

UNDERSTANDING THE DRIVERS OF NATIONAL INNOVATIVE CAPACITY

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ABSTRACT

Motivated by R&D productivity differences across countries, we evaluate the determinants of country-level international patenting. Our framework is built on concept of *national innovative capacity*. Our results suggest that (a) patenting is well-characterized by a small but nuanced set of observable economic factors which may be affected by public policy and (b) the OECD has experienced substantial *convergence* in national innovative capacity over the last quarter century.

INTRODUCTION

In the past decade, both academic scholars and policymakers have focused increasing attention on the central role that technological innovation plays in economic growth. In turning their attention to the sources and consequences of technological innovation, researchers confront a striking empirical puzzle: while R&D activity is relatively dispersed around the world, “new-to-the-world” innovation tends to be concentrated among a small number of countries at any given point in time. For example, during the 1970s and the early 1980s, only Switzerland, a small but technology-intensive country, achieved a per capita “international” patenting rate comparable to the rate achieved by U.S. inventors. Motivated by the geographically concentrated nature of “new-to-the-world” innovation, we have undertaken a series of related studies attempting to identify the drivers of R&D productivity differences among countries and link these drivers to the long-term choices facing policymakers in the public sector and managers in the private sector (Porter and Stern, 1999; Stern, Porter, and Furman, 1999; and Porter and Stern, 2000).

In this brief summary, we describe a conceptual framework for evaluating sources of national R&D productivity differences and review key empirical findings based on this framework. We base our model on the concept of *national innovative capacity*, drawing on three distinct areas of prior research: ideas-driven endogenous growth theory (Romer, 1990), cluster-based theory of national industrial competitive advantage (Porter, 1990), and the literature on national innovation systems (Nelson, 1993). National innovative capacity is the potential of a country – as both a political and economic entity – to produce and commercialize a flow of innovative technology at a given point in time. As such, national innovative capacity depends on an interrelated set of fundamental investments, policies, and resource commitments that determine the extent and success of innovative effort in a country over the long term.

DETERMINANTS OF NATIONAL INNOVATIVE CAPACITY

National innovative capacity is defined as an economy's potential, at a given point in time, for producing a stream of commercially relevant innovations. This capacity depends in part on the technological sophistication and labor force in a given economy, but also reflects the investments and policies of the government and private sector that affect the incentives for and the productivity of a country's R&D activities. Our framework organizes the determinants of national innovative capacity into three main elements (see Figure A): (1) a common pool of institutions, resource commitments, and policies that support innovation, referred to as the common innovation infrastructure; (2) the particular innovation orientation of groups of interconnected national industrial clusters; and (3) the quality of linkages between the two.

FIGURE A about here

Common Innovation Infrastructure. Although the innovative performance of an economy ultimately rests with the behavior of individual firms and industrial clusters, some of the most critical investments that support innovative activity operate across all innovation-oriented sectors in an economy. We describe such elements as an economy's *common innovation infrastructure* (corresponding to the left-hand portion of Figure A). Consistent with models of ideas-based growth (Romer, 1990), our framework suggests that a country's R&D productivity will depend upon the a county's accumulated stock of knowledge (denoted A_t) and the extent of available scientific and technical talent dedicated to the production of new technologies (denoted $H_{A,t}$). In addition to the size of a country's knowledge stock and talent pool, R&D productivity will also depend on national investments and policy choices (denoted as X^{INF}), such as spending on higher education, intellectual property protection, and openness to international competition, which will exert a cross-cutting impact on innovativeness across economic sectors (Nelson, 1993).

Cluster-Specific Innovation Orientation. While the common innovation infrastructure provides resources for innovation throughout an economy, it is the firms in specific industrial clusters that introduce and commercialize those innovations. The innovative capacity of an economy, then, depends upon the extent to which a county's industrial clusters support and compete on the basis of technological innovation. Drawing on the "diamond" framework developed in Porter (1990), we emphasize four key elements of the microeconomic environment – the presence of high-quality and specialized inputs; a context that encourages investment and intense local rivalry; pressure and insight gleaned from sophisticated local demand; and the presence of a cluster of related and supporting industries – that have a central influence on the rate of innovation in a given national industrial clusters (these are the diamonds on the right-hand side of Figure A). Of course, it is possible that there are additional, though perhaps less systematic, spillover potentials across industrial clusters that will also contribute to innovative capacity (i.e., the lines connecting the diamonds on the right-hand side of Figure A).

The Quality of Linkages. Finally, the extent to which the potential for innovation supported by the common innovation infrastructure is translated into specific innovative outputs in a nation's

industrial clusters will be determined by the quality of linkages between these two areas. In the absence of strong linking mechanisms, upstream scientific and technical activity may spill over to other countries more quickly than opportunities can be exploited by domestic industries.

MODELING NATIONAL INNOVATIVE CAPACITY

We use the national innovative capacity framework to direct our empirical analysis of the drivers of R&D productivity across the OECD over the past twenty-five years. In effect, we estimate a production function for economically significant technological innovations, in a manner similar to the ideas production described by endogenous growth theory (Jones, 1995; Stern and Porter, 1999). We choose a specification in which innovations are produced as a function of the factors underlying national innovative capacity:

 EQUATION 1 about here

where $A_{j,t}^*$ represents the flow of new-to-the-world technologies from country j in year t , $H^{A,\lambda}_{j,t}$ is the total level of capital and labor resources devoted to the ideas sector of the economy, and $A^{\text{phi}}_{j,t}$ is the total stock of knowledge held by an economy at a given point in time. In addition, X^{INF} refers to the level of cross-cutting resource commitments and policy choices underlying the common innovation infrastructure, Y^{CLUS} refers to the particular environments for innovation in a country's industrial clusters, and Z^{LINK} captures the strength of linkages between the common infrastructure and a nation's industrial clusters. Letting LX be defined as the natural logarithm of X , our main specification takes the following form:

 EQUATION 2 about here

We conduct our analysis on a panel dataset of OECD countries from 1973 to 1995. Implementing (2) requires observable measures of new-to-the-world innovation and each of the concepts underlying national innovative capacity. While no measure of innovation at the national level is ideal, we organize the analysis around the observed number of "international patents," a useful indicator of the country-specific level of realized, visible "new-to-the-world" innovation at a point in time. We define international patents as those granted by the United States Patent & Trademark Office as well as by the home country of the inventor. Patenting rates (per capita) differ substantially across OECD countries; as well, over the past quarter century, there seems to have been substantial *convergence* – countries with the highest growth rates began the period with modest or relatively low levels of per capita international patenting.

The principal empirical exercise in this paper relates each country's level of international patenting to variables corresponding to elements of the national innovative capacity framework. (see Table 1). Essentially, we utilize a number of observed aggregate measures (such as the number of full-time equivalent scientists and engineers and aggregate R&D expenditures) and indicators of national policies (the strength of intellectual property protection and openness to international trade) to capture the strength of the common innovation infrastructure. We measure the innovation orientation of industrial clusters and the strength of linkages by *compositional*

variables associated with the degree to which R&D is *funded* by the private sector and *performed* by the university sector, respectively.

EMPIRICAL FINDINGS

The above framework allows us to perform empirical analyses dissecting the drivers of national innovative capacity and evaluate historical trends in national innovative performance (Table 1 reports the regression results).¹ Consistent with the ideas-based growth literature, the first specification (1-1) suggests that the level of innovation is influenced powerfully both by a country's technological sophistication (GDP PER CAPITA) and its level of effort devoted to the "ideas" sector (FTE S&E). We then report our "preferred" specification (1-2), highlighting the separate impact of several distinct drivers to national innovative capacity. This specification suggests that each of the elements associated with national innovative capacity, several of which are amenable to policy change, are quantitatively significant in explaining R&D productivity across OECD countries over the past quarter century. In other words, the extent and nature of investments in national innovative capacity are associated with observed levels of innovative output and R&D productivity. Finally, we demonstrate the robustness of the core results to the inclusion of an additional measure of a country's accumulated technological sophistication (PATENT STOCK), a measure explored more thoroughly in Porter and Stern (2000).

TABLE 1 about here

In addition to the factors identified by ideas-based growth theory (GDP PER CAPITA, PATENT STOCK, and FTE S&E) our analysis suggests that national innovative output is affected both by (a) more nuanced elements of the common innovation infrastructure and (b) the *composition* of investments in innovation. For example, international patenting reflects the level of investment in higher education, the strength of intellectual property protection, and the degree of openness to international trade and competition. As well, our measure of innovative output is affected by the extent to which R&D is *financed* by industry and *performed* by universities. In terms of magnitudes (the details of which are reviewed more thoroughly in Stern, Porter, and Furman (1999)), the results from (1-2) suggest that even relatively nuanced factors can have relatively large predicted impacts. For example, a one unit change in the strength of intellectual property protection (e.g., from 7 to 8) is associated with a 22 percent increase in international patenting, and increasing the share of R&D performed by the university sector by 10 percent is predicted to be associated with a 9 percent increase in international patents. Overall, however, whereas no *single* factor is sufficient to drive national innovative capacity by itself, our findings suggest that innovation leadership results from simultaneous strength in the complementary dimensions which contribute to innovative capacity.

In addition to evaluating the drivers of international patenting, our analysis allows us to evaluate trends in national innovative capacity among our sample of OECD economies (where we use a country's predicted per capita international patenting rate as calculated from (1-2)). First, and perhaps most importantly, there appears to be *convergence* in predicted per capita patenting across the OECD during our time period. While the United States and Switzerland have

predicted levels far above other countries at the beginning of the 1970s, the predicted levels of several countries (including Japan, Germany, and several of the Scandinavian countries) are (roughly) equivalent to the United States by the end of the observed period. Moreover, such convergence does not simply reflect convergence in economywide productivity: for example, despite extremely slow economic growth during the 1990s, Japan has remained committed to policies and invested in resources that contribute to national innovative capacity. In contrast, the counterfactuals for several leading Western European economies (including the United Kingdom, France, and Italy) imply that the level of innovative capacity in these countries has remained constant (or even perhaps declined) over the past quarter century.

CONCLUDING THOUGHTS

This paper reviews some of the key findings of our recent research on *national innovative capacity*. In addition to several more subtle results, our findings suggest (a) that patenting is well-characterized by a small but nuanced set of observable economic factors which may be affected by public policy and (b) that the OECD has experienced substantial *convergence* in national innovative capacity over the last quarter century. In future work, we hope to further develop this framework, both to provide quantitative evidence about the relationship between the national innovation infrastructure and R&D productivity in individual industrial clusters and to link national innovative capacity to more “downstream” implications, most notably the rate of economywide productivity growth..

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ENDNOTES

¹ Limited space precludes a fair discussion of a number of methodological and robustness considerations, each of which are discussed extensively in Stern, Porter, and Furman (1999). Though not a complete list, these issues include (a) the appropriateness of using the international

patenting measures, (b) the importance of both year and country-specific effects for interpreting the key results and (c) the use of alternative measures of both innovation and the elements of national innovative capacity.

$$\dot{A}_{j,t} = \mathbf{d}_{j,t}(X_{j,t}^{\text{INF}}, Y_{j,t}^{\text{CLUST}}, Z_{j,t}^{\text{LINK}}) H_{j,t}^{\text{A}^I} A_{j,t}^f \quad (1)$$

$$L\dot{A}_{j,t} = d_{\text{YEAR}} Y_t + d_{\text{COUNTRY}} C_j + d_{\text{INF}} LX_{j,t}^{\text{INF}} + d_{\text{CLUS}} LY_{j,t}^{\text{CLUS}} + d_{\text{LINK}} LZ_{j,t}^{\text{LINK}} + lLH_{j,t}^A + fLA_{j,t} + e_{j,t} \quad (2)$$

TABLE 1
DETERMINANTS OF THE PRODUCTION OF
NEW-TO-THE-WORLD TECHNOLOGIES

Dependent Variable = ln(INTERNATIONAL PATENTS)_{j,t+3}		(1-1) Ideas Production Function	(1-2) National Innovative Capacity Model	(1-3) (1-2) w/ PATENT STOCK
QUALITY OF THE COMMON INNOVATION INFRASTRUCTURE				
A	L GDP PER CAPITA _{j,t}	1.384 (0.086)	0.783 (0.096)	0.118 (0.056)
A	L SUM OF INTL. PATENTS (0 – T-1) _{i,t} (PATENT STOCK)			0.780 (0.027)
H^A	L FTE SCIENTISTS & ENGINEERS _{j,t} (FTE S&E)	1.160 (0.016)	0.883 (0.045)	0.209 (0.034)
H^A	L \$ R&D EXPENDITURES _{j,t}		0.272 (0.044)	0.057 (0.024)
X^{INF}	SHARE OF GDP SPENT ON HIGHER EDUCATION _{j,t}		0.152 (0.016)	0.046 (0.009)
X^{INF}	INTELLECTUAL PROPERTY PROTECTION _{j,t} (survey scale, 1-10)		0.221 (0.045)	-0.005 (0.025)
X^{INF}	OPENNESS TO INTERNATIONAL TRADE _{j,t} (survey scale, 1-10)		0.061 (0.030)	
CLUSTER-SPECIFIC INNOVATION ENVIRONMENT				
Y^{CLUS}	% R&D FUNDED BY PRIVATE SECTOR _{j,t}		0.016 (0.002)	0.004 (0.001)
QUALITY OF THE LINKAGES				
Z^{LINK}	% R&D PERFORMED BY UNIVERSITY SECTOR _{j,t}		0.009 (0.003)	0.0031 (0.0018)
CONTROLS (Regression constant and US Dummy excluded for space constraints)				
Year fixed effects			Significant	Significant
Adjusted R-Squared		0.9375	0.9981	0.9995
Observations (17 countries x 21 years)		353	347	347

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

FIGURE A
 NATIONAL INNOVATIVE CAPACITY

