheless below) those of the leading innovator and middle tier countries over the sample period.

Over the course of the 1980s and 1990s, the average Investment Index for emerging innovator countries increases from an initial level similar to that of third

[20] Preliminary analysis applying the techniques elaborated by (Islam, 1995, 2003) to the data underlying Fig. 4B provides suggestive evidence of statistical convergence in innovative capacity. Further research on statistical convergence in innovative outputs may be a promising avenue for future work.

[21] *Expanded dataset* countries include the Czech Republic, Greece, Poland, Portugal, the Slovak Republic, and Turkey.

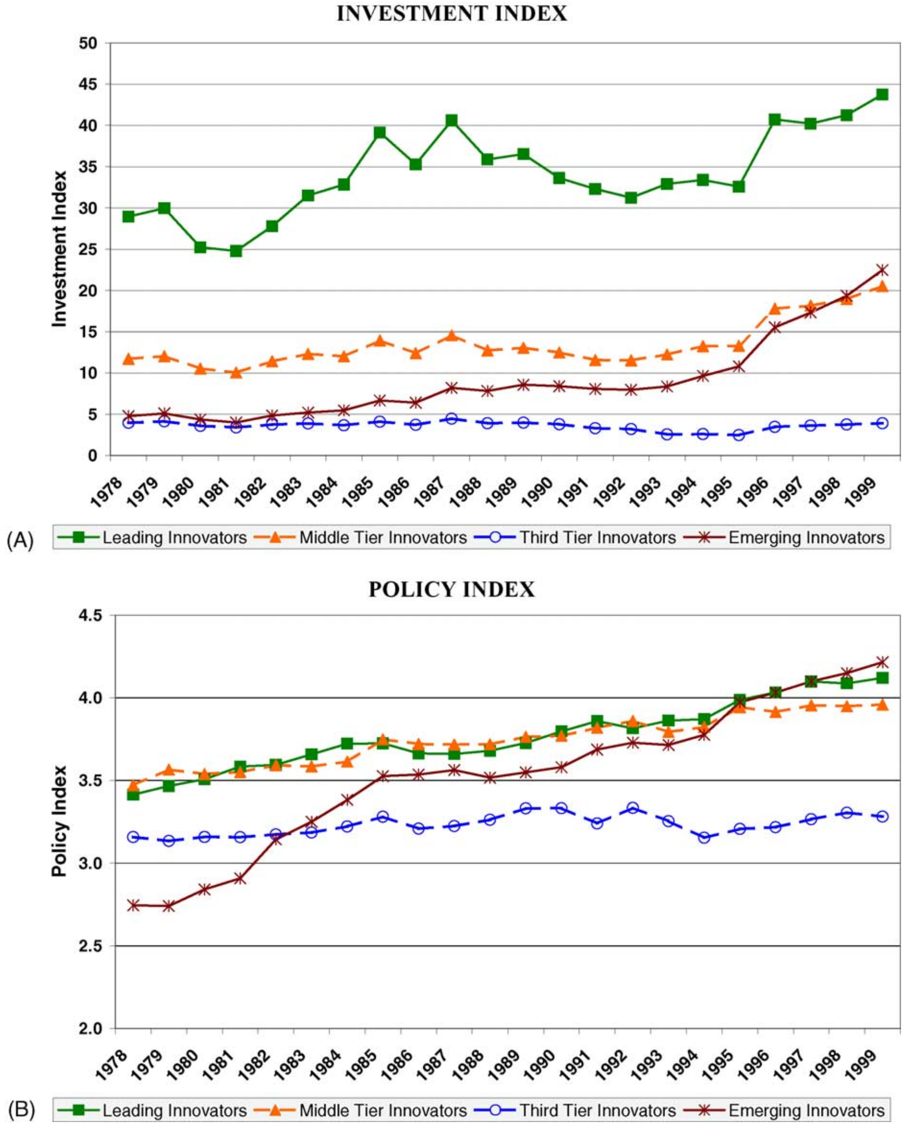
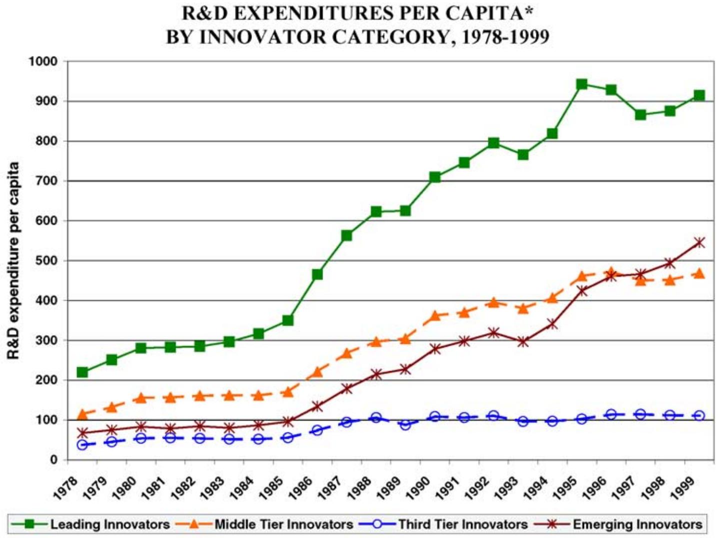


Fig. 5.

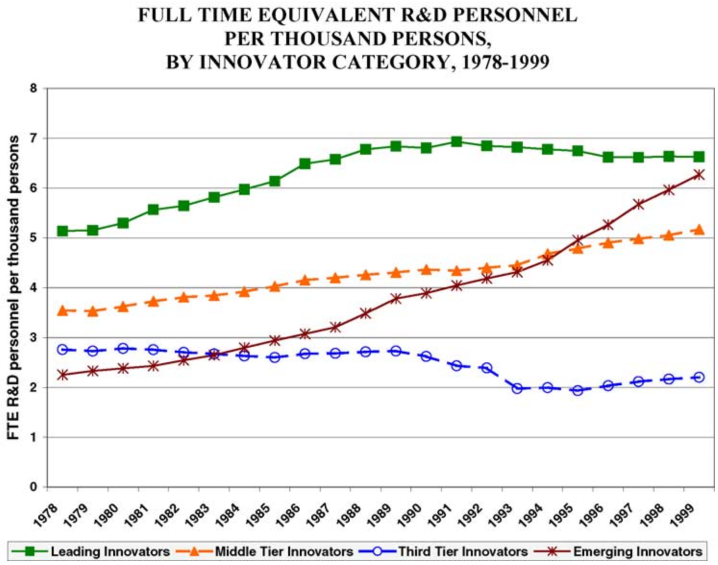
tier innovator countries to a level that exceeds that of middle tier countries. This steady increase reflects, in part, rising levels of per capita GDP in emerging innovator countries, but derives as well from increased commitments to R&D expenditure and human capital. Fig. 6 plots levels of R&D$ PER CAPITA and FTE R&D PERS PER CAPITA by innovator category over time. In each category, emerging innovator countries increase their investments at a rate greater than that of other categories of innovator countries. The increase in FTE R&D PERS PER CAPITA among emerging innovator countries is so significant that per capita R&D employment in these countries is nearly equal to that of leading innovator countries by the end of the 1990s.

Differences in the timing of catch-up in the Investment and Policy indices constitute a second observation of interest in Fig. 5. Beginning in the 1980s, leading innovator and middle tier innovator countries have nearly equal policy index values and the differences between these countries' index values and those of the third tier



(A)

*in year 2000 US dollars



(B)

Fig. 6.

innovators is less than 25%. Again the emerging innovator countries have made startling progress, with policy progress taking them to a comparable level to the leading innovator countries. It is also interesting to note that, with the exception of a few years in the late 1980s and early 1990s, the Policy Index does not increase significantly in third tier innovator countries over the sample period.

The coefficient of variation decreases over time for both the Investment and Policy indices across the sample of countries. Although both coefficients of variation decrease over time, the investment index exhibits greater variation across countries than the policy index. Similarly, the coefficients of variation decrease over time for both the predicted and actual international patenting rates. These results provide preliminary evidence of a “narrowing of the gap” in national innovation rates, driven by decreases in the variation of both investment levels and policy effects.

Taken together, the elements of this descriptive exercise suggest that both changes in the policy environment (i.e., changes in X^{INF}, Y^{CLUS}, and Z^{LINK}) and changes in investment levels (H^A) have affected catch-up dynamics in innovative productivity. The larger source of variation and catch-up across countries and innovator categories appears to derive from the investment index, suggesting that its elements have had the most impact in affecting relative levels of innovative capacity.

6. Discussion

In this paper we contribute on a line of research that investigates the factors affecting national innovative output. We pursue an approach at an intermediate level of abstraction that combines elements from formal economic modeling and the more qualitative and appreciative traditions of research in innovation studies. In this effort, we aim to build on one of the core areas of Keith Pavitt’s research, and to do so in a manner consistent with his principled, eclectic approach to understanding the phenomena associated with innovation. Specifically, we examine the factors that drive levels of innovative output in a sample of 29 countries, including the majority of the world’s most innovative economies during the years 1978–1999. A number of key observations emerge. Consistent with prior research, we find that a parsimonious model based on the national innovative capacity framework performs in a statistically precise way in predicting our measure of national innovative output, international patents. Although our econometric models are based on a particular measure that does not capture the universe of innovation in a country, we believe that this measure correlates well with our underlying concept of interest and that our results provide useful evidence that the factors that drive national innovative capacity are important in affecting country-level innovation.

This econometric analysis serves as the underpinning for our efforts to understand the factors that explain recent developments in innovative productivity. Specifically, we investigate why some countries were able to dramatically increase their ability to generate a stream of leading-edge innovations while other countries – including a number of countries with historically higher levels of innovation – did not. The results suggest that there is no ‘magic bullet’ that explains these changes. Rather, innovative leadership arises from a range of sustained investments and policy commitments. Our analysis suggests that innovation-oriented policies and an appropriate composition of innovation-oriented investments are pre-requites for innovative leadership, in the sense these characterize each of the world’s leading innovator countries. Further, our results provide evidence that, though necessary, these choices alone are not sufficient to ensure innovative leadership. In fact, countries that we classify as middle tier innovators – countries whose levels of innovative capacity have been fairly stable, and consistently less than those of leading innovators – evidence policy commitments quite similar to the leading countries throughout the sample period, although their levels of innovative capacity remain substantially lower than those of the leading innovators. While no country achieves a relatively high level of innovative capacity without such innovation-oriented policy commitments, policy commitments appear to be insufficient in the absence of vastly increased investments in the drivers of innovative capacity.

The data do suggest that continuously increasing investments in innovation is, ultimately, essential for achieving innovative leadership. Japan, consistently among the world’s most innovative countries during the sample period, experienced an increase in R&D personnel of approximately 85%; by contrast, France, which begins the period with a lower fraction of R&D workers in its labor force and is consistently a middle tier innovator country, only experiences a 32% increase in R&D personnel. The results of our counterfactual index suggest that substantial increases in investments characterize the emerging innovator countries whose innovative capacity develops most over the period. For example, Finland’s real R&D expenditures increase 14-fold over the period and South Korea’s real R&D expenditures were more than 450 times greater in 1999 than they were in 1978. These increases are significant in both relative terms and absolute terms, and are part of the factors that enable their substantial increases in overall innovative capacity.

In some sense, a straightforward implication of our results is that greater inputs into innovation at the country level are associated with greater outputs; however, a simplistic interpretation of this result would be incomplete. Whereas all countries that achieve substantial increases in innovative capacity increased investments in key drivers of innovation over the period, each of these countries also maintained innovation-enhancing policies. A number of countries achieved policies supportive of innovation, but did not invest in R&D to the same degree. By contrast, no country appears to achieve high levels of investment in innovation without innovation-oriented policies. Together, these findings suggest to us that a well-functioning innovation infrastructure is necessary but not sufficient to create the environment required to achieve sustained innovation at the world's technological frontier.

Moreover, the finding that a number of wealthy economies with well-functioning science and innovation systems do not increase their investments in innovation sufficiently to enter the 'club' of leading innovator countries suggests either that national innovative leadership is a strategy that countries choose not to pursue or that continuously deepening commitments to innovation are difficult to achieve, even for middle tier innovator economies. Although it is important to exercise caution in interpreting the results for policy, the results suggest that, for such middle tier countries, the greatest challenge in enhancing innovative productivity lies in increasing their levels of investment in innovation rather than in adjusting their national policies or innovation systems. For third tier innovators, it appears as if there is room for improvement on both dimensions. While the success of a number of emerging innovator economies allows for hope, the results also quantify the magnitude of the challenges faced by historically less-innovative economies in increasing their innovative capacity substantially enough to achieve innovative productivity commensurate with the world's innovator countries.

Researchers in innovation studies, including authors in the national innovation systems approach, have often asked about the country-specific factors that affect the composition of inputs into innovation – and often report on the levels of inputs into the innovation process.[22] The results of this study suggest deepening this research agenda to focus as well on the determinants of the *level* of innovative inputs achieved by an economy. In the tradition of Keith Pavitt's research, both qualitative and quantitative approaches could bear fruit. Large-scale empirical analyses that jointly estimate the determinants of innovative inputs and outputs could tackle endogeneity issues not addressed by a reduced form approach; detailed, cased-based research would, however, be a necessary complement that elucidates the underlying mechanisms by which these processes occur.

The complementarity between detailed qualitative work and large-scale empirical analysis is also important for understanding the phenomenon associated with emerging innovator countries. While emerging innovator countries share the fact that they have managed to increase their commitments to innovative capacity in a way not matched by middle tier or third tier innovator countries, these countries – e.g., Iceland, Ireland, and South Korea – vary substantially in the institutional configurations that characterize their national innovation systems. That they are all able to achieve relatively high levels of innovative capacity underscores the point that there is no universal recipe that enables follower countries to catch-up to leading innovator economies. Understanding both the unique circumstances that have led these countries to make substantial commitments to innovative capacity and the common relationships that allow these countries' investments to bear fruit requires the interplay between qualitative and quantitative research methods.

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[22] Romer (2000), for example, investigates whether US government subsidies for scientist and engineering are essential or excessive.

Table A.1

Country	1976–1980	1995–1999	Growth rate
Emerging Latin American economies			
Argentina	115	228	0.98
Brazil	136	492	2.62
Chile	12	60	4.00
Colombia	28	42	0.50
Costa Rica	22	48	1.18
Mexico	124	431	2.48
Venezuela	50	182	2.64
Emerging Asian economies			
China	3	577	191.33
Hong Kong	176	1694	8.63
India	89	485	4.45
Malaysia	13	175	12.46
Singapore	17	725	41.65
South Korea	23	12062	523.43
Taiwan	135	15871	116.56

Source: Porter et al. (2000).

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Appendix A

See Table A.1.

References

Abramovitz, M., 1956. Resource and output trends in the United States since 1870. American Economic Review 46 (2), 5–23.

Abramovitz, M., 1986. Catching up, forging ahead and falling behind. Journal of Economic History 46, 385–406.

Ames, E., Rosenberg, N., 1963. Changing technological leadership and industrial growth. Economic Journal 74, 13–31.

Amsden Alice, H., 1989. Asia's Next Giant. Oxford University Press, New York.

Arora, A., Landau, R., Rosenberg, N., 1998. Chemicals and Long-Term Economic Growth: Insights from the Chemical Industry. Wiley, New York, NY.

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

Barro, R., Sala-i-Martin, X., 1995. Economic Growth. McGraw-Hill.

Baumol, W.J., 1986. Productivity growth, convergence, and welfare: what the long-run data show. American Economic Review 76 (5), 1072–1085.

Baumol, W.J., Batey, S.A., Wolff, E.N., 1989. Productivity and American leadership: The Long View. MIT Press, Cambridge, MA.

Bell, M., Pavitt, K., 1992. Accumulating technological capability in developing countries. The World Bank Research Observer, 257–272.

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

Bush, V., 1945. Science, the Endless Frontier. A Report to the President on a Program for Postwar Scientific Research. National Science Foundation, Washington, DC.

DeLong, J.B., 1988. Productivity Growth, Convergence, and Welfare: Comment. American Economic Review 78 (5), 1138–1154.

Dosi, G. (Ed.), 1988. Technical Change and Economic Theory. Pinter Publishers, London, UK.

Dosi, G., Freeman, C., Silverberg, G., Soete, L., 1988. Technical Change and Economic Theory. Pinter Publishers, London, UK.

Dosi, G., Pavitt, K., Soete, L., 1990. The Economics of Technical Change and International Trade. Columbia University Press, New York, NY.

Eaton, J., Kortum, S., 1996. Trade in ideas: patenting and productivity in the OECD. Journal of International Economics 40 (3), 2–8.

Eaton, J., Kortum, S., 1999. International technology diffusion: theory and measurement. International Economic Review 40 (3), 537–570.

Edquist, C. (Ed.), 1997. Systems of Innovation: Technologies, Institutions, and Organizations. Pinter Publishers, London, UK.

Evenson, R., 1984. International invention: implications for technology market analysis. In: Zvi, Griliches (Ed.), R&D, Patents, and Productivity. University of Chicago Press, Chicago, IL, pp. 89–126.

Fagerberg, J., 1987. A technology gap approach to why growth rates differ. Research Policy 16 (2/4), 87–99.

Fagerberg, J., 1988. Innovation, catching up, and growth. In: Technology and Productivity: The Challenge for Economic Policy. OECD, Paris, pp. 37–46.

Fagerberg, J., 1994. Technology and international differences in growth rates. Journal of Economic Literature 32 (3), 1147–1175.

Fagerberg, J., Verspagen, B., 2002. Technology-gaps, innovation-diffusion, and transformation: an evolutionary interpretation. Research Policy 31, 1291–1304.

Freeman, C., 1987. Technology Policy and Economic Performance: Lessons from Japan. Pinter, London, UK.

Freeman, C., 1988. Japan: a new system of innovation. In: Dosi, G. (Ed.), Technical Change and Economic Theory. Pinter Publishers, London, UK, pp. 330–348.

Furman, J.L., Porter, M.E., Stern, S., 2002. The determinants of national innovative capacity. Research Policy 31, 899–933.

Furman, J.L., Porter, M.E., Stern, S., 2000. Understanding the drivers of national innovative capacity. Academy of Management Best Papers in Proceedings.

Furman, J.L., Stern, S., 2000. Understanding the drivers of national innovative capacity – implications for central european economies. Wirtschaftspolitische Blätter 47 (2).

Gans, J.S., Stern, S., 2003. Assessing Australia's Innovative Capacity in the 21st Century. Intellectual Property Research Institute of Australia Working Paper.

Gerschenkron, A., 1962. Economic Backwardness in Historical Perspective. Belknap Press of Harvard University Press, Cambridge, MA.

Griliches, Z. (Ed.), 1984. R&D, Patent and Productivity. Chicago University Press, Chicago, IL.

Griliches, Z., 1990. Patent statistics as economic indicators: a survey. Journal of Economic Literature 92, 630–653.

Grossman, G., Helpman, E., 1991. Innovation and Growth in the Global Economy. MIT Press, Cambridge, MA.

Hu, M.-C., Mathews, J.A., 2004. National Innovative Capacity in East Asia. Macquarie University Working Paper.

Im, K., Pesaran, M., Shin, Y., 2003. Testing for unit roots in heterogeneous panels. Journal of Econometrics 115, 53–74.

Islam, N., 1995. Growth empirics: a panel data approach. Quarterly Journal of Economics 110, 1127–1170.

Islam, N., 2003. What have we learnt from the convergence debate? Journal of Economic Surveys 17 (3), 309–362.

Jones, C., 1995. R&D based models of economic growth. Journal of Political Economy 103, 739–784.

Jones, C., 1998. Introduction to Economic Growth. W.W. Norton & Company, New York, NY.

Keller, W., Gong, G., 2003. Convergence and polarization in global income levels: a review of recent results on the role of international technology diffusion. Research Policy 32, 55–79.

Kim, L., 1997. Imitation to Innovation: The Dynamics of Korea's Technological Learning. Harvard Business School Press, Cambridge, MA.

Kortum, S., 1997. Research, patenting, and technological change. Econometrica 65 (6), 1389–1419.

Kortum, S., Lerner, J., 1999. What is behind the recent surge in patenting. Research Policy 28 (1), 1–22.

Levin, A., Lin, C., Chu, C., 2002. Unit root tests in panel data: asymptotic and finite-sample properties. Journal of Econometrics 108, 1–24.

Lundvall, B.-A., 1988. Innovation as an interactive process: from user-producer interaction to the national system of innovation. In: Dosi, G. (Ed.), Technical Change and Economic Theory. Pinter Publishers, London, UK, pp. 349–369.

Lundvall, B.-A., 1992. National Systems of Innovation: Towards a Theory of Innovation and Interactive Learning. London, UK, Pinter.

McKelvey, M., 1991. How do national systems of innovation differ? A critical analysis of Porter, Freeman, Lundvall, and Nelson. In: Hodgson, G.M., Screpanti, E. (Eds.), Rethinking Economics – Markets, Technology, and Economic Evolution. Edward Elgar, Aldershot, UK.

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

Neely, A., Hii, J., 1998. Innovation and Business Performance: A Literature Review, mimeo. Judge Institute of Management Studies, University of Cambridge.

Nelson, R.R., 1981. Research on productivity growth and productivity differences: dead ends and new directions. Journal of Economic Literature 19 (3), 1029–1064.

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

Nelson, R.R., Winter, S., 1982. An Evolutionary Theory of Economic Change. Harvard University Press, Cambridge, MA.

Nelson, R.R., Wright, G., 1992. The rise and fall of American technological leadership: the postwar era in historical perspective. Journal of Economic Literature 30 (4), 1931–1964.

North, D.C., 1990. Institutions, Institutional Change, and Economic Performance. Cambridge University Press, Cambridge, UK.

Ohkawa, K., Rosovsky, H., 1973. Japanese Economic Growth. Stanford University Press, Palo Alto, CA.

O'Sullivan, M., 2000. The sustainability of industrial development in Ireland. Regional Studies 34 (3), 277–290.

Patel, P., Pavitt, K., 1987. Is Western Europe losing the technological race? Research Policy 16 (2/4), 59–86.

Patel, P., Pavitt, K., 1989. A comparison of technological activities in West Germany and the United Kingdom, National Westminster Bank. Quarterly Review, 27–42.

Patel, P., Pavitt, K., 1994. National innovation systems: why they are important, and how they might be measured and compared. Economics of Innovation and New Technology 3 (1), 77–95.

Pavitt, K., 1979. Technical innovation and industrial development. Futures 11 (6), 458–470.

Pavitt, K., 1980. Industrial R&D and the British economic problem. R&D Management 10, 149.

Pavitt, K., 1982. R&D, patenting, and innovative activities: a statistical exploration. Research Policy 11 (1), 33–51.

Pavitt, K., 1985. Patent statistics as indicators of innovative activities: possibilities and problems. Scientometrics 7, 77–99.

Pavitt, K., 1988. Uses and abuses of patent statistics. In: van Raan, A. (Ed.), Handbook of Quantitative Studies of Science Policy. North Holland, Amsterdam.

Porter, M.E., 1990. The Competitive Advantage of Nations. The Free Press, New York, NY.

Porter, M.E., Stern, S., 1999. The New Challenge to America's Prosperity: Findings from the Innovation Index. Council on Competitiveness, Washington, DC.

Porter, M.E, Stern, S., 2000. Measuring the 'Ideas' Production Function: Evidence from International Patent Output, NBER Working Paper 7891.

Porter, M.E., Furman J.L., Stern S., 2000. Los Factores Impulsores de la Capacidad Innovadora Nacional: Implicaciones para Espana y America Latina (English title: The Drivers of National Innovative Capacity: Implications for Spain and Latin America), Claves de la Economia Mundial. ICEX, Madrid, Spain, pp. 78–88.

Quah, D.T., 1997. Empirics for growth and distribution: stratification, polarization, and convergence clubs. Journal of Economic Growth 2, 27–59.

Romer, P., 1990. Endogenous technological change. Journal of Political Economy 98, S71–S102.

Romer, P., 1996. Why, indeed, in America? American Economic Review 86 (2), 202–206.

Romer, P., 2000. Should the Government Subsidize Supply or Demand in the Market for Scientists and Engineers? NBER Working Paper No. w7723.

Rosenberg, N., 1963. Technological change in the machine tool industry, 1840–1910. Journal of Economic History 23, 414–443.

Scherer, F.M., 1983. The propensity to patent. International Journal of Industrial Organization 1, 107–128.

Sala-i-Martin, X., 1996. The classical approach to convergence analysis. The Economic Journal 106, 1019–1036.

Schumpeter, J., 1942. Capitalism, Socialism and Democracy, 2nd ed. George Allen & Unwin, Ltd., London.

Schmookler, J., 1966. Invention and Economic Growth. Harvard University Press, Cambridge, MA.

Soete, L.G., Wyatt, 1983. The use of foreign patenting as an internationally comparable science and technology output indicator. Scientometrics 5 (1), 31–34.

Solow, R.M., 1956. A contribution to the theory of economic growth. Quarterly Journal of Economics 70, 65–94.

Suarez-Villa, L., 1990. Invention, inventive learning, and innovative capacity. Behavioral Science 35, 290–310.

Suarez-Villa, L., 1993. The dynamics of regional invention and innovation: innovative capacity and regional change in the twentieth century. Geographical Analysis 25 (2), 147–164.

Trajtenberg, M., 1990. Patents as Indicators of Innovation, Economic Analysis of Product Innovation. Harvard University Press, Cambridge, MA.

Trajtenberg, M., 2001. Innovation in Israel 1968–1997: a comparative analysis using pate data. Research Policy 30 (3), 363.

Veblen, T., 1915. Imperial Germany and the Industrial Revolution. Macmillan, New York.

Vertova, G., 1999. Stability in national patterns of technological specialisation: some historical evidence from patent data. Economics of Innovation and New Technology 8 (4), 331–354.

Young, A., 1995. The tyranny of numbers: confronting the statistical realities of the East Asian growth experience. Quarterly Journal of Economics 110, 641–680.