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# THE DETERMINANTS OF NATIONAL INNOVATIVE CAPACITY

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The Determinants of National Innovative Capacity
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## ABSTRACT

Motivated by differences in R&D productivity across advanced economies, this paper presents an empirical examination of the determinants of country-level production of international patents. We introduce a novel framework based on the concept of *national innovative capacit*y. National innovative capacity is the ability of a country to produce and commercialize a flow of innovative technology over the long term. National innovative capacity depends on the strength of a nation's common innovation infrastructure (cross-cutting factors which contribute broadly to innovativeness throughout the economy), the environment for innovation in its leading industrial clusters, and the strength of linkages between these two areas. We use this framework to guide our empirical exploration into the determinants of country-level R&D productivity, specifically examining the relationship between international patenting (patenting by foreign countries in the United States) and variables associated with the national innovative capacity framework. While acknowledging important measurement issues arising from the use of patent data, we provide evidence for several findings. First, the production function for international patents is surprisingly well-characterized by a small but relatively nuanced set of observable factors, including R&D manpower and spending, aggregate policy choices such as the extent of IP protection and openness to international trade, and the *share* of research performed by the academic sector and funded by the private sector. As well, international patenting productivity depends on each individual country's knowledge "stock." Further, the predicted level of national innovative capacity has an important impact on more downstream commercialization and diffusion activities (such as achieving a high market share of high-technology export markets). Finally, there has been convergence among OECD countries in terms of the estimated level of innovative capacity over the past quarter century.

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## I. INTRODUCTION

While R&D activity is relatively dispersed around the world, innovation of “new-to-the-world” technologies has historically been concentrated in a few countries. During the 1970s and the early 1980s, only Switzerland, a relatively small but technology-intensive economy, achieved a per capita “international” patenting rate comparable to that of U.S. inventors. This variation among advanced economies in their ability to innovate at the global frontier raises an empirical puzzle: if inventors can draw on technological and scientific insights from throughout the world, why does R&D productivity depend on location?

This question is important for at least two reasons. First, technological innovation plays a central role in the process of long-run economic growth. Despite substantial agreement about this proposition, there is a great deal of debate about the underlying drivers of the innovation process itself. International variation in R&D productivity presents an opportunity to examine how different influences contribute to technological innovation and thereby distinguish among different drivers of productivity growth. Second, understanding international differences in R&D productivity informs science, technology, and broader issues of economic policy. Most R&D productivity studies have focused on the “innovation” production function (i.e., the relationship between inputs for innovation such as R&D expenditures or manpower and “visible” outputs such as patenting or new product announcements) within a *given* public policy environment (Griliches, 1984; 1998). However, estimating the impact on innovation of country-level policy differences ties more directly to policy evaluation.

Motivated by these twin concerns, this paper evaluates the sources of differences among countries in terms of their production of visible innovative output. To do so, we introduce a novel framework based on the concept of *national innovative capacity*. National innovative capacity is the ability of a country – as both a political and economic entity – to produce and commercialize a flow of innovative technology over the long term. Innovative capacity depends on an interrelated set of investments, policies, and resource commitments which underpin the production of new-to-the-world technologies. National innovative capacity is not the realized level of innovative output at a single point in time but reflects the more fundamental determinants of the innovation process. Differences in national innovative capacity reflect variation in both economic geography (e.g., the level of spillovers between firms) as well as cross-country differences in innovation policy (e.g., the level of public support for basic research or legal protection for intellectual property).

We develop the national innovative capacity framework by drawing on three distinct areas of prior research: ideas-driven endogenous growth theory (Romer, 1990), the cluster-based theory of national industrial competitive advantage (Porter, 1990), and the literature on national innovation systems (Nelson, 1993). Each of these perspectives seeks to identify factors in a national environment which determines the flow of innovation. Not surprisingly, these theories share common elements; however, each also contributes a distinct perspective. For example, in models of ideas-driven growth, the *ideas production function* depends on two aggregate factors that influence the rate of innovation in a national economy: the prior stock of knowledge accumulated by that economy and the level of R&D effort devoted towards ideas production (as opposed to final goods production). Porter (1990) emphasizes the microeconomic underpinnings of innovation in country-specific industrial clusters; this relationship depends on subtle interactions between input supply and local demand conditions, the presence and orientation of related and supporting industries, and the nature of local competitive rivalry. By focusing on industrial clusters (e.g., information technology) rather than individual industry segments (e.g., printers), this perspective highlights how the rate of innovation depends critically on both knowledge spillovers and the nature of technological interdependencies across related sectors. Finally, the national innovation systems literature, built on rich descriptive accounts of the organization of innovation in specific countries, tends to emphasize the role of the overall national policy environment (e.g., intellectual property or trade policy), the educational sector, as well as more idiosyncratic institutions that affect innovation but for which international comparison is difficult (e.g., the rules of specific funding agencies in individual countries).

When considered together, these perspectives suggest that the determinants of national innovative capacity can be divided into several broad areas. First, national innovative capacity depends on the presence of a strong common innovation infrastructure, or cross-cutting factors which contribute broadly to innovativeness throughout the economy. Among other things, the common innovation infrastructure includes a country's overall science and technology policy environment, the mechanisms in place for supporting basic research and higher education, and the cumulative "stock" of technological knowledge upon which new ideas are developed and commercialized. The common innovation infrastructure therefore includes several of the key elements highlighted by the national innovation systems perspective and ideas-driven growth theory. Second, a country's innovative capacity depends on the more specific innovation environments in a country's industrial clusters. As emphasized by Porter (1990), whether firms invest and compete on the basis of new-to-the-world innovation depends on the microeconomic logic inherent in their local competitive environment. Ultimately, it is the microeconomic conditions associated with a nation's clusters which determine whether firms respond to technological opportunity and innovate at the global frontier. Third, national innovative capacity depends on the strength of linkages between the common innovation infrastructure and specific clusters. The productivity of a strong national innovation infrastructure is higher when specific mechanisms or institutions, such as a strong domestic university system and funding mechanisms for new ventures, migrate ideas from the common infrastructure into commercial practice.

This theoretical framework can be used to evaluate the sources of cross-country R&D productivity differences. The framework highlights the potential importance of the *composition* of research funding and performance. For example, while public R&D spending contributes to the common innovation infrastructure, private R&D spending is a more direct reflection of the innovation environments of a nation's industrial clusters. As well, the framework incorporates both the economic and political roles played by national boundaries. More precisely, whereas one stream of prior research focuses on how geography mediates knowledge spillovers and differential access to human capital (Porter, 1990; Jaffe, Henderson and Trajtenberg, 1993; Krugman, 1991), a second area of prior work has emphasized how national R&D productivity differences may be driven by differential public policies and institutions (Nelson, 1993). Rather than concentrating on a single explanation for R&D productivity differences across countries, our analysis incorporates a relatively diverse set of potential drivers and then adjudicates their empirical salience. Finally, the national innovative capacity framework suggests that while formal ideas-driven growth models offer insight into the broad determinants of innovative activity, cross-country differences in R&D productivity may be driven by more nuanced factors (such as those related to the composition of funding, public policy, and cluster-specific circumstances).

We employ our framework to guide an empirical exploration into the determinants of country-level R&D productivity, estimating the relationship between the production of international patents and a set of observable characteristics associated with national innovative capacity.[1] By focusing on aggregate international patenting data, our analysis cannot fully reflect the full range of innovation produced by an economy nor fully control for differences in countries' industrial composition. However, like other researchers using international patenting data (most notably Eaton and Kortum (1996; 1998)), our approach offers several advantages.[2] First, by examining patenting (an observable consequence of national innovative capacity), we separate the production of new technologies from the more general relationship between investment in R&D and overall productivity growth.[3] Second, by exploiting the panel nature of the data, we can explicitly estimate the strength of several inherently dynamic processes, such as the accumulation of frontier knowledge over time by an individual country, and identify those results which are robust to controls for country-level fixed effects. Finally, our empirical framework can be used to provide comparable quantitative assessments of the innovative capacity of specific countries over time; these estimates complement the richer but less comparable findings of the national innovation system literature.

The bulk of the empirical analysis focuses on a detailed examination of the relationship between international patenting and different potential contributors to national innovative capacity. Since some of the most critical forces (such as the environment for innovation in specific clusters) cannot be observed directly at the aggregate level; we therefore employ a

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[1] International patents are defined as those patents which are granted by the USPTO to a non-US inventor (or in the case of the US, by a major foreign patent granting agency). We also examine alternative indicators of new-to-the-world innovative output, including scientific articles and export shares in "high-technology" industry segments.

[2] In using international patenting data to understand the sources and consequences of innovation, this paper builds on Evenson (1984), Dosi, Pavitt, and Soete (1990), and recent work by Eaton and Kortum (1996; 1998). We extend these prior analyses by linking our results more closely to a range of theories about the determinants of national innovative capacity and by exploring a relatively long panel which allows us to incorporate both cross-sectional and time-series variation.

[3] As such, this study complements a much larger literature on the reduced form impact of R&D on TFP growth (Coe

number of intermediate measures (or proxies) which do not capture the underlying drivers directly but measure important economic outcomes associated with their strength.

Our results suggest that the production function for international patents is surprisingly well-characterized by a small number of observable factors which describe a country's national innovative capacity. In particular, we find decisive and robust effects on international patenting from R&D manpower and spending, aggregate policy choices such as the extent of IP protection and openness to international trade, and the *share* of research performed by the academic sector and the share funded by the private sector. We demonstrate that the production function for international patents depends on each individual country's knowledge stock (using either GDP per capita or the country-specific patent stock). Finally, we show that the predicted level of national innovative capacity has a substantial impact on more downstream commercialization and diffusion activities (such as achieving a high share of high-technology export markets).

Our framework provides insight into the nature of country-level R&D productivity differences. In particular, R&D productivity differences result from factors associated with each of the distinct sources of national innovative capacity. On the one hand, a number of different elements of the economic environment vary across countries, including the access to cutting-edge knowledge, the degree to which R&D expenditures are driven by private sector investment, and the presence of mechanisms such as universities which link innovative efforts across the economy. On the other hand, R&D productivity differences are associated with political factors, such as policy choices and government resource commitments. Consequently, though models of ideas-driven growth abstract away from these phenomena, accounting for nuanced sources of variation in the economic and political environment is important for understanding why countries differ in their R&D productivity. As well, our results suggest that a small set of observable measures usefully characterizes the determinants of national innovative capacity. While the national innovation systems literature has tended to rely on detailed qualitative descriptions of the differences across countries, our results suggest that the consequences of these differences can be captured by nuanced but observable measures of variation.

Further, our results have counterfactual implications in terms of trends in the predicted

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and Helpman, 1995; Jones, 1995; Park, 1995; Keller, 1997).

values of international patenting.[4] We examine how countries differ over time in their predicted flow of international patents per capita and find that there has been substantial *convergence* in the level of per capita national innovative capacity across the OECD since the mid-1970s. During the 1970s and early 1980s, the predicted level of per capita international patenting by the United States and Switzerland was substantially above the level of other members of the OECD. Since that time, several countries (most notably Japan, some Scandinavian countries, and Germany) have achieved levels of predicted per capita international patenting similar to that of the United States. Interestingly, there are several exceptions to this overall pattern of convergence; specifically, the United Kingdom and France have shown little change in their measured level of national innovative capacity over the past quarter century.

The remainder of the paper proceeds by first motivating and developing our theoretical framework. We then outline the relationship between visible innovative output and the elements of national innovative capacity. After a discussion of the data, we turn to the principal empirical results of the paper. A final section concludes.

## II. THEORIES OF NEW-TO-THE-WORLD INNOVATION PRODUCTION

The national innovative capacity framework seeks to integrate several perspectives regarding the sources of innovation at the national level: (1) theories of ideas-driven growth (Romer, 1990); (2) microeconomic models of national competitive advantage and industrial clusters (Porter, 1990); and (3) the literature on national innovation systems (Nelson, 1993). While these perspectives contain some comment elements, each also identifies some distinct drivers of the innovation process.

Ideas-driven growth theory, the most abstract conceptualization, focuses at an aggregate level, emphasizing the quantifiable relationships among a small set of factors which determine the flow of new ideas in an economy. While the centrality of technological innovation in economic growth has been appreciated since the seminal contributions of Solow (1956) and Abramovitz (1956), it was only in the late 1980s that technological change was treated

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[4] Porter and Stern (1999b) review these counterfactuals in much greater detail than is presented here.

endogenously in such models. In particular, the Romer growth model (1990) contributes to this literature by articulating the economic foundations for a sustainable rate of technological progress ($\dot{A}$) through the introduction of an ideas sector of the economy. This operates according the national ideas production function:

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

According to this production structure, the rate of new ideas production is simply a function of the number of ideas workers ($H_A$) and the stock of ideas available to these researchers ($A_t$) (see Figure A). This function makes the rate of technological change endogenous in two distinct ways. First, the share of the economy devoted to the ideas sector is a function of the R&D labor market (which determines $H_A$); allocation of resources to the ideas sector depends on R&D productivity and the private economic return to new ideas. Second, the productivity of new ideas generation is sensitive to the stock of ideas discovered in the past. When $\phi > 0$, prior research increases current R&D productivity (the so-called “standing on shoulders” effect); when $\phi < 0$, prior research has discovered the ideas which are easiest to find, making new ideas discovery more difficult (the “fishing out” hypothesis). Though there is a sharp debate over the precise value of these parameters (Jones, 1995; Porter and Stern, 1999a),[5] there is relatively broad agreement that these two factors are, indeed, crucial in explaining the realized level of economywide innovation.

Whereas ideas-driven growth theory focuses almost exclusively on this critical but narrow set of factors, Porter (1990) also incorporates a more nuanced treatment of the impact of the microeconomic environment in evaluating the relationship between competition, innovation, and realized productivity growth (Figure B).[6] This framework suggests that the microeconomic

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[5] In Romer’s model of sustainable long-term growth from new ideas, $\phi = \lambda = 1$, implying that a given percentage increase in the stock of ideas results in a proportional increase in the productivity of the ideas sector. Under this assumption, the growth rate in ideas is a function of the level of effort devoted to ideas production ($\frac{\dot{A}}{A} = \delta H_A$), ensuring a sustainable rate of productivity growth. In contrast, Jones (1995) suggests that $\phi$ and $\lambda$ may be less than one, with the potential consequence of eliminating the possibility of sustainable long-term growth. However, in a companion paper, we suggest that, at least for explaining the dynamic process of producing visible innovation (i.e., patents), the hypothesis that $\phi = 1$ cannot be rejected (Porter and Stern, 1999a).

[6] Rosenberg (1963) was perhaps the first to identify the critical interdependencies between nuanced microeconomic forces, including the nature of the local competitive environment and the composition of demand, and the realized

environment in a nation's industrial clusters will be an essential determinant of the rate of innovation in the private sector. As shown in Figure B, the first determinant of cluster-level innovative activity is the availability of high-quality and specialized innovation inputs. Above and beyond the simple availability of trained scientists and engineers (as emphasized in ideas-driven growth theory), R&D productivity depends on the degree to which R&D personnel are specialized in disciplines and fields congruent with emerging innovation opportunities in the local environment. This "matching" process is more likely in the presence of institutions such as research universities and allocation mechanisms such as efficient labor markets for newly trained PhDs. A second determinant is the extent to which the local competitive context is both intense and rewards successful innovators. This depends on innovation incentives such as intellectual property protection but also consistent pressure from intense local rivalry and openness to international competition. This stimulates innovation by raising the bar for product and processes while the inflow of ideas (Sakakibara and Porter, 1998). A third determinant of cluster-level innovation is the nature of domestic demand for innovative products and services, which depends in turn on the presence of a sophisticated, quality-sensitive local customer base for the cluster's goods. Through increasingly demanding purchasing behavior, such customers drive domestic commercialization activities toward best-in-the-world technologies, raising the incentives to pursue globally novel innovative investments. The final element in the cluster framework is the availability, density and interconnectedness of vertically and horizontally-related industries within the cluster. The presence of related industries generates positive externalities both from knowledge spillovers and cluster-level scale economies, which are particularly salient when clusters are concentrated geographically. Overall, this framework suggests that the level of realized innovation in an economy depends upon the degree to which the private R&D enterprise is fueled by domestic competitive pressures.

Finally, the national innovation systems approach focuses on textured description of the organization and patterns of activity that contribute to innovative behavior in specific countries, and identifies those institutions and actors who play a decisive role in particular industries (see

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rate of economywide productivity growth.

Nelson, 1993, for the most comprehensive account in this literature).[7] While both the ideas-driven growth models and theories of national industrial competitive advantage incorporate the role of public policies in shaping the rate of innovation (at least to some degree), the national innovation systems literature emphasizes the active role played by government policy and specific institutional actors. Particular institutional and policy choices highlighted by this literature include the nature of the university system (Nelson and Rosenberg, 1994), the extent of intellectual policy protection (Merges and Nelson, 1991), the historical evolution of industrial R&D organization (Mowery, 1984) and the division of labor between private industry, universities and government in R&D performance and funding (Mowery and Rosenberg, 1998).[8]

The national innovation systems approach stresses the diversity in national approaches to innovation. Indeed, a particular goal of this literature is to provide detailed comparisons of national structures, policies, and institutions. For example, Figures C-1 and C-2 sketch some of the important components and linkages in the national innovation system of the United States and Germany, as described in Nelson (1993).

These three perspectives offer common insights about the innovative process. For example, all three perspectives agree about the centrality of R&D manpower and the need for a deep, local technology base. Without skilled scientists and engineers operating in an environment with access to cutting-edge technology, it is unlikely that a country will produce an appreciable amount of new-to-the-world innovative output. Beyond these common elements, Porter highlights how the flow of innovation is shaped by specialized inputs and knowledge, demand-side pressures, competitive dynamics and externalities across related firms and industries; in contrast, the national innovation systems literature stresses the role played by a nation's common institutions and policies in affecting innovative output. Whereas ideas-driven growth and cluster theory focus on the economic impact of geography (i.e., spillovers tend to be localized), the national innovation systems literature focuses more on the political implications of geography (i.e., the impact of policies and institutions is circumscribed by national borders).

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[7] Early articulations of this perspective can be found in Part V of Dosi, et al., (1988).

[8] More generally, this literature builds on insights about the historical relationship between the resource endowments and geographic structure of the United States and the evolution of its institutions and industries relative to that of Great Britain and the rest of Europe (Rosenberg, 1969; 1972; Nelson and Wright, 1991; Romer, 1996).

While the national industrial competitive advantage framework acknowledges the importance of both political and economic factors, prior work has not provided an assessment of how these areas interact in shaping the realized rate of innovation at the economywide level. For example, Patel and Pavitt (1994) call for both more qualitative and quantitative analysis in order to understand “the essential properties and determinants of national systems of innovation,” with an emphasis on a connection with models of endogenous technical change and underlying microeconomic forces. It is useful to keep the differences between these three theoretical perspectives in mind as we introduce and empirically explore an integrated framework based on the concept of national innovative capacity, the task to which we now turn.

## III. NATIONAL INNOVATIVE CAPACITY

National innovative capacity is defined as an economy’s potential – as both an economic and political entity – to produce a stream of commercially relevant innovations. Innovative capacity depends in part on the overall technological sophistication of an economy and its labor force, but also an array of investments and policy choices by both government and the private sector. Innovative capacity is related to but distinct from non-commercial scientific and technical advances, which do not necessarily involve the economic application of new technology. Innovative capacity is also distinct from current national industrial competitive advantage or productivity, which can result from many factors in addition to the development and application of new technologies. Differences in national innovative capacity reflect variation in both economic geography (e.g., the level of spillovers between firms) and innovation policy (e.g., the level of public support for basic research or legal protection for intellectual property).

Technological opportunities are most likely to be first exploited in those countries with environments that are conducive to the development of new-to-the-world technology. Given the sustained investment in innovative capacity in the United States in the two decades after World War II, for example, it should not be surprising that many of the most important scientific and technological breakthroughs of that era – including the transistor, the laser, electronic computing, and gene splicing – were developed and initially exploited by American universities and companies. Even though some technical or scientific advances may occur in countries with lower levels of innovative capacity because technological change is at least partly serendipitous, the development and commercialization of such advances is likely to take place in those countries that have policies which encourage the application of new technology for industrial use. Consider the evolution of the chemical sector in the second half of the 19th century. While the underlying technology was due to the (somewhat accidental) discoveries of the British chemist Perkins, the sector quickly developed and became a major exporting area for Germany. 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 (Murmann, 1998; Arora, Landau and Rosenberg, 1998).

We propose a novel framework for organizing the determinants of national innovative capacity into the *common* pool of institutions, resource commitments, and policies that support innovation across the economy, the *particular* innovation environment in the nation's industrial clusters, and the *linkages* between them. The overall innovative performance of an economy results from the interplay between the common infrastructure, which benefits a wide array of fields, and the specific factors that shape innovation in particular clusters.[9]

Figure D illustrates the framework. The left-hand side represents the cross-cutting factors that support innovation in most, if not all, industries. These include such elements as the overall level of technological sophistication in the economy, the supply of scientifically and technically trained workers, the extent of overall investments in basic research and higher education, and the policies that affect the incentives for innovation in any industry. The diamonds on the right side represent the innovative environment in a nation's clusters.[10] The influences identified by Porter (1990) shape the ability of firms in a cluster to pursue innovation-oriented strategies and the pressures on them to do so. Finally, the last part of the framework represents the extent and quality of linkages between the common innovation infrastructure and the clusters – each cluster both draws on the common infrastructure while its investments and competitive choices

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[9] While the current discussion is focused at the country level, we recognize that one could also conduct such an analysis at the regional level, particularly for countries (e.g., Italy) with substantial heterogeneity across regions.

[10] We focus on clusters (e.g., information technology) rather than individual industries (e.g., printers) because of the powerful spillovers connecting the competitiveness and rate of innovation of clusters as a whole. As well, previous research has suggested that many of the most dynamic industrial clusters are quite local in nature and should be understood to operate at the regional or even city level (see, in particular, Porter, 1990, 1998).

contribute in part to that infrastructure.

### *Common Innovation Infrastructure*

Some of the most important investments and choices that support innovative activity operate across *all* innovation-oriented sectors in an economy and so belong to the common innovation infrastructure. Figure E portrays some of its elements. These begin with the two factors identified by endogenous growth theory as important to the production of ideas in an economy: an economy's aggregate level of technological sophistication (A) and the size of the available pool of scientists and engineers who may be dedicated to the production of new technologies ($H_A$). We expand on this conception with additional cross-cutting elements that may be important for explaining the level of innovative output by a country at a point in time (these factors are denoted $X^{INF}$ in Figure E). Specifically, we include the extent to which an economy invests in higher education and the funding of basic research. In Germany, for example, a set of basic research organizations, including the Helmholtz research centers, Max Planck institutes, and the "Blue List" institutes, complement the work of universities by performing basic scientific research. Together, these institutions contribute to the pool of knowledge available for commercial innovation. For our current purpose, the precise interactions among these actors is less important than their net impact on the aggregate level and productivity of resources devoted to innovative activity. Conditional on an economy's overall technological sophistication and science and technical labor force, spending on higher education and R&D will boost the potential for and productivity of innovation throughout the economy.

Public policy choices can also importantly impact the overall incentives and pressures for innovation an economy, including patent and copyright laws, the extent of R&D tax credits, the nature of antitrust laws, the rate of taxation of capital gains, and the openness of the economy to international competition. While some of these policies have stronger impact on some industries than others – intellectual property protection is especially salient for pharmaceutical innovation, for example –such policies support innovation across all sectors.

### *The Cluster-Specific Innovation Environment*

While the common innovation infrastructure sets the general context for innovation in an economy, it is ultimately firms, influenced by their microeconomic environment, that introduce and commercialize innovations. Indeed, the innovative performance of an economy ultimately rests on the behavior of individual firms and clusters. Despite a strong infrastructure supporting biological and chemical sciences and related technical training in France, for example, the particular regulatory policies towards pharmaceuticals have limited innovation in the French cluster through the 1970s and 1980s (Thomas, 1994).

In thinking about the overall innovative performance of an economy, then, one must examine the extent to which innovation is supported by the specific environments of a country's industrial clusters (see Figure B).[11] Measuring these conditions comparably across countries is difficult. In our empirical work, we employ a proxy measuring the extent of financing of R&D by a nation's private sector.

### *The Quality of Linkages*

The relationship between the common innovation infrastructure and industrial clusters is reciprocal: for a given cluster innovation environment, innovative output will tend to increase with the strength of the common innovation infrastructure (and vice versa). While the microeconomic structure of the environmental technologies cluster in Sweden may encourage innovation-oriented competition, for example, the ability of the Swedish cluster to generate and commercialize environmental innovations depends on the overall availability of trained scientists and engineers, access to basic research, and overall policies which reward the development and commercialization of new technologies in the economy.

The strength of linkages determines the extent to which the potential for innovation induced by the common innovation infrastructure is translated into specific innovative outputs in a nation's industrial clusters. While there have been some attempts to understand the role played by these linking mechanisms, most international comparative studies have confined themselves

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[11] Following Porter (1990, 1998), these industrial clusters are the sources of the geographic and cross-industry spillovers which shape and reinforce productivity and with it national industrial competitive advantage.

to carefully identifying and highlighting the existence of institutions that play such roles in particular countries (from the Fraunhofer Institutes in Germany to MITI in Japan to the use of Cooperative Research and Development Associations (CRADAs) in the United States).

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. Germany took advantage of British discoveries in chemistry, for example, while three Japanese firms were the ones to successfully commercialize VCR technology initially developed in the United States (Rosenbloom and Cusumano, 1987).

It is difficult to identify comparable measures of the strength of overall linkages across countries, given the myriad forms such linkages may take. In our empirical work, we do not attempt to construct a summary measure but focus on two specific but important linkage mechanisms -- higher education and venture capital – for which data is available.

## IV. MODELING NATIONAL INNOVATIVE CAPACITY

The national innovative capacity framework highlights several issues which have not been adequately addressed in prior empirical research on cross-country R&D productivity differences. First, our framework allows the incorporation of a wide set of both the economic and political influences of national boundaries. We draw on the stream of prior research that focuses on the impact of geography on knowledge spillovers and differential access to human capital,[12] as well as the work that emphasizes how regional differences may be driven by differential public policies and institutions (Nelson, 1993; Ziegler, 1997). Second, our framework suggests that while formal ideas-driven growth models highlight broad determinants of innovative activity, cross-country differences in R&D productivity may also be related to more nuanced factors (such as those related to industrial organization, the composition of funding, and public policy) which have not been incorporated into formal models but are important to evaluate. Finally, the framework highlights the potential importance of the *composition* of research funding and performance. For example, while public R&D spending adds to the innovative process by

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[12] In addition to Porter (1990), see Jaffe, et al., 1993; Krugman, 1991; Saxenian, 1994; Zucker, et al., 1998; Audretsch and Stephan, 1996; Glaeser, et al., 1992; and Bostic, et al, 1996.

reinforcing the common innovation infrastructure, private R&D spending is a more direct reflection on the environments for innovation in a nation's industrial clusters.

To estimate the relationship between the production of international patents and a set of key observables which contribute to national innovative capacity, we adopt the ideas production function of endogenous growth theory as a baseline (recall (1)). The national innovative capacity framework suggests that a broader set of influences determine innovative performance; hence,, our framework suggests a slightly more general production function for new-to-the-world technologies than the Romer formulation:

$$\dot{A}_{j,t} = \delta_{j,t}(X^{INF}_{j,t}, Y^{CLUS}_{j,t}, Z^{LINK}_{j,t}) H^{A\ \lambda}_{j,t} A^{\phi}_{j,t} \qquad (2)$$

As before, $\dot{A}_{j,t}$ is the flow of new-to-the-world technologies from country j in year t, $H^{A}_{j,t}$ is the total level of capital and labor resources devoted to the ideas sector of the economy, and $A_{j,t}$ is the total stock of knowledge held by an economy at a given point in time 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 countries' industrial clusters, and $Z^{LINK}$ captures the strength of linkages between the common infrastructure and the nation's industrial clusters. Under (2), we are assuming that the various elements of national innovative capacity are complementary with one another in the sense that the marginal boost to production from increasing one factor is increasing in the level of all of the other factors.

Deriving an empirical model from (2) requires addressing three issues: the source of statistical identification, the precise specification of the innovation output production function, and the source of the econometric error. Our choices with respect to each of these issues reflects our overarching goal of letting the data speak for itself as much as possible.

First, the parameters associated with (2) are estimated using a panel dataset of 17 OECD countries over twenty years. These estimates can therefore depend on cross-sectional variation, time-series variation, or both. Choosing among these potential sources of identification depends on what production relationships we would like to highlight in our analysis. On the one hand, while comparisons across countries can easily lead to problems of unobserved heterogeneity, cross-sectional variation provides the direct inter-country comparisons that can reveal the importance of specific drivers of national innovative capacity. On the other hand, while time-series variation may be subject to its own sources of endogeneity (e.g., shifts in a country's fundamentals may reflect idiosyncratic circumstances in its environment), time series variation provides insight into how countries' choices manifest themselves in terms of observed innovative output. Recognizing the benefits (and pitfalls) associated with each identification strategy, our analysis explicitly compares how estimates vary depending on the source of identification used. In most (but not all) of our analysis, we include either year dummies or a time trend, in order to account for the evolving differences across years in the overall level of innovative output. Much of our analysis also includes either country dummies or measures which control for aggregate differences in technological sophistication (e.g., as reflected in GDP per capita).[13]

Second, our analysis is organized around a log-log specification, except for qualitative variables or variables expressed as a percentage. The estimates therefore have a natural interpretation in terms of elasticities, are less sensitive to outliers, and are consistent with the majority of prior work in this area (Jones, 1998).

Finally, with regard to the sources of error, we assume that the observed difference from the predicted value given by (2) (i.e., the disturbance) arises from an idiosyncratic country/year-specific technology shock unrelated to the fundamental drivers of national innovative capacity.

Integrating these choices and letting L X be defined as the natural logarithm of X, our main specification takes the following form:

$$\mathrm{L}\,\dot{\mathrm{A}}_{\mathrm{j,t}} = \delta_{\mathrm{YEAR}}\mathrm{Y}_{\mathrm{t}} + \delta_{\mathrm{COUNTRY}}\mathrm{C}_{\mathrm{j}} + \delta_{\mathrm{INF}}\mathrm{LX}^{\mathrm{INF}}_{\mathrm{j,t}} + \delta_{\mathrm{CLUS}}\mathrm{LY}^{\mathrm{CLUS}}_{\mathrm{j,t}} + \delta_{\mathrm{LINK}}\mathrm{LZ}^{\mathrm{LINK}}_{\mathrm{j,t}} + \lambda\mathrm{LH}^{\mathrm{A}}_{\mathrm{j,t}} + \phi\mathrm{LA}_{\mathrm{j,t}} + \varepsilon_{\mathrm{j,t}} \quad (3)$$

Implementing (3) requires that each of the concepts underlying national innovative capacity be tied to observable measures. As $\dot{\mathrm{A}}_{\mathrm{j,t}}$, measured by the level of international patenting, is only observed with delay, our specification imposes a lag between the measures of innovative capacity and the observed realization of innovative output (the details of which are reviewed in the next section).

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[13] By controlling for year and country effects in most of our analysis, we address some of the principal endogeneity and autocorrelation concerns. However, we have extensively checked that the results reported in Section V are robust to various forms of autocorrelation (results available on request) and have investigated the potential for

## V. THE DATA

This paper employs a novel dataset of patenting activity and its determinants in a sample of 17 OECD countries from 1973 through 1996. Our results, then, describe the relationship between innovative inputs and outputs in highly industrialized economies. Table 1 lists all included countries, and Table 2 defines and provides sources for all variables. We drew on several public sources in assembling and checking the comparability of these data; the bulk have been taken from the patent statistics of CHI Research and the most recent publications of the OECD Basic Science & Technology Statistics, the World Bank, and the NSF Science & Engineering Indicators.[14] We first describe the measures of visible innovative output – most notably, international patenting – and then discuss our measures of contributors to national innovative capacity.

### *The Measurement of Visible Innovative Output*

To conduct empirical analyses of the determinants of visible innovative output, we required a measure comparable across countries that provides an indicator of commercially valuable innovative output. We satisfy both objectives by building on the literature that utilizes patenting activity as an summary statistic for the level of innovative output (Pavitt, 1982; Griliches, 1984; 1990; Kortum, 1997). While no measure derived from patenting statistics provides a perfect index of the level of new-to-the-world technological innovation, we use the number of "international patents" as the best available indicator of the country-specific level of realized, visible innovative output at one point in time. For this study, we define international patents (PATENTS) as the number of patents granted to inventors from a particular country by the USPTO in a given year. For the United States, we utilize the number of patents granted to establishments in the United States and one additional jurisdiction outside of the US (thus

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endogeneity more fully in related work (Porter and Stern (1999a)).

[14] To ensure comparability across countries and time, we subjected each measure to extensive analysis and cross-checking, including confirming that OECD data conformed with comparable data provided by individual national statistical agencies. When appropriate, we interpolated missing values for individual variables. For example, most countries report educational expenditure data only once every other year; our analysis employs the average of the years just preceding and following a missing year. Financial variables are in PPP-adjusted 1985 $US.

ensuring symmetry with the patenting numbers from other countries).

Four factors drive our decision to focus our analysis around PATENTS. First, patenting, by its very nature, reflects an important portion of the innovative output by a country, which as also be correlated with other innovative outputs, such as protected copyrights and trade secrets. Second, because USPTO approval requires that patents constitute novel, non-obvious inventions, patenting captures a sense of the degree to which a national economy is developing and commercializing new-to-the-world technologies. By only including inventions that are granted patent protection in the United States, we can be confident both that a relatively common standard has been applied and that the counted inventions are, in fact, near the global technological frontier.

Third, PATENTS measures both technological and economic significance Obtaining a patent in a foreign country is a costly undertaking, which is only worthwhile for an organization that anticipates a commercial return in excess of these costs.[15] Finally, our use of international patents draws on an extensive body of prior work (building on the foundations developed in Griliches (1984)) which has established the advantages (as well as the limitations) of using patent data relative to other measures of innovation (Evenson, 1984; Dosi, Pavitt and Soete, 1990; Cockburn and Henderson, 1995; Eaton and Kortum, 1996; 1998). Like these prior studies, we recognize that patents are but an imperfect measure for the total level of innovation in a given country. For example, the propensity to apply for patent protection may reflect differences in countries' industrial composition (e.g., having a large pharmaceutical sector) or differences in countries' internal intellectual property institutions. In part, we address these concerns by including comparisons with alternative measures of innovative outputs (such as the level of scientific publication and international high-technology industrial success which we discuss below) and by examining the robustness of our results to the use of regional subsets and country-level dummies. Ultimately, our approach is justified by the fact that patents are the *most* concrete and comparable measure of innovative output across countries and time. Simply put, patenting rates constitute "the only observable manifestation of inventive activity with a well-grounded

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[15] See Eaton and Kortum (1996, 1998) for a thorough discussion of the economics of international patenting.

claim for universality" (Trajtenberg, 1990: p. 183).[16]

For the current sample, the average number of PATENTS produced by a country in a given year in our sample is 3986 (with a standard deviation of 8220). As can be seen in Figure F, there has been a temporal increase in PATENTS over the past 20 years, reaching a peak in the final year of the sample (which corresponds to patents issued in 1996). Figures G shows "per-capita" patenting rates (i.e., PATENTS / MILLION POP) for different countries over the sample. Three facts about observed rates of international patenting are of interest. First, there are substantial differences among countries in realized patenting intensity. Second, at the beginning of the sample, the only country with a per-capita patenting rate similar to the United States' rate is Switzerland.[17] Third, over time there is noticeable narrowing of the gap in the realized level of per capita international patenting across countries. This *convergence* in per capita international patenting is most apparent for Japan, but is also characteristic of a substantial number of OECD countries (although this phenomenon does not hold for countries such as Italy and the U.K.).

We also explored several potential alternatives to PATENTS which are both less comparable across countries and less closely linked to the level of innovative output. For example, the extent of publication in scientific journals (JOURNALS), although a product of inventive effort, is a more upstream indicator of scientific exploration than an indicator of commercial significance. Our analysis also includes two more downstream measures of the impact of national innovative capacity: the realized market share of a country in "high-technology" industries (MARKET SHARE) and a measure of total factor productivity (TFP), defined as the level of GDP controlling for the levels of CAPITAL and LABOR. Both MARKET SHARE and TFP should depend on national innovative capacity over the long run; however, in the near term, both of these measures will be affected by trade agreements, the rate and character of the diffusion of innovations, currency rates, and other macroeconomic factors

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[16] Trajtenberg (1990) and Griliches (1998) provide a thorough discussion of the role of patents in understanding innovative activity, stretching back to their use by Schmookler (1966) and noting their ever-increasing use by scholars in recent years (Griliches, 1984; 1990; 1994). Our use of international patents also has precedent in prior work comparing international inventive activity (see Dosi, Pavitt, and Soete, 1990; Eaton and Kortum, 1996; 1998).

[17] Recall that the U.S. patenting level is determined by the number of patents issued to U.S. inventors associated with an institution such as a company, governmental body, or university.

that affect patterns of international trade and productivity growth but are only indirectly related to the level of innovation realized by a given country.

Several measures of technological output are neither available nor usefully comparable across countries or time. For example, the level of technology licensing revenues realized by a country captures activity in some technology areas, but in practice is not nearly broad-based enough to have a well-founded claim for comparability. While measures such as copyrights and trademarks are direct indicators of innovative output in certain industries (e.g., software), the lack of comparability of these data across countries limits their usefulness for our analysis.

### *Measuring the Contributors to National Innovative Capacity*

To estimate our model, we require measures of a nation's common innovation infrastructure, the innovation environment in its industrial clusters, and the quality of linkages between them. Especially in the area of common innovation infrastructure, direct measures are available. More subtle and multi-faceted concepts, such as the cluster-specific innovation environment, cannot be quantified directly from available international data. We address this challenge by employing intermediate measures or proxies that do not capture the underlying drivers but measure important economic outcomes associated with strength in specific areas.

The common innovation infrastructure consists broadly of a country's knowledge stock, the overall level of labor and capital resources devoted to innovative activity, and the other broad-based policies and resource commitments supporting innovation. Our analysis explores two distinct measure for a country's relative knowledge stock at a given point in time ($A_{j,t}$): GDP PER CAPITA and the sum of PATENTS from the start of the sample up until the year of observation (PATENT STOCK).[18] Although both measure the overall state of a country's technological development, they differ in important ways. GDP PER CAPITA captures the ability of a country to translate its knowledge stock into a realized state of economic development (and so yields an aggregate control for a country's technological sophistication). In contrast, PATENT STOCK constitutes a more direct measure of the country-specific pool of

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[18] See Porter and Stern (1999a) for a derivation and thorough discussion of differences between these two measures.

new-to-the-world technology.

We capture the level of capital and labor resources devoted to the ideas-producing sector using each country's number of full-time-equivalent scientists and engineers (FT S&E) and gross expenditures on R&D (R&D $). While individual R&D and engineering efforts will tend to be specialized in particular technical and scientific areas, the outputs of R&D (either via direct application or as a basis for future efforts) will impact a wide variety of economic sectors (Rosenberg, 1963; Glaeser, et al., 1992). Hence, we classify the overall supply of innovation-oriented labor and capital as a key element of the common innovation infrastructure.

Similar to the convergence in PATENTS, there is evidence for convergence in the level of resources devoted to R&D activity. While FT S&E per capita has generally increased among OECD countries (Figure H), this growth has been higher for those countries whose initial levels were lower. As a result, disparities in this ratio have decreased over the sample period. In particular, whereas growth in FT S&E per capita has been particularly substantial in Japan and the Scandinavian countries, the United Kingdom and United States experienced small declines in FT S&E per capita. R&D $ also displays a similar pattern of convergence, though somewhat less dramatically than FT S&E.

The common innovation infrastructure also encompasses the resources devoted to human capital investment and policies providing innovation incentives. We include the fraction of GDP spent on secondary and tertiary education (ED SHARE) as a measure of the intensity of human capital investment; a high level of ED SHARE creates a base of highly skilled personnel upon which firms and other institutions across the economy can draw, both for formal R&D activities as well as other innovation-related activities involving complex problem solving. We include measures of general broad-based policy choices that particularly affect the environment for innovative activity, including the relative strength of intellectual property protection (IP), the relative stringency of country's antitrust policies (ANTITRUST), and the relative openness of a country to international trade and competition (OPENNESS). Each of these three policy variables (measured on a 1-10 Likert Scale from the IMD World Competitive Report for various years, beginning in the late 1980s)[19] should increase the productivity of international patenting activity for a given level of resources, and so we expect a positive relationship between each and the rate of international patenting.[20] Given that these variables are drawn from an imperfect survey instrument, however, each can capture the underlying concept with inevitable noise.

While the common innovation infrastructure is quite amenable to measurement, capturing the aggregate environment for innovation in a nation's industrial clusters is quite difficult, due both to the subtlety of the concepts involved as well as the lack of systematic international data. We address this challenge by employing intermediate measures that do not capture the environment directly but measure an outcome associated with the quality of that environment, namely the intensity of privately financed R&D activity in a nation's clusters. We measure the share of overall R&D expenditures which are privately financed (PRIVATE R&D FUNDING).[21] Figure I shows the variance in this measure. In 1990, for example, companies *financed* between 40 to 60 percent of R&D in most countries. Only in Japan and Switzerland did companies fund more than 70 percent of R&D expenditure. Interestingly, the social market economies of Sweden and Finland are among the highest countries in terms of company funding of R&D.

The final element of the framework, the strength of linkages between industrial clusters and the common innovation infrastructure, is similarly difficult to quantify. The mechanisms for scientific and technological transfer vary both across countries and over time. Our analysis considers two mechanisms which more qualitative research suggests are relatively consistent contributors to the strength of linkages: the share of R&D performed by the university sector (UNIV R&D PERFORMANCE) and the availability of venture-backed financing (VC). By many accounts, strength in these areas will translate to a more effective transfer of knowledge and commercially relevant technologies from the common innovation infrastructure to specific

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[19] IP, OPENNESS, and ANTITRUST are average (1-10) Likert score variables from an annual survey in which executives rank their perceptions of countries' orientations on a variety of dimensions relevant to international business. It is important to note that these variables enter the data in the late 1980s (between 1986-1989 depending on the variable) and so the analysis corrects for the "missing values" for this variable prior to these years.

[20] As well, each of these policy measures may increase the level of resources devoted towards innovation; however, our analysis focuses on the productivity effects of these policies, above and beyond the measured level of resources.

[21] We abstract away from higher-order terms in our analysis. While including such measures would allow us to incorporate concavity into the analysis, our focus is on these measure's first-order impact rather than their predicted impact outside of their observed range.

industrial clusters (and vice versa). For example, relative to government laboratories, university research will tend to be more accessible to researchers in industry (i.e., universities provide a forum for the exchange of ideas between different R&D communities). Further, the unique role that universities play in training future industrial researchers suggests another way in which common resources for innovation (i.e., S&E graduate students) are mobilized in a nation's industrial clusters. Similarly, VC (measured as a 1-10 Likert scale variable by the IMD Competitiveness Report) reflects the degree to which risk capital is available to translate scientific and technological outputs into domestic opportunities for further innovation and commercialization.

## VI. EMPIRICAL RESULTS

Our empirical results are presented in three parts. First, we present the primary results of the paper, estimating the determinants of the production of new-to-the-world technologies. The second section explores the relationship between national innovative capacity and more upstream basic scientific activity (JOURNALS), as well as the downstream consequences of innovative capacity, including TFP and high-technology MARKET SHARE. The final section discusses the patterns in national innovative capacity implied by the estimates over the sample period.

### *Determinants of the Production of New-to-the-World Technologies*

The results of estimating the relationship between innovative output ($\text{PATENTS}_{t+3}$)[22] and the drivers of national innovative capacity ($A_{j,t}, H^{A}_{j,t}, X^{INF}_{j,t}, Y^{CLUS}_{j,t}, Z^{LINK}_{j,t}$) are presented in Tables 4, 5, and 6. We present a broad range of results, in order to highlight the main relationships in the data as well as the source of variation underlying particular findings. Tables 4 and 5 each use a different measure of a country's knowledge stock ($A_{j,t}$) with a similar battery of specifications; Table 4 uses GDP PER CAPITA while Table 5 is based on the PATENT STOCK variable. Table 6 explores the robustness of the results from these two prior tables to alternative specifications and different sample subsets. Overall, we find a robust relationship between

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[22] Recall that we evaluate the relationship of PATENTS in year t+3 to the level of the contributors to innovative capacity in year t and that our main results are robust to changes in this lag structure.

PATENTS and measures associated with each source of national innovative capacity: the common innovation infrastructure, the cluster-specific innovation environment, and the linkages between these two areas.

Table 4 begins with a specification which is analogous to the formal model of the national ideas production function suggested by Romer (1990) and Jones (1995). In the first regression (4-1), we see that PATENTS is increasing in the variables suggested by endogenous growth theory, L GDP PER CAPITA and L FTE S&E. Interpreting these coefficients as elasticities, (4-1) implies that a 10 percent increase in GDP per capita is associated with over a 13 percent rise in international patent output.[23] As suggested by proponents of endogenous growth, a country's existing level of technological sophistication and the extent of resources devoted to R&D play key roles in determining innovative output.

Though striking, (4-1) does not imply that A and $H_A$ are the *only* decisive factors in the production function for observable innovative output. In (4-2), we include the remainder of the measures of $H^A$ and $X^{INF}$ , which describe the quality of the common innovative infrastructure. This specification (along with (4-3) and (4-4)) also includes year-specific fixed effects to control for variation arising from changes in the rate of patent grants per year. With the exception of ANTITRUST, each of the elements representing the common innovation infrastructure impacts international patenting significantly, with the expected sign, and with an economically important magnitude. In addition, these regressors have only a modest impact on the coefficients associated with L GDP PER CAPITA and L FT S&E. Perhaps more interestingly, the sum of the coefficients on L R&D $ and L FT S&E in (4-2) is approximately equal to the single coefficient on L FT S&E in (4-1). In other words, the total impact of employment and financial resources is similar whether we focus on a single variable (e.g., FT S&E in (4-1)) or include both measures (e.g., FT S&E and R&D $ in (4-2)).

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[23] It is interesting to note that, by themselves, the two regressors in (4-1) explain nearly 94 percent of the total variance in PATENTS. However, further analysis (available from the authors) suggests that, using our measures of national innovative capacity, an extremely high overall proportion of the variance associated with PATENTS can be explained through the inclusion of only two or three regressors. In other words, a number of different measures associated with our framework are effective in distinguishing the relatively persistent cross-sectional variation between countries.

The elements of $X^{INF}$ are expressed as Likert scale measures (IP, OPENNESS, and ANTITRUST) and as shares (ED SHARE). The coefficients associated with the Likert scale measures are equal to the predicted percentage change in PATENTS which would result from a one *unit* change in that variable (e.g., from a value of 3 to 4). For example, the coefficients on IP (0.22) and OPENNESS (0.10) imply that a one-point increase in these Likert measures is associated, on average, with a 22 percent and 10 percent increase in PATENTS, respectively. Given the relative crudeness and paucity of these measures, it is striking that these variables enter significantly, suggesting their potential importance for understanding national innovative capacity.[24] Given that it is specified as a share between 0 and 100, the ED SHARE coefficient (0.11) implies that an increase of 1 *percentage point* in ED SHARE (approximately a standard deviation) is associated with an 11 percent increase in the level of PATENTS.

In (4-3), we add the remaining measures of the determinants of national innovative capacity, the cluster-specific innovation environment ($Y_{CLUS}$) and the quality of linkages between the common infrastructure and clusters ($Z_{LINK}$) The fraction of R&D *funding* provided by industry and the fraction of R&D *performed* by universities enter with a positive sign and are significant at the 5 percent level. In other words, controlling for the level of R&D spending in an economy, the composition of such spending is associated with the level of realized international patenting. Strikingly, the significant impact of UNIV R&D PERFORMANCE suggests that countries who have located a higher share of their R&D performance in the educational sector (as opposed to the private sector or in intramural government programs) have been able to achieve significantly higher patenting productivity. VENTURE CAPITAL, while it does enter positively into the equation, is not significant (perhaps reflecting the relatively low level of variation of VC across the world outside the United States and the existence of non-VC channels of risk capital in many OECD countries). Finally, consistent with prior studies, the coefficients on the year dummies decline over time, suggesting that average global R&D has declined since the mid 1970s. In other words, while PATENTS has been increasing over time as a result of increased investments in innovation and improvements in the policy environment, countries have also

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[24] Indeed, given the noisy nature of the Likert variables and the fact that overly rigorous enforcement of antitrust policies can stifle rather than stimulate innovation (e.g., by expropriating the returns from successful R&D efforts), it

tended to experience a "raising the bar" effect, in which ever-more R&D resources must be devoted in order to yield a constant flow of visible innovative output.

Equation (4-4) presents our preferred model of national innovative capacity, which includes only those contributors to national innovative capacity that enter significantly in prior models. This specification (along with (4-1) through (4-3)) documents a robust relationship between PATENTS and measures that reflect the quality of the common innovation infrastructure, the cluster-specific innovation environment, and the linkages between them. As well as being statistically significant, each of the included regressors has a quantitatively important impact. While at one level the results are consistent with a central tenet of science and technology policy emphasizing the centrality of R&D manpower (FT S&E), the more general conclusion is that high levels of innovative output are associated with coordinated investments across each of the sources of national innovative capacity.

In Table 5, we evaluate a set of regressions which resemble Table 4, except in two respects. First, throughout Table 5, we use the alternative measure of $A_{jt}$, PATENT STOCK, rather than GDP PER CAPITA.[25] Whereas GDP PER CAPITA is a comprehensive, composite measure of a country's technological sophistication, PATENT STOCK provides a more direct (but less inclusive) measure of the knowledge stock upon which a country draws for technological innovation. Second, the specifications experiment with alternative structures to control for year and country effects; while (5-1) includes dummies for every country and year, (5-2) through (5-4) rely on the use of a control for the "baseline" knowledge stock, GDP 1967, to account for country-level heterogeneity, as well as a time trend.[26] By exploring differences in the measure of the knowledge stock as well as by varying the means of identification, Table 5 highlights results robust to alternative assumptions about the nature of heterogeneity and the

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is perhaps not surprising that the model does not identify a separate impact for the ANTITRUST variable.

[25] By including PATENT STOCK in the specification which includes FT S&E and controls for year and country effects, (5-1) serves as an empirical test of a key parametric restriction associated with ideas-driven growth models. In particular, in order for ideas production to be a sustainable source of equilibrium long-term growth, $\phi = 1$ (a hypothesis which cannot be rejected in (5-1)). Such parametric restrictions for ideas-driven growth models are explored much more extensively (and derived formally) in Porter & Stern (1999a).

[26] This contrasts with our use of year-specific fixed effects from Table 4. However, note that because the Likert variables are not observed until the late 1980s, we include separate dummy variables to denote whether such variables are included in the regression.

specification for the country-specific level of technological knowledge.

Though there are differences in the magnitude of some variables and the significance of others, the results obtained using PATENT STOCK are in broad agreement with those of Table 4. Perhaps the most important difference is that the coefficient on FT S&E is much smaller in the equations of Table 5, suggesting a higher degree of concavity in the patent production function than the prior models. In addition, the coefficient on R&D $ is insignificant (though of similar magnitude to Table 4), implying that PATENT STOCK incorporates much of the statistical information embedded in R&D $. Further, OPENNESS becomes negative and insignificant, perhaps because of the small number of observations for this variable. Nonetheless, the basic elements of our framework, including the cluster-specific innovation environment and the quality of linkages, continue to be significant and economically important in this alternative formulation. Finally, the coefficients on the YEAR trend again exhibit the overall declining trend for PATENTS for a given level of resources. With each passing year, a constant level of the elements of national innovative capacity results in approximately 6 percent fewer PATENTS.

Table 6 further explores the empirical robustness of the determinants of national innovative capacity. Equations (6-1) and (6-2) simultaneously include GDP PER CAPITA and PATENT STOCK. Both measures of the knowledge stock are significant in these models; however, the relative magnitudes of each depend on the inclusion of other regressors. Specifically, whereas the magnitude on GDP PER CAPITA is almost one when *only* PATENT STOCK and FT S&E are included, the magnitude of GDP PER CAPITA decreases (to 0.11) while the coefficient on PATENT STOCK increases (to 0.78) when the remaining variables from (4-4) are included. Together with the relatively consistent results from Tables 4 and 5, we interpret this as suggesting that both PATENT STOCK and GDP PER CAPITA provide useful measures of a nation’s knowledge stock, but that it is difficult to identify their separate effects.

To establish the precise role of cross-sectional variation in our results, equation (6-3) includes country-specific fixed effects along with the regressors of our preferred model (4-4). Most of the results are robust to this modification: GDP per capita, R&D expenditure, FTE R&D, and higher education spending remain significant and of the expected sign in explaining patent output. It is interesting to note that the magnitude of the coefficient on FT S&E increases, suggesting that the level of innovative output is quite sensitive to *changes* in the level of the scientific workforce within a given country. However, the R&D composition variables become insignificant. In part, this occurs because UNIV R&D PERFORMANCE and PRIVATE R&D FUNDING tend to change only very slowly over time; we therefore cannot estimate their impact by relying only on time-series variation. As well, the coefficient on OPENNESS becomes significant and negative, though it seems that this result depends on the short time-series for which this variable is observed (1989 – 1993) and the existence of a few outlying observations.

Finally, in (6-4) and (6-5), we check for robustness to restricting the sample to specific sample subsets. In (6-4), we restrict the sample only to post-1984 data, highlighting a period of relatively higher macroeconomic stability and in which the reliability of the data is most likely improved. Interestingly, all of the results remain significant, though the sensitivity of international patent output to GDP PER CAPITA is slightly lower in this period, while the sensitivities to other factors, including PRIVATE R&D FUNDING and UNIV R&D PERFORMANCE increase. Equation (6-5) evaluates whether the results obtain when restricting attention to only European countries. Again, the results remain largely the same. The impact of GDP PER CAPITA on innovative output is somewhat lower in these countries, while the relative influence of ED SHARE is somewhat higher. Similar to earlier results, OPENNESS loses its significance in this sub-sample, suggesting that this result is driven by variation outside of the European data.

### ***Scientific Inputs, Innovative Outputs, and Productivity***

Our analysis so far has focused exclusively on the sensitivity of PATENTS to measures of the strength of national innovative capacity. In this sub-section, we extend our analysis in two distinct ways. First, we consider an alternative measure of the output of national innovative capacity, the level of publication in academic journals (JOURNALS). Here we find that the determination of JOURNALS is not as easily characterized by the national innovative capacity framework as PATENTS. After this brief analysis, we consider more downstream consequences of innovative capacity, where we establish that the elements of national innovative capacity play an important role in shaping downstream consequences, such as TFP and MARKET SHARE.

In Table 7, we consider the relationship between JOURNALS and the other elements of our national innovative capacity framework. Whereas PATENTS constitutes a measure of commercializable output, JOURNALS embodies the realization of more basic scientific and engineering activity. Scientific achievement will be an important byproduct (though not the central consequence) of national innovative capacity, and the degree to which the two are related is subject to debate. Indeed, (7-1) suggests that many of the key drivers of PATENTS do not significantly enter the JOURNALS production function. While there are some common factors (such as GDP PER CAPITA, FT S&E, and ED SHARE), the remainder of the variables are either insignificant or of the opposite sign from the results in Tables 4 through 6. In other words, JOURNALS is less closely associated with the foundations of national innovative capacity than the realized level of international patent production.

As well, in (7-2), we explore the impact of JOURNALS in our preferred PATENTS specification, (4-4). Although this specification is obviously subject to endogeneity (and we leave separating out the separate exogenous drivers of each to future work), the results suggest that while JOURNALS is positively correlated with PATENTS, its inclusion does not substantially change our earlier qualitative conclusions, except for reducing OPENNESS to insignificance (consistent with some of our other robustness checks), and reducing the coefficient on GDP PER CAPITA. In other words, the empirical relationship between international patenting and key drivers of commercially-oriented innovative output is relatively unaffected, at least in the short to medium term, by the level of abstract scientific knowledge produced by a country.

Table 8 turns attention to more downstream outcomes and, in particular, the consequences of PATENTS. We begin with an overall assessment of the sensitivity of TFP to cumulative ideas production (PATENT STOCK). Specifically, (8-1) evaluates the sensitivity of GDP to PATENT STOCK, conditional on the level of LABOR AND CAPITAL. As such, we can interpret the coefficient on PATENT STOCK as a contributor to the level of TFP.[27] As

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[27] Alternatively, we could have simply imposed factor shares on LABOR and CAPITAL and computed TFP directly; while we experimented with this formulation, the less restrictive specification in (8-1) is more consistent with the

discussed more fully in Porter and Stern (1999a), this relationship is critical for establishing the role of "ideas production" in long-run economic growth. Theoretical growth models assume that there is a strong R&D productivity advantage associated with technological sophistication (see Tables 4 and 5) that translates into a proportional advantage in the realized level of TFP. In contrast, (8-1) suggests that while the PATENT STOCK has a significant effect on TFP, this effect is *much* smaller than proportionality (which would require that the coefficient be equal to unity). While this modest relationship lends support to the idea that national innovative capacity plays a significant role in shaping the medium-term level of productivity, (8-1) also raises the possibility that the linkage between national innovative output and productivity growth may be more subtle than commonly assumed.

Finally, (8-2) through (8-4) examine whether MARKET SHARE can be explained in the context of the national innovative capacity framework. First, equation (8-2) shows that (lagged) PATENT STOCK and a time trend explain nearly 80 percent of the variance in MARKET SHARE across countries. This demonstrates that countries which accumulate advanced knowledge stocks also achieve high shares in worldwide high-technology markets. Equation (8-3) replaces PATENT STOCK with the predicted level of PATENTS, where the weights are derived from (4-4). Not surprisingly, given how closely we characterize PATENTS in (4-4), this measure provides precise predictive value in explaining MARKET SHARE. Finally, in (8-4), we include the measures incorporated into our preferred model of national innovative capacity (4-4). This exercise also fits the data similarly well. However, while several elements of national innovative capacity are strongly significant in the analysis (L FT S&E, ED SHARE, OPENNESS, PRIVATE R&D FUNDING, and UNIV R&D PERFORMANCE), others show no association, such as GDP PER CAPITA and the IP measure. In other words, national innovative capacity can usefully provide insight into the evolution of international trade patterns in high-technology areas.

### *Trends in Innovative Capacity*[28]

We now turn to our final empirical exercise, exploring the quantitative implications of

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exploratory nature of the exercise in this paper (but see Porter and Stern (1999a) for further details).

[28] This material is drawn from Porter and Stern (1999b).

our findings by deriving an "index" of innovative capacity which is consistent across countries and over time. This was based on applying the coefficients from our preferred model (4-4) to the realized values of resource and policy choices for each country in each year; this predicted PATENTS value is then converted into a per capita measure by dividing by the contemporaneous level of POPULATION. In effect, we compute the predicted value for a country's level of international patenting per capita based on its fundamental resource and policy commitments, and so provide a useful benchmark to compare the relative ability of countries to produce innovations at the international frontier.

The results of this exercise are presented in Figure J. Consistent with the historical data, the United States and Switzerland are in the top tier throughout the sample period. As a result of sustained investments in fundamentals, Japan, Germany, and Sweden join this top group over the course of the 1980s. A second set of countries, including the remaining Scandinavian countries, France, and the UK, comprise a "middle tier," while a third group, including Italy, New Zealand and Spain, lags behind the rest of the OECD over the full time period.[29]

The most striking finding of this exercise is the *convergence* in measured innovative capacity among OECD countries over the past quarter century. Not only has the top tier expanded to include Japan, Germany, and Sweden, but some middle tier countries, such as Denmark and Finland, have achieved substantial gains in innovative capacity. Moreover, this convergence seems to be built on fundamentals rather than transient changes. This is exemplified by the case of Germany, in which innovative capacity grew strongly throughout the 1980s. Despite a drop-off resulting from reunification with the East beginning in 1990, Germany maintained a relatively high level of innovative capacity throughout the 1990s. In general, there has been a slow but steady narrowing of the gap between the innovation leaders in the OECD and nations with historically lower levels of innovative capacity. It is important to note, however, that some major countries, most notably France and the United Kingdom, have remained at a constant level. Compared to others, these countries have eroded their relative innovative

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[29] It is important to bear in mind that these results are in part affected by the industrial composition of national economies. Our choice of PATENTS implies that innovative in countries whose clusters are concentrated in industries with low patent intensities (such as Italy in textiles) will be understated relative to those with clusters in patent-intensive industries (such Switzerland in pharmaceuticals).

capacity over the past quarter century by neglecting investments in common innovation infrastructure, supportive cluster environments, and/or linkage mechanisms. While this approach cannot provide a forecast of the ability of a country to commercialize new technologies in the short term, our results do suggest that that both Japan and Scandinavia have already established themselves as important innovation centers and that the sources of new-to-the-world innovation are likely to become more diverse over time.

## VII. CONCLUDING THOUGHTS

Evaluating the sources of differences in R&D productivity across countries serves the dual purpose of informing science and technology policy and illuminating the factors that underlie national productivity growth. We draw on several distinct research streams which inform this debate, including ideas-driven endogenous growth theory (Romer, 1990), cluster-based models of national competitive advantage (Porter, 1990), and the literature on national innovation systems (Nelson, 1993). Although these perspectives share common elements, each emphasizes different factors in the realization of national innovative output. We introduce the concept of *national innovative capacity* to integrate these previous perspectives and provide a framework for empirical testing across countries.

Using this framework, we explore the country-level determinants of innovative output in OECD countries between 1973 and 1993. Our results suggest that the empirical determinants of international patenting activity are (a) amenable to systematic empirical analysis motivated by our framework yet (b) more nuanced than the limited factors highlighted by ideas-driven growth theory. We find a small but important set of additional factors also plays an important role in realized R&D productivity. Further theoretical and empirical research in growth theory may benefit from incorporating the role of industrial organization and the national policy environment (e.g., the role of the university system or the composition of private versus public funding).

To the extent that we found a parsimonious set of regressors which usefully characterizes the production function for international patents, country-level R&D productivity seems to be amenable to quantitative analysis. This finding should be of particular interest to researchers in the tradition of the national innovation systems literature. In particular, it would seem that future research should distinguish carefully between those phenomena which are reflected in observable measures of innovative output (such as the patenting activities we examine here) versus more subtle effects which may not be subject to direct observation (such as institutions or mechanisms encouraging non-patented process innovations). At the very least, our results suggest that qualitative studies may benefit from articulating the potential impact of specific institutions on observed national R&D productivity as well as on observables associated with national innovative capacity.

Our results suggest that public policy plays an important role in shaping a country's national innovative capacity. Beyond simply increasing the level of R&D resources available to the economy, the government's policy agenda plays an important role in shaping human capital investment and innovation incentives. Each of the countries that have increased their estimated level of innovative capacity over the last quarter century – Japan, Sweden, Finland, Germany – have implemented policies which encourage human capital investment in science and engineering (e.g., by establishing and investing resources in technical universities) as well as competition on the basis of innovation (e.g., through the adoption of R&D tax credits and the gradual opening of markets to international competition).

Finally, the United States, which since World War II has been the dominant supplier of new technologies to the rest of the world, has been less proactive in its investment in innovative capacity since the late 1980s. With the conclusion of the Cold War, the traditional American rationale for investing in its national innovation infrastructure was reduced, and U.S. policy has consequently become less focused. Convergence in innovative capacity across the OECD is therefore should not be surprising. However, this convergence holds important implications for the future distribution of innovative activity: specifically, it suggests that the commercial exploitation of emerging technological opportunities (from biotechnology to robotics to Internet technologies) may well be less geographically concentrated than was the case during the post World War II era.

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# TABLE 1
# SAMPLE COUNTRIES (1973-1995)

Australia
Austria
Canada
Denmark
Finland
France
Germany[*]
Italy
Japan
New Zealand
Netherlands
Norway
Spain
Sweden
Switzerland
United Kingdom
United States

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[*] Prior to 1990, data for the Federal Republic of Germany include only the federal states of West Germany; beginning in 1991, data for Germany incorporate the New Federal States of the former German Democratic Republic.

# TABLE 2
# VARIABLES* & DEFINITIONS

| VARIABLE | | FULL VARIABLE NAME | DEFINITION | SOURCE |
|---|---|---|---|---|
| **INNOVATIVE OUTPUT** | | | | |
| PATENTS$_{j,t+3}$ | | International Patents | Patents granted in the US to establishments in country j in year (t+3); for the United States, the number of patents granted both domestically and in at least one other CHI-documented country | CHI US patent database |
| PATENTS / MILLION POP$_{j,t+3}$ | | International Patents per Million Persons | PATENTS divided by million persons in the population | CHI US patent database |
| **QUALITY OF THE COMMON INNOVATION INFRASTRUCTURE** | | | | |
| **A** | GDP PER CAPITA$_{j,t}$ | GDP Per Capita | Gross Domestic Product in thousands of PPP-adjusted 1985 US$ | World Bank |
| **A** | PATENT STOCK$_{j,t}$ | Stock of International Patents | Cumulative PATENTS from 1973 until (t-1) | CHI US patent database |
| $\mathbf{H^A}$ | FT S&E$_{j,t}$ | Aggregate Employed S&T Personnel | Full Time Equivalent scientists and engineers in all sectors | OECD Science & Technology Indicators |
| $\mathbf{H^A}$ | R&D \$$_{j,t}$ | Aggregate R&D Expenditures | R&D expenditures in all sectors in millions of PPP-adjusted 1985 US$ | OECD Science & Technology Indicators |
| $\mathbf{X^{INF}}$ | OPENNESS$_{j,t}$ | Openness to International Trade & Investment | Average survey response by executives on a 1-10 scale regarding relative openness of economy to international trade and investment | IMD World Competitiveness Report |
| $\mathbf{X^{INF}}$ | IP$_{j,t}$ | Strength of Protection for Intellectual Property | Average survey response by executives on a 1-10 scale regarding relative strength of IP | IMD World Competitiveness Report |
| $\mathbf{X^{INF}}$ | ED SHARE$_{j,t}$ | Share of GDP Spent on Higher Education | Public spending on secondary & tertiary education divided by GDP | World Bank |
| $\mathbf{X^{INF}}$ | ANTITRUST$_{j,t}$ | Stringency of Antitrust Policies | Average survey response by executives on a 1-10 scale regarding relative strength of national antitrust policies | IMD World Competitiveness Report |
| **CLUSTER-SPECIFIC INNOVATION ENVIRONMENT** | | | | |
| $\mathbf{Y^{CLUS}}$ | 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 & Technology Indicators |
| **QUALITY OF LINKAGES** | | | | |
| $\mathbf{Z^{LINK}}$ | UNIV R&D PERFORMANCE$_{j,t}$ | Percentage of R&D Performed by Universities | R&D expenditures performed by universities divided by total R&D expenditures | OECD Science & Technology Indicators |
| $\mathbf{Z^{LINK}}$ | VC$_{j,t}$ | Strength of Venture Capital Markets | Average survey response by executives on a 1-10 scale regarding relative strength of venture capital availability | IMD World Competitiveness Report |
| **CONTRIBUTING AND RELATED OUTCOME FACTORS** | | | | |
| JOURNALS$_{j,t}$ | | Publications in Academic Journals | Number of publications in international academic journals, using 1981 journal set | CHI database of Science Citation Index |
| GDP$_{j,t}$ | | Gross Domestic Product | Gross domestic product in billions of PPP-adjusted 1985 US$ | Penn World Tables |
| LABOR$_{j,t}$ | | Labor Force | Number of full time equivalent persons employed in the labor force | Penn World Tables |
| CAPITAL$_{j,t}$ | | Capital | Non-residential capital stock in billions of PPP-adjusted 1985 US$ | Penn World Tables |
| MARKET SHARE$_{j,t}$ | | Market Share | Share of exports in high technology industries (among countries in our sample) | National Science Foundation |

* The natural logarithm of a variable, X, is denoted L X.

# TABLE 3
# MEANS & STANDARD DEVIATIONS

| | | N | MEAN | STANDARD DEVIATION |
|---|---|---|---|---|
| **INNOVATIVE OUTPUT** | | | | |
| PATENTS | | 378 | 3986.23 | 8219.89 |
| PATENTS / MILLION POP | | 378 | 3.73 | 1.02 |
| **QUALITY OF THE COMMON INNOVATION INFRASTRUCTURE** | | | | |
| **A** | GDP / POP | 357 | 18.66 | 5.10 |
| **A** | PATENT STOCK | 357 | 38016.59 | 98252.46 |
| $\mathbf{H^A}$ | FT S&E | 353 | 226344.60 | 407124.50 |
| $\mathbf{H^A}$ | R&D $ | 355 | 12859.86 | 27930.46 |
| $\mathbf{X^{INF}}$ | ED SHARE | 351 | 3.08 | 1.20 |
| $\mathbf{X^{INF}}$ | IP | 162 | 6.87 | 0.97 |
| $\mathbf{X^{INF}}$ | OPENNESS | 216 | 7.00 | 1.10 |
| $\mathbf{X^{INF}}$ | ANTITRUST | 162 | 5.75 | 1.09 |
| **CLUSTER-SPECIFIC INNOVATION ENVIRONMENT** | | | | |
| $\mathbf{Y^{CLUS}}$ | PRIVATE R&D FUNDING | 355 | 48.60 | 12.88 |
| **THE QUALITY OF LINKAGES** | | | | |
| $\mathbf{Z^{LINK}}$ | UNIV R&D PERFORMANCE | 355 | 21.50 | 6.20 |
| $\mathbf{Z^{LINK}}$ | VENTURE CAPITAL | 214 | 5.45 | 1.32 |
| **CONTRIBUTING AND RELATED OUTCOME FACTORS** | | | | |
| JOURNALS | | 378 | 17446.39 | 28621.21 |
| GDP | | 357 | 772.44 | 1161.64 |
| LABOR | | 321 | 18.10 | 25.60 |
| CAPITAL | | 306 | 550.00 | 795.00 |
| TFP | | 304 | 1.42 | 0.21 |
| MARKET SHARE | | 357 | 5.88% | 6.85% |

## TABLE 4

## DETERMINANTS OF THE PRODUCTION OF NEW-TO-THE-WORLD TECHNOLOGIES (GDP/POP AS KNOWLEDGE STOCK)

| | | **Dependent Variable = ln(PATENTS)$_{j,t+3}$** | | | |
|---|---|---|---|---|---|
| | | **(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 | **1.384**<br>**(0.086)** | **1.252**<br>**(0.086)** | **0.746**<br>**(0.098)** | **0.783**<br>**(0.096)** |
| **$H_A$** | L FT S&E | **1.160**<br>**(0.016)** | **0.878**<br>**(0.046)** | **0.870**<br>**(0.046)** | **0.883**<br>**(0.045)** |
| **$H^A$** | L R&D $ | | **0.327**<br>**(0.047)** | **0.284**<br>**(0.044)** | **0.272**<br>**(0.044)** |
| **$X^{INF}$** | ED SHARE | | **0.110**<br>**(0.016)** | **0.154**<br>**(0.016)** | **0.152**<br>**(0.016)** |
| **$X^{INF}$** | IP | | **0.254**<br>**(0.056)** | **0.226**<br>**(0.051)** | **0.221**<br>**(0.045)** |
| **$X^{INF}$** | OPENNESS | | **0.095**<br>**(0.033)** | **0.053**<br>**(0.032)** | **0.061**<br>**(0.030)** |
| **$X^{INF}$** | ANTITRUST | | -0.051<br>(0.050) | -0.040<br>(0.045) | |
| **CLUSTER-SPECIFIC INNOVATION ENVIRONMENT** | | | | | |
| **$Y^{CLUS}$** | PRIVATE R&D FUNDING | | | **0.016**<br>**(0.002)** | **0.016**<br>**(0.002)** |
| **QUALITY OF THE LINKAGES** | | | | | |
| **$Z^{LINK}$** | UNIV R&D PERFORMANCE | | | **0.009**<br>**(0.003)** | **0.009**<br>**(0.003)** |
| **$Z^{LINK}$** | VENTURE CAPITAL | | | 0.032<br>(0.021) | |
| **CONTROLS** | | | | | |
| Year fixed effects | | | **Significant** | **Significant** | **Significant** |
| US dummy | | | **-0.249**<br>**(0.092)** | -0.014<br>(0.090) | 0.001<br>(0.088) |
| Constant | | **-10.327**<br>**(0.307)** | | | |
| R-Squared | | 0.9378 | 0.9979 | 0.9983 | 0.9983 |
| Adjusted R-Squared | | 0.9375 | 0.9977 | 0.9981 | 0.9981 |
| Observations | | 353 | 347 | 347 | 347 |

# TABLE 5
# DETERMINANTS OF THE PRODUCTION OF NEW-TO-THE-WORLD TECHNOLOGIES
# (USING PATENT STOCK AS KNOWLEDGE STOCK)

| | | **Dependent Variable = ln(PATENTS)$_{j,t+3}$** | | | |
|---|---|---|---|---|---|
| | | **(5-1)**<br>Baseline<br>Ideas Production Function<br>(with year FE) | **(5-2)**<br>Common Innovation Infrastructure | **(5-3)**<br>National Innovative Capacity:<br>including all variables | **(5-4)**<br>National Innovative Capacity:<br>Preferred Model |
| **QUALITY OF THE COMMON INNOVATION INFRASTRUCTURE** | | | | | |
| **A** | L PATENT STOCK | **1.174**<br>**(0.072)** | **0.644**<br>**(0.028)** | **0.593**<br>**(0.029)** | **0.589**<br>**(0.028)** |
| **$H^{A}$** | L FT S&E | **0.431**<br>**(0.062)** | **0.420**<br>**(0.025)** | **0.464**<br>**(0.024)** | **0.464**<br>**(0.024)** |
| **$H^{A}$** | L R&D $ | | 0.038<br>(0.034) | 0.025<br>(0.033) | 0.029<br>(0.032) |
| **$X^{INF}$** | ED SHARE | | **0.039**<br>**(0.011)** | **0.067**<br>**(0.013)** | **0.068**<br>**(0.012)** |
| **$X^{INF}$** | IP | | **0.066**<br>**(0.038)** | **0.067**<br>**(0.035)** | **0.073**<br>**(0.029)** |
| **$X^{INF}$** | OPENNESS | | -0.026<br>(0.023) | -0.025<br>(0.022) | -0.026<br>(0.021) |
| **$X^{INF}$** | ANTITRUST | | -0.009<br>(0.035) | 0.012<br>(0.033) | |
| | | | | | |
| **$Y^{CLUS}$** | PRIVATE R&D FUNDING | | | **0.009**<br>**(0.001)** | **0.009**<br>**(0.001)** |
| | | | | | |
| **$Z^{LINK}$** | UNIV R&D PERFORMANCE | | | **0.009**<br>**(0.002)** | **0.009**<br>**(0.002)** |
| **$Z^{LINK}$** | VENTURE CAPITAL | | | -0.009<br>(0.015) | |
| | | | | | |
| Year fixed effects | | **Significant** | | | |
| $Y_0$ | | | **0.961**<br>**(0.085)** | **0.884**<br>**(0.080)** | **0.883**<br>**(0.080)** |
| YEAR | | | **-0.062**<br>**(0.003)** | **-0.065**<br>**(0.003)** | **-0.065**<br>**(0.003)** |
| Country fixed effects | | **Significant** | | | |
| L GDP 1967 | | | **0.418**<br>**(0.053)** | **0.247**<br>**(0.055)** | **0.241**<br>**(0.054)** |
| US dummy | | | **-0.245**<br>**(0.068)** | **-0.054**<br>**(0.068)** | **-0.057**<br>**(0.067)** |
| R-Squared | | 0.9997 | 0.9989 | 0.9989 | 0.9990 |
| Observations | | 353 | 347 | 347 | 347 |

# TABLE 6
# EXPLORING ROBUSTNESS

| | | Dependent Variable = $\ln(\text{PATENTS})_{j,t+3}$ | | | | |
|---|---|---|---|---|---|---|
| | | **(6-1)** Baseline Ideas Production Function with GDP per Capita and Patent Stock | **(6-2)** National Innovative Capacity with GDP per Capita and Patent Stock | **(6-3)** (4-4), with country fixed effects | **(6-4)** (4-4), using only post-1984 observations | **(6-5)** (4-4), using only European countries |
| **QUALITY OF THE COMMON INNOVATION INFRASTRUCTURE** | | | | | | |
| **A** | L GDP PER CAPITA | **0.966**<br>**(0.122)** | **0.118**<br>**(0.056)** | **0.827**<br>**(0.219)** | **0.538**<br>**(0.133)** | **0.641**<br>**(0.102)** |
| **A** | L PATENT STOCK | **0.180**<br>**(0.038)** | **0.780**<br>**(0.027)** | | | |
| **$H^{A}$** | L FT S&E | **0.945**<br>**(0.048)** | **0.209**<br>**(0.034)** | **0.558**<br>**(0.090)** | **0.890**<br>**(0.073)** | **0.857**<br>**(0.049)** |
| **$H^{A}$** | L R&D $ | | **0.057**<br>**(0.024)** | **0.113**<br>**(0.042)** | **0.309**<br>**(0.070)** | **0.331**<br>**(0.048)** |
| **$X^{INF}$** | ED SHARE | | **0.046**<br>**(0.009)** | **0.044**<br>**(0.021)** | **0.153**<br>**(0.025)** | **0.244**<br>**(0.025)** |
| **$X^{INF}$** | IP | | -0.005<br>(0.025) | -0.008<br>(0.026) | **0.229**<br>**(0.044)** | **0.239**<br>**(0.051)** |
| **$X^{INF}$** | OPENNESS | | | **-0.050**<br>**(0.017)** | **0.066**<br>**(0.028)** | 0.040<br>(0.037) |
| **CLUSTER-SPECIFIC INNOVATION ENVIRONMENT** | | | | | | |
| **$Y^{CLUS}$** | PRIVATE R&D FUNDING | | **0.004**<br>**(0.001)** | 0.002<br>(0.003) | **0.019**<br>**(0.003)** | **0.013**<br>**(0.002)** |
| **QUALITY OF THE LINKAGES** | | | | | | |
| **$Z^{LINK}$** | UNIV R&D PERFORMANCE | | **0.0031**<br>**(0.0018)** | -0.005<br>(0.004) | **0.015**<br>**(0.005)** | **0.015**<br>**(0.004)** |
| **CONTROLS** | | | | | | |
| Year fixed effects | | | **Significant** | **Significant** | **Significant** | **Significant** |
| Country fixed effects | | | | **Significant** | | |
| US dummy | | | -0.062<br>(0.047) | | 0.042<br>(0.123) | |
| Constant | | **-8.284**<br>**(0.523)** | | | | |
| R-Squared | | 0.9416 | 0.9995 | 0.9996 | 0.9986 | 0.9979 |
| Adjusted R-Squared | | 0.9411 | 0.9995 | 0.9995 | 0.9984 | 0.9976 |
| Observations | | 353 | 347 | 347 | 153 | 267 |

## TABLE 7
## EXPLORING RELATIONSHIP TO SCIENTIFIC PUBLICATION

| | | **(7-1)**<br>Explaining journal articles | **(7-2)**<br>Base Model Including journal articles |
|---|---|---|---|
| **Dependent Variable** | | ln(JOURNALS)$_{j,t+3}$ | ln(PATENTS)$_{j,t+3}$ |
| **QUALITY OF THE COMMON INNOVATION INFRASTRUCTURE** | | | |
| **A** | L GDP/POP | **0.224**<br>**(0.067)** | **0.561**<br>**(0.098)** |
| **A** | L JOURNALS | | **0.473**<br>**(0.076)** |
| **$H^{A}$** | L FT S&E | **0.832**<br>**(0.031)** | **0.474**<br>**(0.079)** |
| **$H^{A}$** | L R&D $ | -0.032<br>(0.030) | **0.300**<br>**(0.044)** |
| **$X^{INF}$** | ED SHARE | **0.106**<br>**(0.011)** | **0.099**<br>**(0.018)** |
| **$X^{INF}$** | IP | -0.042<br>(0.034) | **0.228**<br>**(0.042)** |
| **$X^{INF}$** | OPENNESS | 0.030<br>(0.023) | 0.040<br>(0.028) |
| **CLUSTER-SPECIFIC INNOVATION ENVIRONMENT** | | | |
| **$Y^{CLUS}$** | PRIVATE R&D FUNDING | **-0.010**<br>**(0.001)** | **0.023**<br>**(0.002)** |
| **QUALITY OF THE LINKAGES** | | | |
| **$Z^{LINK}$** | UNIV R&D PERFORMANCE | -0.001<br>(0.002) | **0.011**<br>**(0.003)** |
| **CONTROLS** | | | |
| Year fixed effects | | **Significant** | **Significant** |
| US dummy | | **0.272**<br>**(0.062)** | -0.107<br>(0.089) |
| R-Squared | | 0.9995 | 0.9985 |
| Adjusted R-Squared | | 0.9995 | 0.9983 |
| Observations | | 330 | 323 |

# TABLE 8
# EXPLORING RELATIONSHIP TO TFP AND INTERNATIONAL TRADE

| | | **(8-1)** Sensitivity of TFP to Ideas Production | **(8-2)** Sensitivity of Market Share to Patent Stock | **(8-3)** Sensitivity of Market Share to predicted National Innovative Capacity | **(8-4)** Sensitivity of Market Share to elements of National Innovative Capacity |
|---|---|---|---|---|---|
| **Dependent Variable** | | ln(GDP)$_{j,t+3}$ | MARKET SHARE$_{j,t+3}$ | MARKET SHARE$_{j,t+3}$ | MARKET SHARE$_{j,t+3}$ |
| **MEASURES OF NATIONAL INNOVATIVE CAPACITY** | | | | | |
| PREDICTED PATENTS$_{t+3}$ | | | | **0.615**<br>**(0.062)** | |
| L PATENT STOCK | | **0.114**<br>**(0.015)** | **0.528**<br>**(0.052)** | | |
| **QUALITY OF THE COMMON INNOVATION INFRASTRUCTURE** | | | | | |
| **A** | L GDP/POP | | | | 0.127<br>(0.208) |
| **H$^{A}$** | L FT S&E | | | | **0.503**<br>**(0.150)** |
| **X$^{INF}$** | L R&D $ | | | | -0.151<br>(0.094) |
| **X$^{INF}$** | ED SHARE | | | | **0.150**<br>**(0.035)** |
| **X$^{INF}$** | IP | | | | 0.080<br>(0.087) |
| **X$^{INF}$** | OPENNESS | | | | **0.254**<br>**(0.062)** |
| **CLUSTER-SPECIFIC INNOVATION ENVIRONMENT** | | | | | |
| **Y$^{CLUS}$** | PRIVATE R&D FUNDING | | | | **0.038**<br>**(0.004)** |
| **QUALITY OF THE LINKAGES** | | | | | |
| **Z$^{LINK}$** | UNIV R&D PERFORMANCE | | | | **0.040**<br>**(0.007)** |
| **CONTROLS** | | | | | |
| L LABOR | | **0.643**<br>**(0.040)** | | | |
| L CAPITAL | | **0.213**<br>**(0.051)** | | | |
| Y$_0$ | | 0.044<br>(0.053) | -0.022<br>(0.194) | -0.052<br>(0.199) | -0.062<br>(0.180) |
| YEAR | | -0.001<br>(0.003) | -0.068<br>(0.010) | **-0.016**<br>**(0.007)** | -0.019<br>(0.015) |
| L GDP 1967 | | | **0.472**<br>**(0.076)** | **0.353**<br>**(0.090)** | **0.757**<br>**(0.152)** |
| US dummy | | **0.276**<br>**(0.055)** | | | **0.063**<br>**(0.010)** |
| Constant | | | **-5.297**<br>**(0.766)** | **-8.457**<br>**(0.662)** | **-14.167**<br>**(1.603)** |
| R-Squared | | 0.9772 | 0.7978 | 0.7962 | 0.7880 |
| Adjusted R-Squared | | 0.9767 | 0.7955 | 0.7938 | 0.7783 |
| Observations | | 304 | 357 | 347 | 323 |

**Figure A**

**Ideas Production in Endogenous Growth Theory**

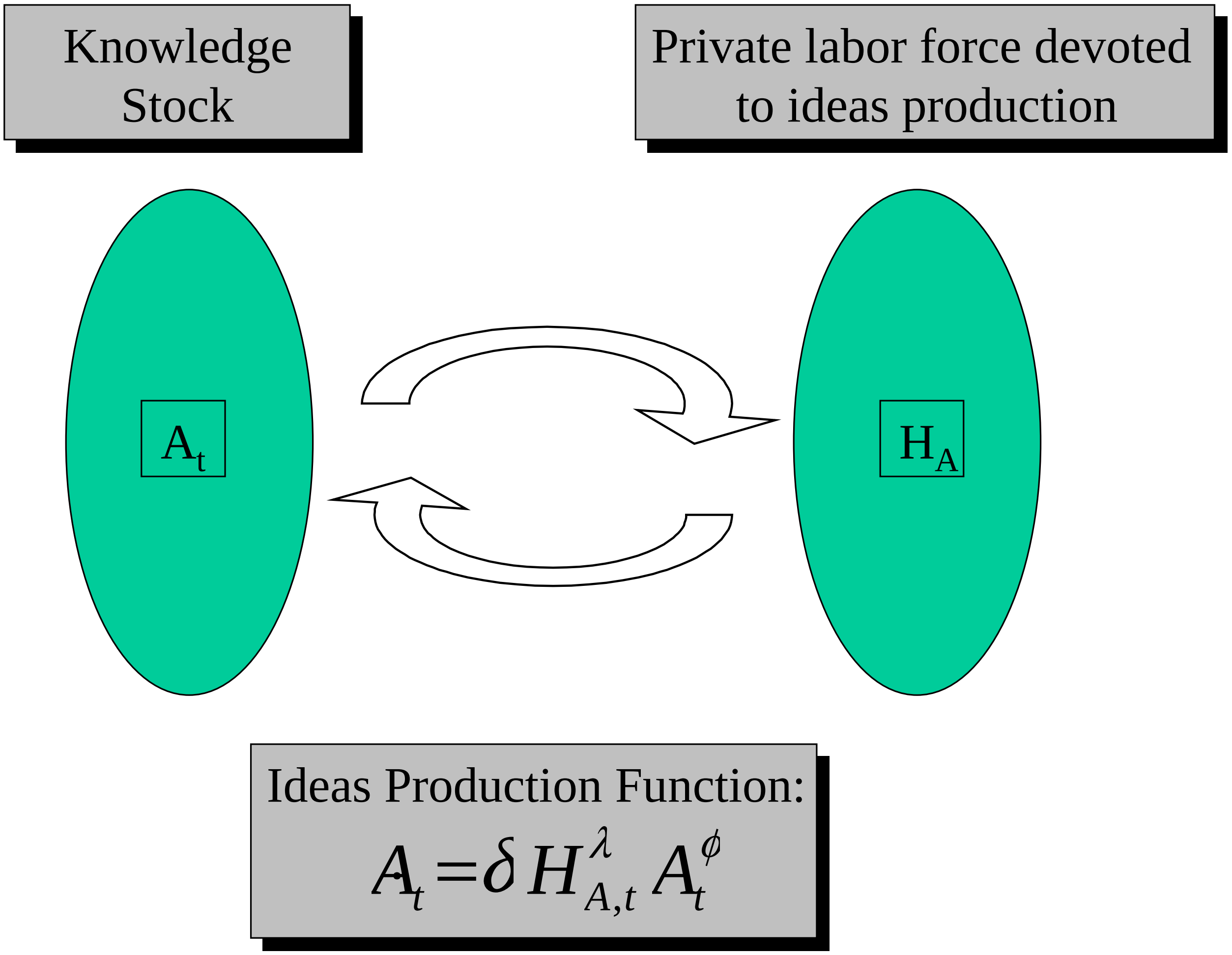
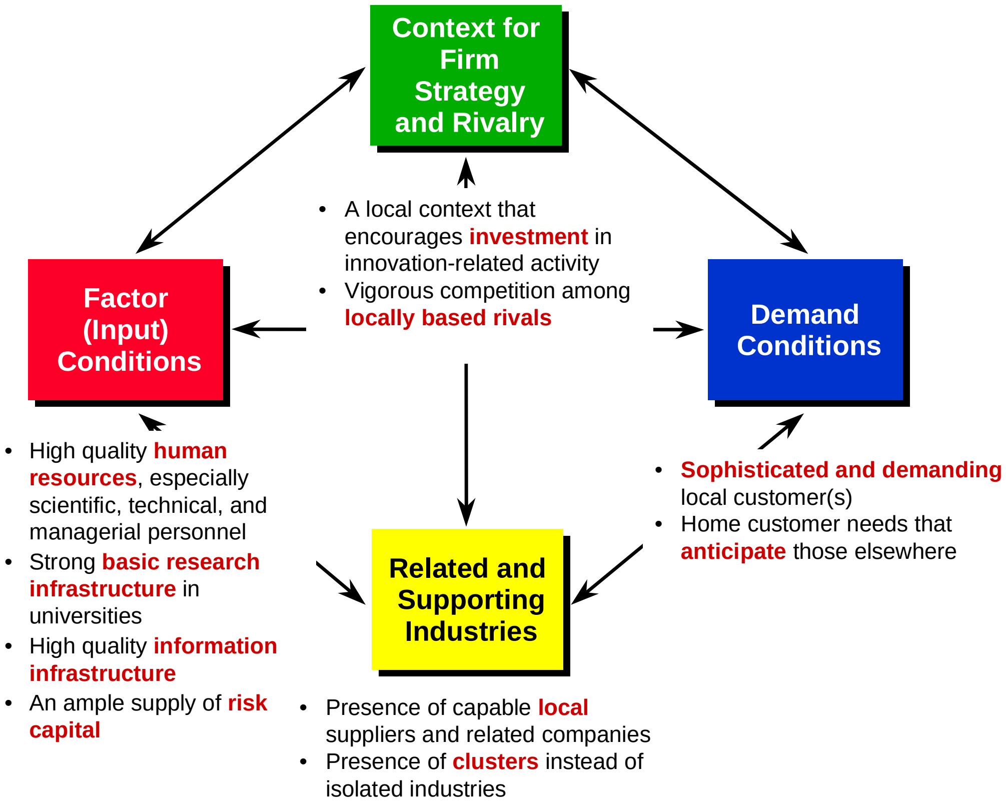


**Figure B**

**The Innovation Orientation of National Industry Clusters**



- A local context that encourages **investment** in innovation-related activity
- Vigorous competition among **locally based rivals**

- High quality **human resources**, especially scientific, technical, and managerial personnel
- Strong **basic research infrastructure** in universities
- High quality **information infrastructure**
- An ample supply of **risk capital**

- **Sophisticated and demanding** local customer(s)
- Home customer needs that **anticipate** those elsewhere

- Presence of capable **local** suppliers and related companies
- Presence of **clusters** instead of isolated industries

## Figure C-1

## Some Important Elements of the National Innovation System in the United States

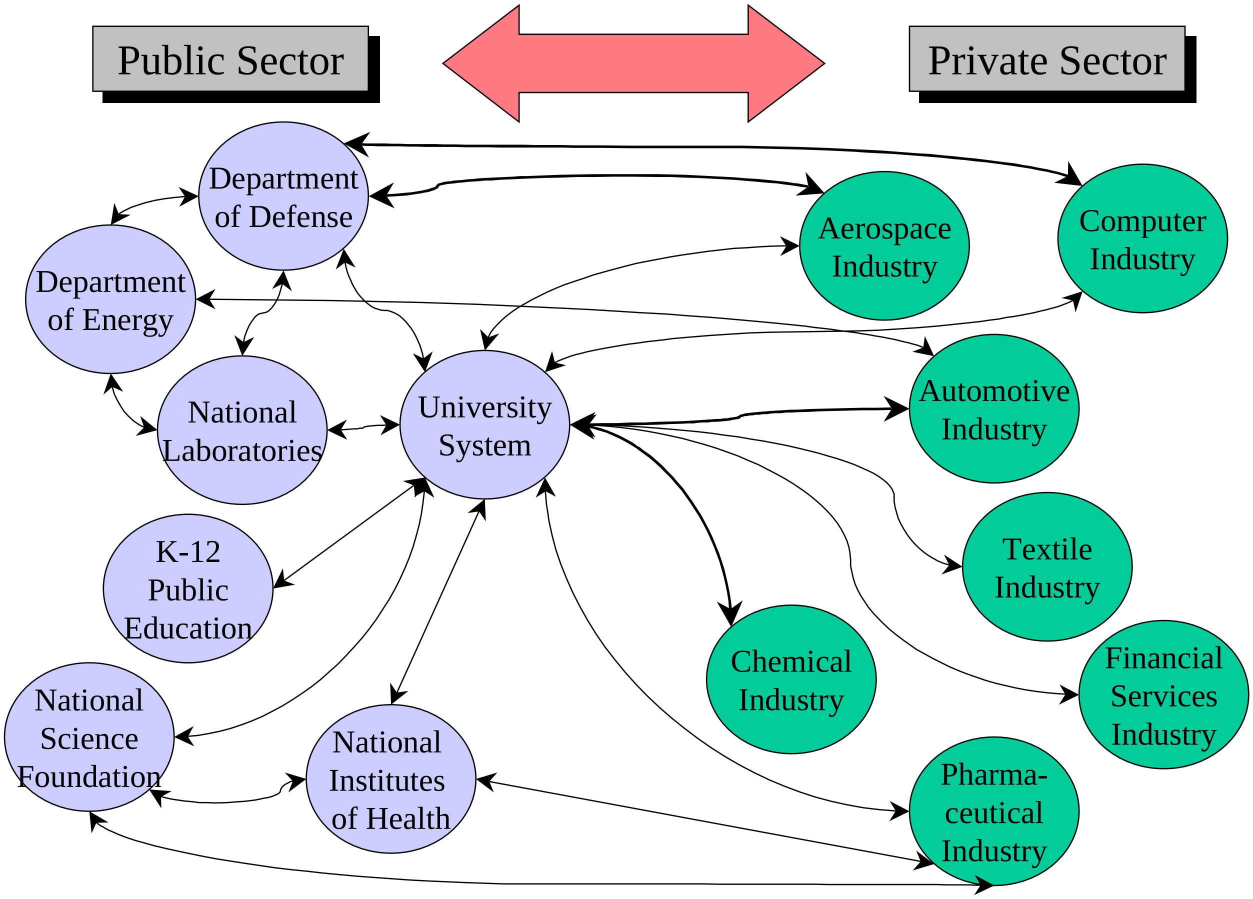
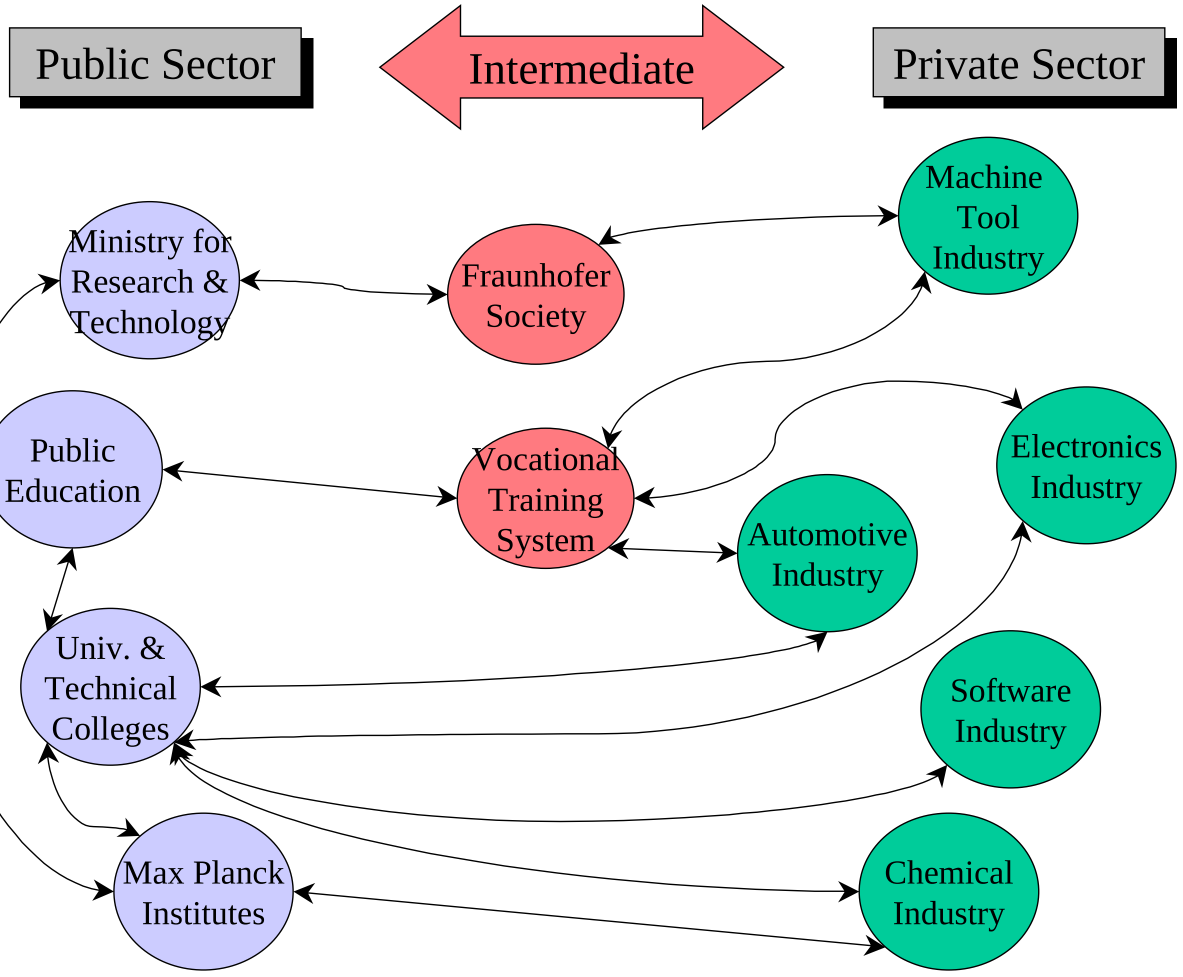


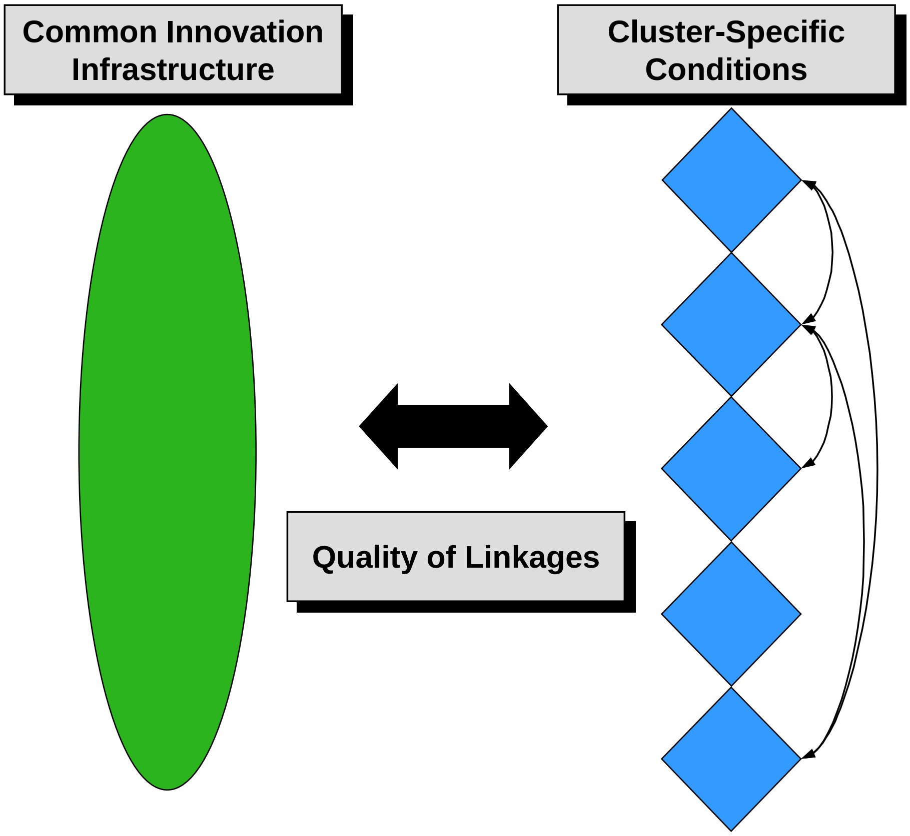
**Figure C-2**

**Some Important Elements of the National Innovation System in Germany**



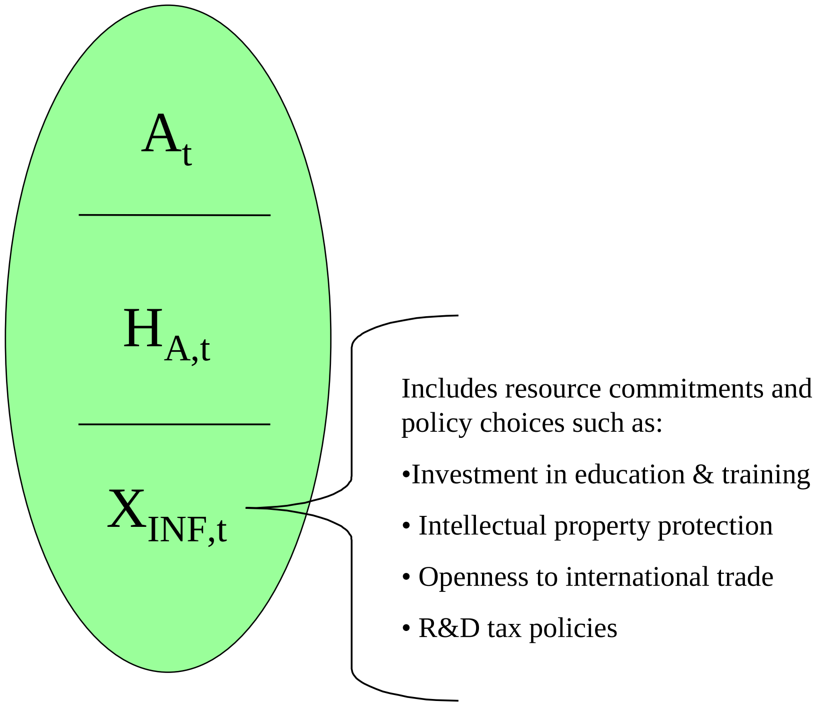
## Figure D

## Measuring National Innovative Capacity



## Figure E

## The Common Innovation Infrastructure

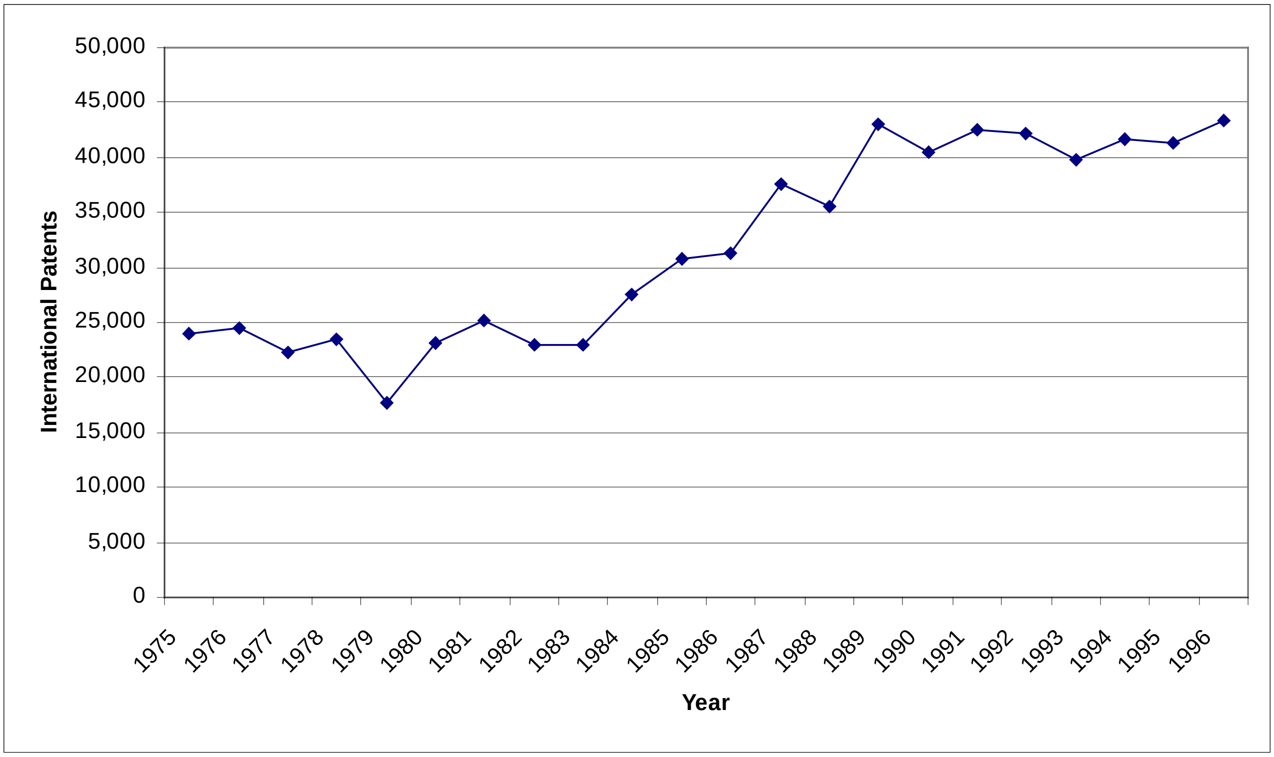


Includes resource commitments and policy choices such as:

- •Investment in education & training
- • Intellectual property protection
- • Openness to international trade
- • R&D tax policies

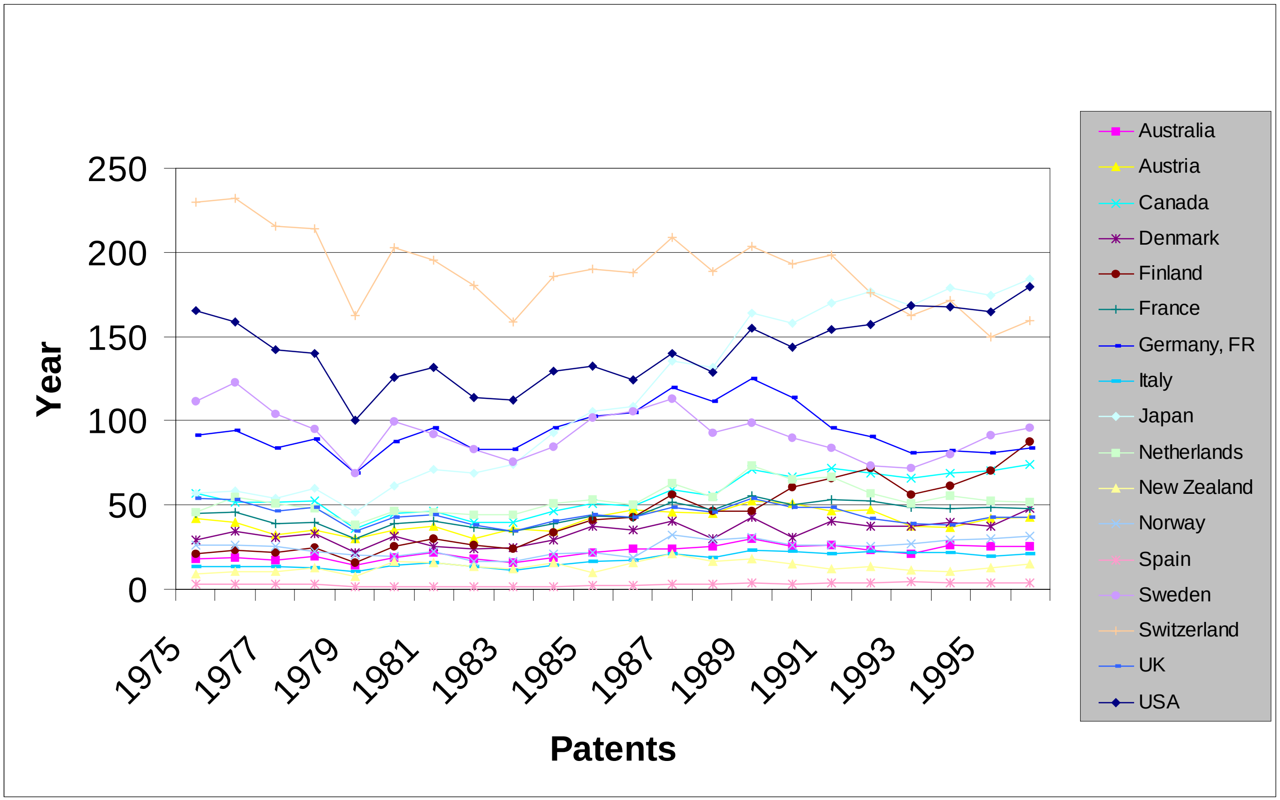
## Figure F

## International Patents Granted by the USPTO



## Figure G

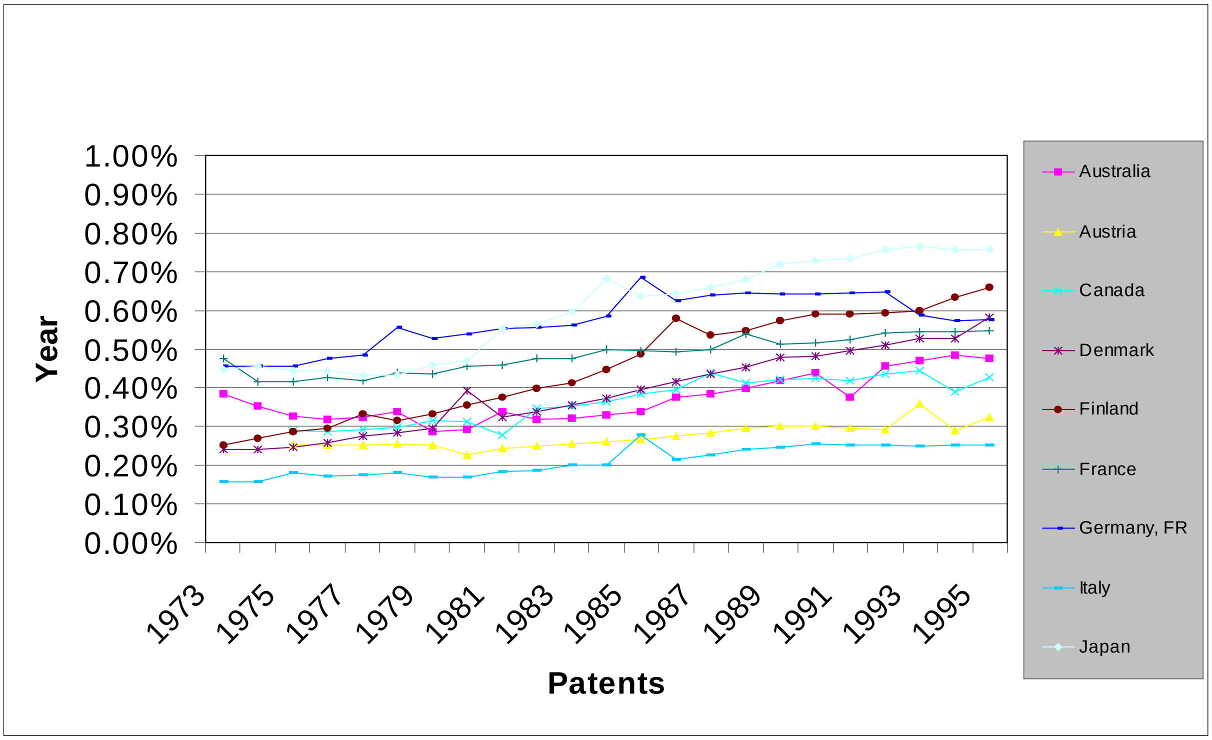
## International Patents per Million Persons



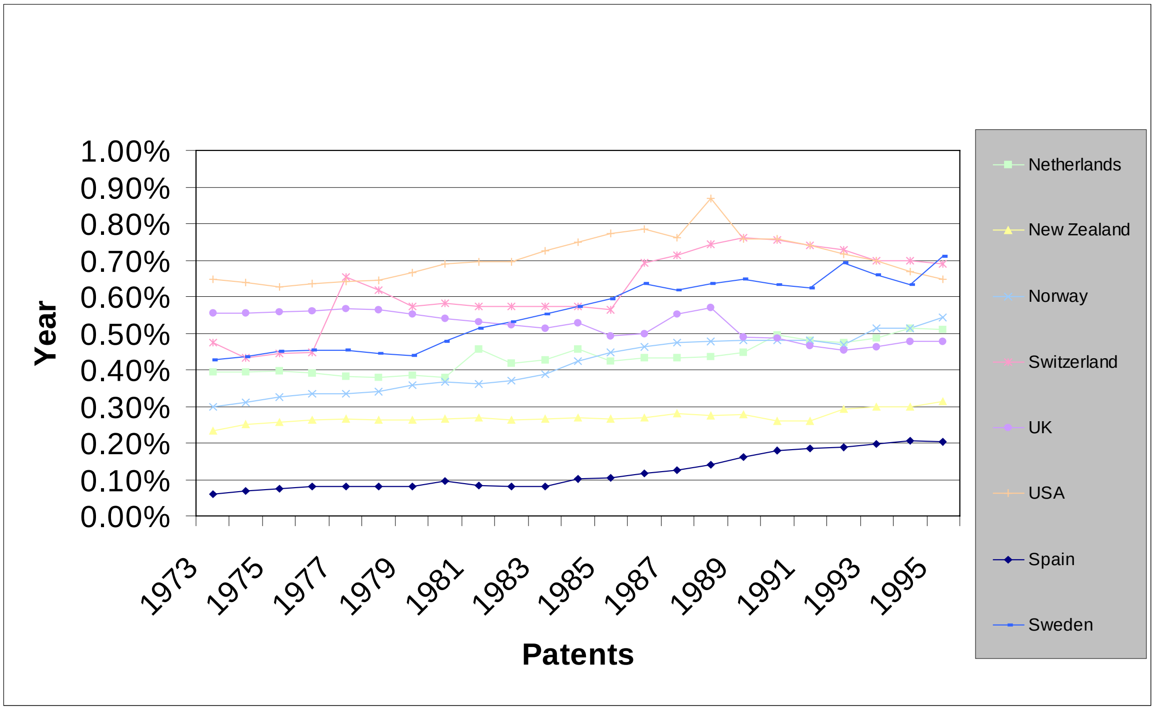
## Figure H

## FTE Scientists & Engineers as a Percentage of Population

### Selected Countries (A-J)

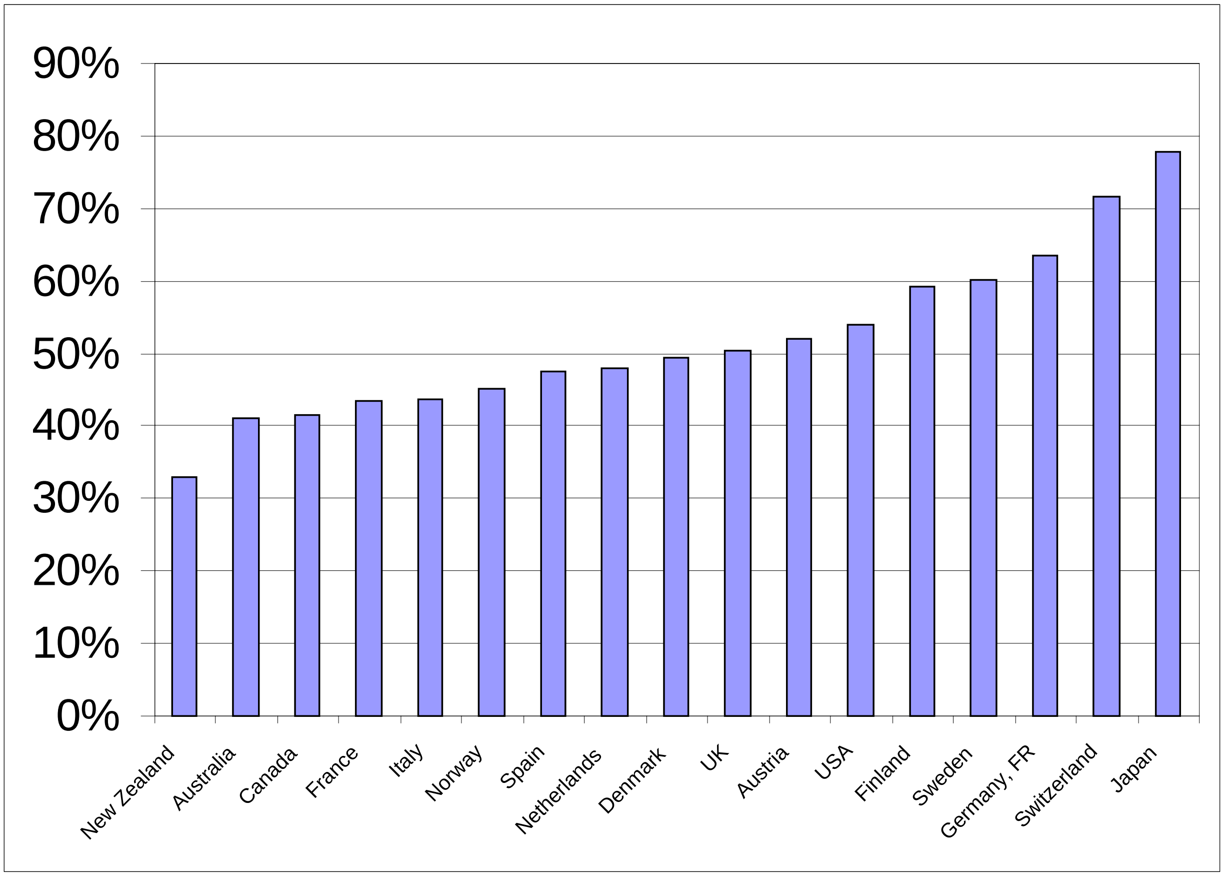


### Selected Countries (N-Z)



## Figure I

## Percent of R&D Expenditure Funded by Industry



## Figure J

## Trends in National Innovative Capacity