The Political Economy of Technological Innovation: A Change in the Debate

by

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M.A. International Relations
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Abstract

Why are some countries more technologically innovative than others? The dominant explanation amongst political-economists is that domestic institutions determine national innovation rates. However, after decades of research, the empirical evidence for this relationship remains equivocal. There are simply many countries with “good” institutions that do not innovate at the technological frontier, and many countries with “bad” institutions that have nonetheless built impressive records of technological progress. Therefore, in this dissertation, in order to probe the sources of variance in national innovation rates, I analyze quantitative data on innovation, various domestic institutions, and four types of international relationships. First, I review the National Innovation Systems literature. Second, I test the Varieties of Capitalism theory of innovation. Third, I ask whether decentralized states are better at technological innovation than centralized states. In each case, I find that there exists little empirical evidence for an aggregate relationship between domestic institutions and technological innovation. That is, although a specific domestic institution or policy might appear to explain a particular instance of innovation, they fail to explain national innovation rates across time and space. However, the empirical evidence does suggest that a country’s international relationships may be the missing piece to the national innovation rate puzzle. More specifically, the evidence presented in this dissertation suggests that certain kinds of international relationships (e.g. capital goods imports, foreign direct investment, educational exchanges) do affect national innovation rates in the aggregate. And countries which have these kinds of relationships with the lead innovating nations tend to become more innovative than states which do not, almost regardless of their domestic institutions. In other words, explaining national innovation rates may not be so much a domestic institutions story as it is an international story. My empirical evidence includes data on simple patent counts, patents weighted by forward citations, science and engineering publications (both simple counts and citations-weighted), and high-technology exports.

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Biographical Note

Mark Zachary Taylor graduated U.C. Berkeley in 1990 with a Bachelor’s degree in Physics and a minor in Japanese Studies. He then traveled to Japan, living in both Tokyo and Osaka, where he taught English, operated a small business, and attended the Kansai University of Foreign Studies. In 1993, he entered Yale University, where he earned a Master’s Degree in International Relations under the guidance of Professor D. Allan Bromley, former science and technology advisor to President George H.W. Bush and director of the Office of Science and Technology Policy. Zak published his Master’s thesis, “Dominance Through Technology” in the Nov/Dec 1995 issue of the journal *Foreign Affairs*. During this time he also interned at the Technology Administration in the U.S. Department of Commerce. In 1995, he was hired into the technology consulting practice of Price Waterhouse LLP where he spent two years attached to projects in Cleveland and Toronto. He also volunteered at the American Red Cross in Washington D.C. where, as an international logistician, he helped to streamline procedures for the shipping and distribution of food and relief goods to projects in Rwanda, Cuba, Armenia, and Poland. He also served as a damage assessment technician during the Hurricane Fran disaster-relief operation in Virginia. In 1998, he returned to graduate school at MIT, publishing a chapter of his PhD dissertation research in the Summer 2004 issue of the journal *International Organization*. He has accepted a position of Assistant Professor at the Sam Nunn School of International Affairs at the Georgia Institute of Technology in Atlanta.

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Chapter 1

Introduction: The Puzzle of National Innovation Rates

1.1 The Research Question and Its Motivation

Why are some countries more technologically innovative than others?[1] This question should interest social scientists and policymakers alike because of the prominent role that technology plays in almost every aspect of modern political economy.[2] For example, a nation's technological capability has a significant effect on its economic growth, industrial might, and military prowess. Therefore, relative national technological capabilities necessarily influence domestic standards of living, economic adjustment, and the balance of military power between states.[3] Technology and capacity to innovate also determine a nation's trade profile, affecting which products it will import and export, as well as where multinational corporations will base their production facilities.[4] Finally, insofar as innovation-driven economic growth both attracts investment and produces surplus capital, a nation's technological ability will also affect international financial flows and who has power over them.[5] Therefore understanding the determinants of national innovation rates is important for practical, as well as intellectual, reasons.

The conventional wisdom amongst most political scientists and economists is that domestic institutions determine national innovation rates. For example, some theories posit that differences in macro-level institutions, such as democracy or markets, are fundamental to explaining why some countries are better able to innovate at the technological frontier over the long-run. Other hypotheses focus more on the benefits or barriers to innovation created by different types of mid-level institutions, such as legal systems, regulatory regimes, financial systems, trade practices, defense policies, etc. The idea here is that the right policy mix or domestic incentive structures are instrumental for fostering technological innovation.

But regardless of the institution studied or definition used,[6] there are multiple justifications for this focus on domestic institutions. Some scholars highlight the non-rival and non-excludable aspects of inventive activity, thus casting innovation as a public goods problem. Other scholars emphasize the high levels of uncertainty, risk, high transactions costs, and incomplete information associated with innovation. Still other researchers call attention to the distributive aspects of technological change, and the ability of interest groups hurt by it to influence government policy and obstruct innovation. In theory, domestic institutions help solve all of these problems. Institutions solve the free-rider problem by providing selective incentives. Institutions also lower information and transaction costs; they lower and spread risk and uncertainty. And properly designed domestic institutions can also prevent the Stiglerian capture of

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[1] *Technology* is defined here as a physical product, or a process of handling physical materials; which is used as an aid in problem solving. More precisely, technology is a product or process which allows social agents to perform entirely new activities or to perform established activities with increased efficiency. *Innovation* is defined as the discovery, introduction, and/or development of new technology, or the adaptation of established technology to a new use or to a new physical or social environment.

[2] Scholars of security studies will also appreciate the importance of civilian technological innovation and its role in production and the general economy as complementary, if not foundational, to relative military power. See Samuels 1994.

[3] Tyson 1992; Mokyr 1990; Krugman 1986; and Solow 1957.

[4] Saxenian 1994; Krugman 1991, 1986; Helpman 1984.

[5] Strange 1986.

[6] Though in this dissertation, I limit my treatment to those theories which adhere closest to Douglass North's description of institutions as "the rules of the game in a society", sets of established practices, rules, or laws that regulate the relations between individuals, groups, and organizations. North (1990), pp. 3-10.

government policy by ensuring political competition, or checks and balances, between domestic interest groups. Thus domestic institutions have come to play a determining causal role in theories of national innovation rates. Of course, theory is not the only motivation for focusing on institutions. Since institutions are the proximate tools which governments use to promote innovation, and since institutions differ across the industrialized democracies as do innovation rates, a causal linkage between domestic institutions and technological change also makes sense to many policymakers and more empirically-minded scholars.

However, after decades of research, the evidence for a causal relationship between domestic institutions and national innovation rates remains equivocal. There are simply many countries with "good" institutions that do not innovate at the technological frontier, and many countries with "bad" institutions that have nonetheless built impressive records of technological progress. For example, we can observe that some countries with relatively high levels of corruption, poorly functioning markets, low levels of democracy, etc. have nonetheless come to innovate at the technological frontier over the past century (e.g. Taiwan, Singapore, South Korea, Japan). While other countries with good or improving institutional structures have seen little corresponding benefits in their national technological performance (e.g. Spain, New Zealand, Australia, Norway, Austria). As a result of this mixed evidence, a second problem within the institutional approach is that no one seems to agree on which institutions determine innovation rates. As will be seen in this dissertation, different scholars favor different combinations of institutions and different levels of analysis. A final problem with domestic institutions arguments is that they tend to be either purely theoretical, atheoretical, or are based on just a case study or two. Thus we have a situation in which there is a large consensus amongst political-economists that domestic institutions determine innovation rates, but no consensus on precisely how this happens, and little supporting evidence in the aggregate.

This dissertation will attempt to resolve some of these conflicts and inconsistencies, and contribute some additional empirical rigor to the debate over national innovation rates. In it, several major institutional hypotheses will be examined and tested using regression analysis of different quantitative data on technological innovation and various domestic institutions. In each case, I attempt to triangulate the quantitative data by using multiple, distinct, and independent measures of both domestic institutions and technological innovation, often while controlling for factors such as population, size of the economy, level of development, etc. Contrary to the accepted wisdom, I find little evidence of domestic institutions aiding innovation in the aggregate, regardless of the type of institution tested or the measure of innovation used. That is, I argue that although institution or policy "X" might appear to explain a certain country's innovation rate at a specific point in time, it does not do so over time nor in other countries. However, the empirical evidence does suggest that a country's international relationships may be the missing piece to the national innovation rate puzzle. More specifically, the evidence presented in this dissertation suggests that certain kinds of international relationships (e.g. capital goods imports, foreign direct investment, educational exchanges) do affect national innovation rates in the aggregate. And countries which have these kinds of relationships with the lead innovating nations tend to become more innovative than states which do not, almost regardless of their domestic institutions. In other words, explaining national innovation rates may not be so much a domestic institutions story as it is an international story.

This research is new in several respects. First, it tests the causal effects of previously untested independent variables. Second, it takes advantage of both new data and previously unused data on innovation and institutions. Third, it uses new techniques for measuring innovation not employed in prior research on national innovation rates. Finally, the research presented here is more generalizeable than prior research. That is, I test hypotheses using cross-national quantitative datasets covering several decades, where previously these hypotheses had been established only on the basis of anecdotal evidence, temporally limited deviant cases, or (often stylized) small-N qualitative case studies.

In the remainder of this introductory chapter, I lay the foundations for the research presented in this dissertation. First, I present a brief overview of the historical debate over the causal explanations of national innovation rates. I then discuss the strengths and weaknesses of one research program in particular: the "National Innovation Systems" (NIS) approach to explaining technological innovation. The failure of the NIS research program, despite almost two decades of scholarship, to produce a causal theory linking domestic institutions with national innovation rates will then act as the starting point for the research presented in the following chapters.

1.2 A Brief History of the Debate

Various explanations for national differences in innovation rates have been proposed over the years. Often generated by individual case studies from across the social sciences, these hypotheses have covered a wide range of independent variables including: the importance of military spending and weapons systems development,[7] factor scarcity,[8] first-mover advantages,[9] population or economic size, late-industrialization,[10] culture,[11] and historical contingencies.[12] However, explanations based on domestic institutions have come to dominate the innovation debate. This is not necessarily due to a superiority of domestic institutions theories over other schools of thought. Rather it appears that the focus on institutions is largely a product of the broad interest, and major advances, in 1) empirical research on the economics of science, and 2) formal economic growth theory. Since this dissertation will examine domestic institutions hypotheses in particular, I limit the following literature review to the major antecedents of the domestic institutions side of the innovation debate, which is located within the fields of political economy and economics. Those readers interested in a more comprehensive history are referred to other sources.[13]

Economic historians can point to no single clear origin of domestic institutions explanations for technological innovation. Certainly the practice of using micro-institutions to foster innovation is at least hundreds, if not thousands, of years old. Awards of special privileges, prizes, or monopolies for inventors have been granted since antiquity, while national patents in their modern form appear to have originated in Florence during the early 15th century.[14] Elements of a national level domestic institutions theory of technological change can be recognized as early as the 1791 *Report on Manufactures* by Alexander Hamilton and Tench Coxe, and certainly in the writings of German political-economist Friedrich List.[15] Granted, these men did not seek to explain technological innovation per se. Instead they argued for the creation of what today might be called "industrial policy": a combination of trade, finance, budgetary, procurement, and regulatory policies (and the formal government institutions necessary to support them) which would foster growth and improvement in their nations' domestic industrial base. Throughout the following two centuries, these ideas were taken up with great enthusiasm by policymakers in developing Germany, Japan, and other states in Europe, Asia, and even Latin America.

However, for much of the history of political economy, research on the causes of national differences in technological innovation rates has remained at the periphery of the field. One reason for this is that, at least during much of the 19th & 20th centuries, questions about innovation rates were often subsumed by the great debate amongst the political followers (and scholarly descendents) of Adam Smith and Karl Marx. Another reason was the apparently random, or at least inexplicable, nature of innovation itself. Even those social scientists who attempted to deal systematically with technological change (including Marx, Schumpeter, and Solow) generally regarded it, and the underlying body of scientific knowledge upon which it drew, as a "black box" proceeding according to its own internal processes largely independent of political or economic forces.[16] For example, Smith rarely discussed technological

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[7] Smith 1985.

[8] Hicks; 1932; Habakkuk 1962; Leontief 1954.

[9] Porter 1990.

[10] Gerschenkron 1962.

[11] Dore 1987.

[12] Burke 1978.

[13] Mokyr 1990, 2002; Rosenberg 1982, 1994; Freeman & Louçã 2001; Bijker, Hughes, & Pinch 1987.

[14] For a brief historical survey see Nard & Morriss 2004; Sobel 1996.

[15] Hamilton 1791; List 1841.

[16] For an alternative view of Marx, see Bimber 1994.

change in particular, and his major works imply that he believed that government had little direct role in fostering it. Rather, he described technological innovation as either a natural outcome of the market and division of labor, or as a product of "philosophyers or men of speculation...[who] are often capable of combining together the powers of the most distant and dissimilar objects."[17] And although technological change was central to Marx's theory of political economy, he was more concerned about its catastrophic effects, and went into little detail about its causes.

This began to change during the Cold War, when interest in the sources of technological innovation increased amongst economists. One major line of inquiry involved scholars who focused on the economics of scientific research. It grew out of the scholarship of Kenneth Arrow, Richard Nelson, Zvi Griliches and other like-minded economists.[18] These men lived in the immediate wake of several unusual technological events, including Japan's first industrialization miracle, World War II's swath of highly successful government R&D programs (both Allied and Axis), and the Soviet launch of Sputnik. Hence their historical experience informed them that science drives much innovation,[19] and that government can play a useful role in the innovation process. And living in a society dominated by capitalist ideology, the question which confronted them was whether perfect market competition was necessarily the best mechanism by which to produce scientific research and technological innovation. Arrow (1962) formalized the answer. He described inventive activity as the high-risk, high-cost production of scientific & technical knowledge. However, scientific & technical knowledge was characterized as being intrinsically non-rival and non-excludable; therefore, once produced, it could then be copied and transmitted at low cost and low risk. Thus Arrow concluded that free enterprise economies will under-invest in invention and research. Yet socialist and communist societies arguably lacked the scientific freedoms, competitive forces, or freedom to fail, that seemed necessary for technology's gale of creative destruction to take effect. Arrow's compromise was to recommend stronger domestic institutions for ensuring proper compensation to innovators.[20]

A second major line of inquiry into the causes of technological innovation came out of the economic growth debate sparked by Robert Solow and Moses Abramovitz during the mid-1950s.[21] They found that technological change could account for much of the differences in national productivity and economic growth rates across time and space during the preceding decades.[22] However, explaining technological change itself was problematic. In the end, Solow modeled technological change as exogenous, descending like "manna from heaven" in more or less random fashion. Almost two decades later, Douglass North & Robert Thomas used historical analysis to suggest instead that technological change is endogenous to domestic institutions.[23] The institutions they focused on were property rights and efficient markets for trading them, and for motivating the investments and risk-taking necessary for innovation.[24] North later noted that the specification and enforcement of property rights and markets are political issues, hence political institutions need also be efficient.[25] He asserted that, though far from perfect, democratic institutions are those most favorable to political efficiency. At the same time, Paul Romer succeeded in formally endogenizing technological change within mathematical models of economic growth theory.[26] Adopting Arrow's characterization of innovation, Romer again drew attention to the non-rival nature of knowledge, and hence the tendency for pure markets to under-provide it. Since the production of new knowledge depended on the human capital which produces it, Romer argued that

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[17] Smith 1776, p. 114.
[18] Griliches 1957, 1958; Nelson 1959; Arrow 1962.
[19] Though Nelson explicitly stated that the causal arrow can also run in the opposite direction. See Nelson 1959; also Rosenberg 1982.
[20] Arrow 1962.
[21] Solow 1957; Abramovitz 1956.
[22] Solow 1957; Abramovitz 1956.
[23] Douglass & Thomas 1973.
[24] Douglass & Thomas 1973.
[25] North 1981, 1990.
[26] Romer 1986, 1990.

economic growth and technological innovation should be a function of the number of trained scientists, engineers, and inventors. Subsequent growth theorists (e.g. Robert Hall, Charles Jones, Philippe Aghion, Peter Howitt), then argued that domestic institutions determine a country's investment in its human capital, and thereby determine innovation rates.[27]

Meanwhile, interesting empirical puzzles developed in the world economy that challenged the predictions of both these institutional lines of research. These puzzles were posed by radical and unexpected changes in national innovation rates during the during 1970s and 1980s. They included the apparent decline of established technological leaders such as the US and Great Britain, the rapid rise to technological power of Japan, and the sudden appearance of Taiwan, South Korea and other newly industrialized countries at or near the technological frontier. None of these phenomena were easily explained by existing theories of innovation in politics or economics. Moreover, many of the most technological successful countries seemed to suffer from relatively "bad" institutions, while countries on the technological decline were typified by relatively "good" institutions. Much research was published to explain these puzzles, though it was often based on anecdotal evidence or individual case studies, resulting in a confusing array of often conflicting theories and policy prescriptions. In response, political economists in the United States and Europe initiated a new "national innovation systems" research program which took a more holistic and empirical approach to study the effects of domestic institutions on innovation rates.

1.3 National Innovation Systems

National Innovation Systems (NIS) will serve as the point of entry for this dissertation into the innovation debate. Since its inception in the mid-1980s, NIS has become one of the dominant paradigms within the subfield of innovation research. It was also the first systematic, empirical, cross-national examination of the relationship between domestic institutions and innovation. NIS scholars advanced their research program in order to address what they described as the feebleness of existing innovation theory, and the "hyped and haphazard" innovation research and policy of the time.

The NIS approach to explaining national innovation rates starts with the recognition that innovation, be it performed by firms or individuals, occurs within the context of broader political and economic institutions and policies. NIS further posits that these institutions and policies together form a "system" which determines a country's rate and direction of technological "innovation". And since these institutions and policies differ from nation to nation, and in fact define nations to some extent, they therefore constitute "national innovation systems". The first explicit use of the term "national innovation system" in modern political-economy appears in Christopher Freeman's book *Technology and Economic Performance: Lessons from Japan* (1987)[28]. However, NIS scholars also recognized that their national systems view of technological change was not entirely new, but was reminiscent of Hamilton and List.[29]

What was new in the NIS research program was the empirical depth and thoroughness with which its proponents approached the subject. Generally using a case study approach, NIS scholars focused their research on identifying and probing the roles of dozens of specific national institutions and policies which affect innovation. Pioneered by economists Christopher Freeman, Bengt-Ake Lundvall, Richard Nelson, and Charles Edquist, [30] NIS scholars examined the interactions and effects on innovation of different educational institutions, science policies, trade regimes, legal frameworks, financial institutions, anti-trust laws, etc. They also took care to observe these domestic institutions across a wide spectrum of nations, many of which had been little studied in previous research on innovation. For instance, in Nelson's seminal publication, NIS scholars analyzed large, wealthy, frontier innovators (Japan, US, Germany),

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[27] Hall & Jones 1999; Aghion & Howitt 1998.

[28] Though Freeman later credited scholar Bengt-Ake Lundvall with coining the term "national innovation system". See Freeman 1995.

[29] Lundvall 1992; Freeman 1995.

[30] Nelson 1993; Lundvall; 1992; Edquist 1997.

small wealthy but innovative states (Denmark, Canada, Sweden), and lesser developed countries both innovative (Israel, Taiwan) and not (Argentina, Brazil). Since then, other researchers have gone on to apply the NIS methodology to a variety of disparate states from Finland to China, Slovakia to Algeria, Hungary to Argentina.[31]

The NIS research program made a major contribution to the debate by bringing to light the complexity of the innovation process and the diversity of factors involved in it; however a problem with generalizability soon emerged. Taken as a whole, the separate NIS case studies suggest some 20-30 major independent variables (policies and institutions), each of which may play a role in technological innovation depending on its configuration vis-à-vis the other variables. For example, in the case of the U.S., NIS scholars contend that the key drivers of technological progress since World War II include military procurement, timely and strong anti-trust actions, small firms, and universities.[32] Yet none of these variables figure significantly in Japan’s national innovation system. Rather, Japan’s innovative strength during the post-war period emanates from tight government control over trade and investment, cooperative industry-labor relations, and specific corporate management techniques, each of which are missing from the U.S. case.[33] Studies of the UK, Germany, France, Korea, and Taiwan similarly expand the list of variables.[34] Furthermore, since the successful operation of each NIS variable often depends upon its context, we find ourselves with a rapid proliferation of viable national innovation systems. For example, while the relatively strong American anti-trust regime helps innovation, it does so in the context of free trade and capital mobility; conversely, Japan’s relatively weak anti-trust enforcement seems to aid innovation when configured with its system of industrial policy and captive finance. Hence, in addition to a large number of variables, the NIS approach produces an exponentially greater number of possible combinations of these variables, each of which may promote or hinder innovation. This lack of parsimony poses a problem for both theorizing and testing, especially in cases where the *same* independent variable is attributed with *different* effects on innovation rates in different countries.

While some have critiqued NIS for its lack of strong theoretical foundations, it is important to note that its atheoretical approach was a strategic choice by some of its founders, not a product of bad research design.[35] For example, the 1993 case studies coordinated by NIS pioneer Richard Nelson were written in direct response to perceived weaknesses in existing theory. While endogenous growth theory had made enormous contributions to economists’ understanding of innovation, Nelson critiqued it for neglecting or mis-specifying many important independent variables and causal relationships. He recommended that empirical research, in the form of in-depth qualitative case studies, was necessary to capture the causal factors missed by grand theory.[36] However, much of the existing empirical research of the sort suggested by Nelson was based on just a single country (often Japan). Hence, NIS scholars explicitly sought to increase “the number of ‘points’ that a causal theory had to ‘fit’”.[37]

Yet, regardless of their motivations, after almost fifteen years of research NIS scholars have yet to produce any general hypotheses to explain differences in national innovation rates. That is, while they have achieved their empirical goal of increasing the set of datapoints and potential relationships between them, NIS scholars have yet to fit a theory to them. This failure of NIS to produce any general theory of how domestic institutions determine national innovation rates marks the starting point for the research presented in this dissertation.

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[31] Oinas 2005; Sun 2002; Balaz 2005; Saad & Zawdie 2005; De Tournemine & Muller 1996; Correa 1998.

[32] Mowrey & Rosenberg 1993.

[33] Odagiri & Goto 1993.

[34] Nelson 1993; see also Kim & Nelson 2000.

[35] It is important to note that not all NIS scholars have avoided theorizing. Certainly those contributors to Lundvall 1992 sought to base their investigations on more substantial theoretical foundations.

[36] Nelson 1997.

[37] Nelson 1993.

1.4 Overview of the Dissertation

In chapter 2, I examine the “Varieties of Capitalism” (VOC) theory of innovation as put forward by Peter Hall and David Soskice (2001). VOC theory recognizes that the NIS approach is neither generalizable nor parsimonious. As an improvement, VOC scholars make their focus of research the structural differences amongst political-economies and the interactions between the nation-state and the firm. While the NIS approach focuses more on mid-level institutions and policies, VOC theory holds that variance in macro- political institutions is the primary cause of differences in national innovative behavior. In brief, VOC theory predicts that the more a polity allows the market to structure its economic relationships, the more it will direct its inventive activity towards industries typified by “radical” technological change. Conversely, the more a polity chooses to coordinate economic relationships via non-market mechanisms, the more it will direct its inventive activity towards “incremental” technological change. Implicit in these predictions is an assumption that industries differ by the type of technological innovation conducted within them: that some industries are more technologically revolutionary and others more incremental. As VOC theory has yet to be proven, in this chapter I make use of new data on patents, scholarly publications, and technological diffusion to test VOC theory’s assumptions and predictions and to see whether VOC theory properly describes the empirical world of technological innovation. It will be shown that while some industries are indeed more radically innovative than others in the short-run, this cannot be confirmed in the long-run as industries age and mature technologically. I also find that VOC theory does not accurately predict innovative behavior over time and space, and that VOC’s existing empirical support strongly depends upon the inclusion of a major outlier, the United States, in the set of radically innovative countries.

In chapter 3, I ask whether decentralized states are better at technological innovation than centralized states. This political decentralization thesis suggests that NIS institutions and VOC economic coordination are both endogenous to government structure. That is, they fail to help innovation because politically powerful interest groups use government to interfere with them. Politically powerful interest groups will interfere with markets, they will interfere with science policies, financial institutions, education, whatever they can to protect their interests. And what states need to minimize this interference are the competitive forces and overlapping jurisdictions of decentralized government. Furthermore, we can cite numerous economic and political theories, from Hayek to Weingast, which imply additional economic advantages of decentralized government for innovators. Overall, decentralized state structures are seen as conducive to competitive and agile policymaking, and hence a political-economy that is well structured to adapt to innovation’s gale of creative destruction. Meanwhile, centralized governments are viewed as rigid and thus hostile to the risks, costs, and change associated with new technology. As a result, decentralized states have come to be perceived as better at fostering technological innovation than centralized states. Yet this accepted wisdom has never been thoroughly tested. I therefore analyze data on international patent activity, scientific publications, and high-technology exports, and show that there exists little evidence for an aggregate relationship between government structure and technological innovation.

In chapter 4, I contend that international relationships may be the missing piece to the national innovation rate puzzle. I note that anecdotal observations, both from my own research and within the evidence provided by domestic institutionalists, suggests that certain kinds of international relationships might have a role in determining national innovation rates. In order to test this possibility, I perform regression analysis on various measures of innovation, domestic institutions, and international relationships. These regressions suggest that certain kinds of international relationships (e.g. capital goods imports, foreign direct investment, educational exchanges) with the lead innovator (the United States) strongly affect countries’ innovation rates, even when controlling for domestic institutions. In other words, explaining national innovation rates is not so much a domestic institutions story as it is an international story.

In chapter 5, conclusions are drawn, new avenues of research are suggested, potential problems are diagnosed, and the contributions of this dissertation are discussed. It is argued that the findings reported in this dissertation suggest a change in the debate over national innovation rates. If the research presented here is correct, then it suggests that scholars should move away from pure domestic institutions theories of innovation, and towards explanations based at least in part on international relationships. This is not to argue that domestic institutions do not matter at all for innovation, but rather that existing institutional theories of innovation have been over-stated and over-simplified.

Chapter 2

Varieties of Capitalism and Technological Innovation[38]

2.1 Introduction

"Varieties of Capitalism" (VOC) scholars, in part, seek to fill the gap between endogenous growth theory and the NIS research program. They agree with both schools of thought that domestic institutions best explain national innovation rates. However, they critique the NIS approach for its lack of theory and parsimony. And they fault endogenous growth theory for its failure to adequately consider non-market relationships between economic actors. VOC theory is an attempt to address both sets of weaknesses. In brief, the central claim of VOC's innovation theory is that the more a polity allows the market to structure its economic relationships, the more it will direct its inventive activity towards industries typified by "radical" technological change. Conversely, the more a polity chooses to coordinate economic relationships via non-market mechanisms, the more it will direct its inventive activity towards "incremental" technological change.

In particular, VOC scholars see innovation theory as a key to resolving current problems in understanding global trade flows and production patterns. Classic trade theory holds that free trade will not deplete national wealth by impelling production abroad, but will instead enhance economic performance and expand each trader's production possibilities frontier. In this basic model, societies specialize production in their most efficient sectors and then trade the surplus for more goods than they otherwise could have produced locally. The Stolper-Samuelson model improves upon this basic theory by arguing that nations' relative endowments of basic economic factors (land, labor, capital) should determine the general lines along which international production and trade are structured. However, the rise of intra-industry trade during the last thirty years has contradicted the inter-industry trading patterns predicted by the Stolper-Samuelson model. Instead of thoroughly specializing in particular sectors of production, the industrialized nations have maintained a broad spectrum of general economic activity, and instead geographically concentrated their sectoral productive efforts. Recent attempts to explain these phenomena posit an initially random distribution of productive activity which is then followed by agglomeration due to either increasing returns to scale or network externalities.[39] VOC scholars generally accept these agglomeration arguments, but they notice certain non-random patterns of international production and trade which are neither explained nor predicted by current agglomeration theories.[40]

VOC's innovation theory offers a resolution to the anomalies above, suggesting that domestic institutional structures can account for the different degrees of innovative effort and achievement between nations, and the production and trade relationships that subsequently develop. If VOC theory is correct, it would explain why nations maintain their innovative profiles in spite of strong pressures to change them, and why certain kinds of innovation-dependent production might tend to be concentrated in particular countries. However, the central claim made by VOC's innovation theory has yet to be proven. The purpose of this chapter is to use new data on patents and scholarly publications to test VOC theory's central assumptions and predictions and to see whether VOC theory properly describes the empirical world of technological innovation. It will be shown that VOC theory does not accurately predict innovative behavior over time and space, and that VOC's existing empirical support strongly depends upon the inclusion of a major outlier, the United States, in the set of radically innovative countries. I also

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[38] This chapter published as Taylor 2004.

[39] Saxenian 1994; Krugman 1991; Helpman 1984.

[40] Hall and Soskice 2001, pp. 36-37.

find that some industries are more radically innovative than others in the short-run, as assumed by VOC theory, but that this cannot be confirmed in the long-run as industries age and mature technologically.

2.2 Varieties of Capitalism's Theory of Technological Innovation

VOC theory does not limit itself to technology, but is broad and foundational; it touches upon multiple aspects of political and economic life, of which innovation is but one part. At its most basic level, it is a theory of capitalism by gradation: some countries use markets more than others to coordinate economic actors and this variation is used to explain a myriad of comparative and international political-economic behavior. However, when fully articulated, we find that VOC theory does not divide the world into "free-trade vs. protectionist" or "state-owned vs. privatized" systems of political economy as is traditionally done. To do this would be to focus attention on the state, which VOC scholars wish to avoid. Rather, they view the firm as the locus of trade and production in the capitalist economy, and therefore take the firm, not the state, as their primary unit of analysis. Nor is the firm a lone or independent actor in VOC's analysis; successful operation of the firm depends heavily upon its relationships with labor, investors, and other firms. It is these crucial relationships that, in turn, explain patterns of economic activity and policymaking. Therefore the central claims of VOC theory focus on how a given political-economy's institutional structure determines the conduct of these crucial relationships and how economic actors organize to solve the classic coordination problems which afflict such relations.[41] At one end of this relationship spectrum lie the "Liberal Market Economies" (LME's), such as the United States, in which firms tend to coordinate their relations and activities in the manner described by Oliver Williamson: through internal corporate hierarchies and external competitive market arrangements.[42] At the other end of the spectrum sit the "Coordinated Market Economies" (CME's), such as Germany, where firms tend to coordinate via non-market relationships, with greater dependency on relational and incomplete contracting, exchanges of private information within enduring networks, and a high degree of actor collaboration (as opposed to competition or confrontation). As we shall see in the next section, these distinctions have important implications for explaining and predicting national differences in innovation.

According to VOC theory, technological innovation comes in two types, radical and incremental, each of which forms the basis for a different mode of production. While an exact definition is elusive, VOC scholars describe radical innovation as that which "...entails substantial shifts in product lines, the development of entirely new goods, or major changes to the production processes."[43] They argue that radical innovation is therefore vital to production in high-technology sectors which require rapid and significant product changes (biotechnology, semiconductors, software) or in the manufacture of complex systems-based products (telecommunications, defense, airlines). Incremental innovation, on the other hand, is that which is "marked by continuous but small-scale improvements to existing product lines and production processes."[44] Unlike production based on radical innovation where speed and flexibility are crucial, production based on incremental innovation prioritizes the maintenance of high quality in established goods. This involves constant improvements in manufacturing processes to bring down costs and prices, but only occasional minor improvements in the product line. Incremental innovation is therefore essential for competitiveness in capital goods production (machine tools, factory equipment, consumer durables, engines).

VOC theory further predicts that LME's and CME's will tend to exert greater effort towards, and be successful in, different types of technological innovation. VOC theory interprets innovation as just another productive activity, therefore innovation should be sensitive to the firm's crucial relationships described above and the institutions which structure them. This does not mean that a given political-economic structure will result in only one kind of innovation, but that different institutions will create different types of comparative advantage for innovators. For example, incremental innovation requires a

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[41] I am concerned here with those aspects of VOC theory discussed in Hall and Soskice 2001, pp. 1-44.

[42] Williamson 1975, 1985.

[43] Hall & Soskice 2001, pp. 38-39.

[44] Hall & Soskice 2001, p. 39.

workforce that is skilled enough to come up with it, secure enough to risk suggesting it, and have enough autonomy to see innovation as a part of their job. This in turn requires that firms provide workers with secure environments, autonomy in the workplace, opportunities to influence firm decisions, education and training beyond just task-specific skills (preferably industry-specific technical skills), and close inter-firm collaboration which encourages clients and suppliers to suggest innovations as well. These are exactly the kinds of apparatus provided by CME institutions. In fact, CME's are *defined* by the very institutions which provide a comparative advantage for incremental innovation. These institutions include highly coordinated industrial-relations systems; corporate structures characterized by works councils and consensus-style decision-making; a dense network of inter-corporate linkages (such as interlocking corporate directorates and cross-shareholding); systems of corporate governance that insulate against hostile takeovers and reduce sensitivity to current profits; and appropriate laws for relationship-based, incomplete contracting between firms. VOC scholars argue that this combination of institutions results in long employment tenures, corporate strategies based on product differentiation rather than intense product competition, and formal training systems for employees which focus on high-skills and a mix of company-specific and industry-specific skills; in other words, the very factors which combine to foster incremental innovation.

On the other hand, VOC scholars argue that these same CME institutions which provide comparative advantages for incremental innovation also serve as obstacles to radical innovation. For instance, worker representation in the corporate leadership combines with consensus-style decision-making to make radical change and reorganization difficult. Also, long employment tenures make acquisition of new skills and re-balancing one's labor mix difficult. And dense inter-corporate networks make the diffusion of disruptive innovations slow and arduous, and technological acquisition by M&A or takeovers hard. All of these act against, or reduce the potential rewards of, radical innovation.

In LME's, the situation is reversed. LME's are defined by institutions which provide a comparative advantage for radical innovation, while creating obstacles to incremental innovation. LME's have flexible labor markets with few restrictions on layoffs, which means that companies can drastically change their product lines and still acquire the proper labor mix. LME's also support extensive equity markets with dispersed shareholders providing innovators of all sizes with relatively unfettered access to capital. Also, inter-firm relations in LME's allow for a variety of aggressive asset exchanges with few restrictions on mergers and acquisition, buyouts, personnel poaching, licensing, etc., which permits firms to easily acquire scientific expertise and new technology. Concentration of power at the top of LME-based firms augments these institutions, allowing management to quickly force major change on complex organizations. All of these factors combine to create large incentives for, and an environment accommodative to, radical innovation. Conversely, LME's capacity for incremental innovation is limited due to financial arrangements which emphasize current profitability, corporate structures that concentrate unilateral control at the top and eliminate workforce security, and anti-trust and contract laws which discourage inter-firm collaboration in incremental innovation. Meanwhile, fluid labor markets and short job tenures motivate workers to pursue selfish career goals and to acquire mobile general skills rather than firm-specific or industry-specific skills. Hence, in VOC's analysis, neither workers nor firms in LME's tend to have the incentives or the resources for sustained incremental innovation.

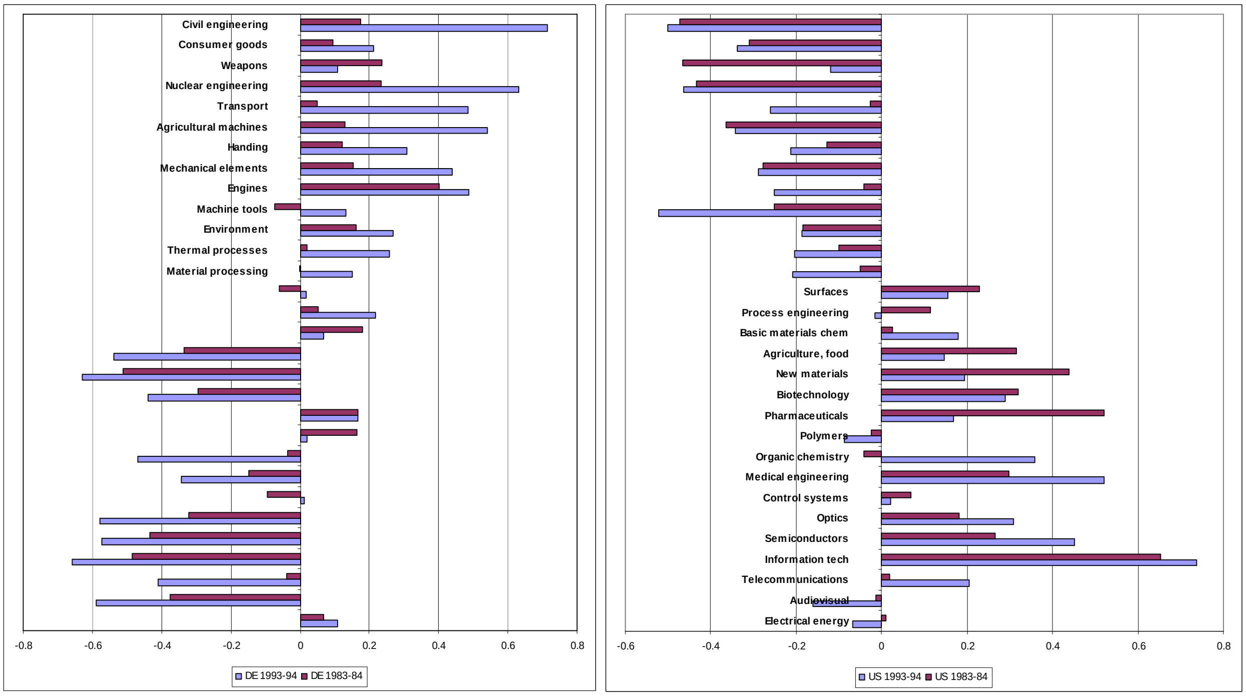
2.4 Testing the Varieties of Capitalism Claims

The purpose of the remainder of this chapter is not to evaluate the accuracy of the LME-CME classification system or test a specific causal mechanism involved in VOC's theory of innovation. Rather, the question asked here is whether the international patterns of innovation which VOC theory predicts actually exist. The VOC causal story outlined above is both theoretically appealing and dovetails with some widely held stereotypes about national differences in innovation; however, little empirical data has yet been produced to support its central claim. The evidence offered by Hall & Soskice consists of four years of patent data from the European Patent Office (EPO) which shows that Germany and the US concentrate their patents according to the LME vs. CME model discussed above. Specifically, Hall & Soskice examine patenting activity by Germany and the US in 30 technology classes during 1983-84 and

1993-94 (Figure 2.1). Overall, they found that Germany's patent specialization was almost equal and opposite that of the US in both time periods.[45] More specifically, the Germans were found to be more active innovators in industries which Hall & Soskice characterize as dominated by incremental innovation (such as mechanical engineering, product handling, transport, consumer durables, and machine tools); meanwhile, firms in the US innovated disproportionately in industries which the authors perceive as more radically innovative (including medical engineering, biotechnology, semiconductors, and telecommunications).

We can identify several possible problems with this approach. First, VOC theory implicitly assumes that some industries are inherently characterized by radical innovation, others by incremental innovation, and that these industries have been correctly identified. Second, in supporting their claims, Hall & Soskice use only 4 years worth of patent data from only 2 countries, one of which, the United States, is an outlier by almost any measure. Third, Hall & Soskice use only simple patent counts as their measure of innovation, hence frivolous patents are counted the same as highly innovative ones; nor do they use any non-patent measures of innovation.

Figure 2.1: Patent Specialization by Technology Class



Note: Higher scores indicate greater specialization in innovation in that particular type of technology. *Source*: Charts reproduced here with data obtained through the cooperation of Thomas Cusack, David Soskice, and Peter Hall. See also Hall & Soskice 2001, pp 42-43.

In the following sections, I will address these issues in turn. In some instances, I will use Hall & Soskice's own data and methods to test the generality of their claims. In others, I will take advantage of a new dataset compiled at the National Bureau of Economic Research (NBER) of over 2.9 million utility patents granted by the US Patent & Trademark Office (USPTO) to applicants from the United States and 162 other countries during 1963-1999, and the 16 million citations made to these patents between 1975 and 1999.[46] This new dataset will allow us to go beyond Hall & Soskice's empirical investigation and to consider some thirty-six years of patenting activity for *all* of the LME and CME countries and to weight a

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[45] Hall & Soskice's methodology will be discussed in greater detail below.

[46] Hall, Jaffe, & Trajtenberg, 2001; database available at www.nber.org/patents.

majority of these patents by forward citations in an attempt to control for the quality of the innovations being patented. Later, data from the Institute for Scientific Information (ISI) on scholarly and professional journal publications, also weighted by forward citations, will be considered as an additional measure of innovation.

2.4.1 Independent Variable: LME vs. CME

According to VOC theory, the primary independent variable for predicting innovation characteristics is the type of national political-economic institutional structure (LME or CME) within which innovators operate. The LME's include Australia, Canada, Great Britain, Ireland, New Zealand, and the United States. The CME's include Austria, Belgium, Denmark, Finland, Germany, Japan, Netherlands, Norway, Sweden, and Switzerland. In between these two ideal types, and of less importance to VOC scholars, sit a handful of hybrids denoted as "Mediterranean Market Economies" (MME's) which have mixed CME and LME characteristics. These countries include France, Greece, Italy, Portugal, Spain, and Turkey.[47] For the remainder of this dissertation, references to the set of "LME", "CME", or "MME" countries should be understood to mean only those states listed above, as these are the only ones explicitly mentioned in the VOC claims tested here. Later, in the multivariate regressions, "LMEx" will be used to refer to the set of all LME countries except the US.

Some critics might question the "LME-ness" or "CME-ness" of certain states classified above, for example the Oceanic countries during much of the Cold War. However, I employ the existing VOC classifications for several reasons. First, in VOC theory, it is not the amount of protectionism or regulatory burden that defines an LME or CME and determines its innovative profile, but whether markets or hierarchies form the context within which economic actors organize, conduct their relationships, and solve coordination problems. Therefore when accepting the VOC country classifications, I privilege the relational aspects of the LME-CME distinction as discussed by Hall & Soskice, rather than protectionist or state-interventionist behavior, since the former are the most relevant and active mechanisms in VOC's theory of innovation. Second, recall that the LME-CME dichotomy is not definitive but rather "constitute[s] ideal types at the poles of a spectrum".[48] All states have some degree of tariff and non-tariff barriers to trade, and no nation is free from regulation. Therefore there are shades of LME and CME in every economy, and these change over time, hence when accepting particular classifications, I pay attention not to absolute qualities but to relative ones. Finally, all classification systems have debatable aspects, and their acceptance is often based more on their usefulness rather than their exactitude. Part of the goal of this chapter is to test VOC theory as stated, which includes the usefulness of their typology.

2.4.2 Dependent Variable: Innovation

The most frequently used measure of innovation is patents. The debate over the proper use of patent data has proceeded vigorously and with increasing sophistication over the past several decades. The current consensus holds that patent data are acceptable measures of innovation when used in the aggregate (e.g. as a rough measure of national levels of innovation across long periods of time), but are not appropriate when used as a measure of micro-level innovation (to compare the innovativeness of individual firms or specific industries from year to year). And while this debate is ongoing and is better recounted elsewhere, this section will address some of the more pressing issues surrounding patent measures and their use in testing VOC theory.[49]

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[47] Countries such as Luxemborg and Iceland are eliminated from the VOC typology due to their small size, while others, such as Mexico, are disqualified because they are developing nations.

[48] Hall & Soskice 2001, p. 8.

[49] For a review of the debate see Griliches 1990; Trajtenberg 1990; Archibugi & Pianta 1996; Harhoff, Narin, Scherer, & Vopel 1999; Eaton & Kortum 1999; Jaffe, Trajtenberg, & Fogarty 2000; Hall, Jaffe & Trajtenberg 2000, 2001.

Strictly speaking, a patent is a temporary legal monopoly granted by the government to an inventor for the commercial use of her invention, where the invention can take the form of a process, machine, article of manufacture, or compositions of matters, or any new useful improvement thereof. (USPTO)[50] A patent is a specific property right which is granted only after formal examination of the invention has revealed it to be nontrivial (i.e. it would not appear obvious to a skilled user of the relevant technology), useful (i.e. it has potential commercial value), and novel (i.e. it is significantly different than existing technology). As such, patents have characteristics which make them a potentially useful tool for the quantification of inventive activity. First, patents are by definition related to innovation, each representing a "quantum of invention" that has passed the scrutiny of a trained specialist and gained the support of investors and researchers who must dedicate time, effort, and often significant resources for its physical development and subsequent legal protection. Second, patent data are widely available, and are perhaps the only observable result of inventive activity which covers almost every field of invention in most developed countries over long periods of time. Third, the granting of patents is based on relatively objective and slowly changing standards. Finally, the United States Patent and Trademark Office and the European Patent Office provide researchers with centralized patenting institutions for the two largest markets for new technology. In practical terms, this allows researchers to get around the issue of national differences in patenting laws as well as providing two separate and fairly independent data pools.

Given these qualities, patents have been used as a basis for the economic analysis of innovative activity for over thirty-five years. Current use began with the pioneering work of Frederic Scherer and Jacob Schmookler who used patent statistics to investigate the demand-side determinants of innovation.[51] However, the labor intensive nature of patent analysis, which used to involve the manual location and coding of thousands of patent documents, severely limited the extent (or at least the appeal) of their use in political and economic research. These limitations were eased somewhat during the 1970s when the advent of machine-readable patent data sparked a wave of econometric analysis.[52] In the late 1980s, the use of patent data was further facilitated by computerization, which increased the practical size of patent datasets into millions of observations. Most recently, Hall, Jaffe, & Trajtenberg at the NBER have compiled a statistical database of several million patents complete with geographic, industry, and citation information, which I will use later to test the VOC claims.[53]

However, patents do have significant drawbacks which somewhat restrict, but by no means eliminate, their usage as an index of innovation. First, there is the classification problem, in that it is difficult to assign a particular industry to a patent, especially since the industry of invention may not be the industry of eventual production or the industry of use or benefit. I address this issue, where possible, by using two different patent datasets with assorted systems and levels of patent classification.

Second, it is not yet clear what fraction of a nation's innovation is represented by patents (since not all inventions are patentable and not all patentable inventions are patented), or to what degree selection bias exists in any given set of patent data. This problem is exacerbated when attempting comparative research since different industries and different countries may exhibit significant variance in their propensity to patent. However, at the national level, patents have also been found to correlate highly with other measures which we generally associate with aggregate innovation rates, including GDP growth, manufacturing growth, exports of capital goods, R&D spending, capital formation, Nobel Prize winners, etc.[54] And I further address these concerns by using scientific publications data to corroborate my patents findings (discussed in greater depth below in section 2.5). Scholarly publications data are a measure of innovation completely independent of patents: they are generally produced by a different set

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[50] Designs and plant life can also be patented, however most econometric analysis of patent data is confined to utility patents granted for inventions such as those listed above. For a fuller description of patents and patent laws, classifications, and the application process see http://www.uspto.gov/main/patents.htm.

[51] Scherer 1965; Schmookler 1966.

[52] Summaries of which can be found in Griliches 1984; Pakes 1986; and Griliches, Hall, & Pakes 1987.

[53] Hall, Jaffe, & Trajtenberg 2001.

[54] Amsden & Mourshed 1997.

of innovators, affected by different incentives, and judged according to different institutional standards. And although patents and publications both may be imprecise measures of innovation, as long as this measurement error is random and uncorrelated with the explanatory variables, then regressions using this data should produce unbiased estimates of the coefficients (and generally with inflated standard errors).

Finally, some critics point out that patents vary widely in their technical and economic significance: most are for minor inventions, while a few represent extremely valuable and far-reaching innovations. Moreover, it has been found that simple patent counts do *not* provide a good measure of the radical-ness, importance, or "size" of an innovation. Simple patents counts correlate well with innovation inputs such as R&D outlays, but they are too noisy to serve as anything but a very rough measure of innovation output.[55] Therefore I use patent counts which have been weighted by forward citations. Forward citations on patents have been found to be a good indicator of the importance or value of an innovation, just as scholarly journal articles are often valuated by the number of times they are cited. The idea here is that minor or incremental innovations receive few if any citations, and revolutionary innovations receive tens or hundreds. Empirical support for this interpretation has arisen in various quarters: citation weighted patents have been found to correlate well with market value of the corporate patent holder, the likelihood of patent renewal and litigation, inventor perception of value, and other measures of innovation outputs.[56]

2.4.3 Testing the VOC Industry Assumption

Armed with a better understanding of patents, we can now use them to test some of the more controversial claims made by VOC scholars. One such controversy resides in their implicit assumption about the innovative characteristics of particular industries. VOC theory assumes that some industries are inherently and statically more radically innovative, and other industries inherently and statically more incrementally innovative. However, this assumption is contradicted by a vast empirical literature which shows that the innovative characteristics of any given industry are not static but dynamic, and depend not so much on industry type but on the industry's technological maturity.[57] More specifically, studies have found that most industries are typified by two successive waves of innovation: first a flurry of radical product innovations which eventually converge on a dominant product design, followed by a flurry of process innovations in manufacturing the product at lower cost. In each wave, earlier innovations tend to be more revolutionary than subsequent ones which build upon them. For example, during the first thirty years of automobile production, more than 100 US firms produced competing models of automobiles with tremendous variance in features and operability. During this period innovation focused on radical product changes: introduction of enclosed bodies, wheel-based steering, electrical systems, gasoline-based fuel and engine systems, etc. These innovations tended to be revolutionary and dramatically affected the look and performance of successive versions of the automobile, such that cars from this period bear little resemblance to the cars of today. However, as the market converged on a dominant design for automobiles, product innovations became gradually more incremental, and the focus of radical innovation shifted to production processes. This type of innovation dynamic has been observed in almost every industry which produces assembled products.

If the innovative character of industry changes over time, then Hall & Soskice's use of snapshots of patent activity in particular industries may not properly test VOC theory. That is, for the two brief time periods covered by Hall & Soskice's patent data, we must ask whether the researchers correctly identify which industries were more radically or incrementally innovative. In order to answer this question I rely on the ability of forward citations to serve as a measure of "degree" or "value" of an innovation. For my empirical evidence, I make use of the newly compiled NBER patent dataset described above. Using the USPTO patent classifications, the NBER scholars have grouped their data into six industry categories,

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[55] Griliches 1984.

[56] Trajtenberg 1990; Hall, Jaffe, and Trajtenberg 2000; Lanjouw & Shankerman 1997, 1999; Jaffe, Trajtenberg, & Fogarty 2000.

[57] Summarized in Utterback 1994.

each consisting of 4-7 sub-categories (for a total of 36 subcategories), which will allow us to compare the average patent citation rates across different industries.

Figure 2.2: Patents & Forward Citations by Industry, 1963-1999

Industry Category	# patents	Mean†	Standard Dev.†	Min.†	Max.†
IT/Telecom	290,337	6.44	10.6	0	779
Drugs/Med	204,199	5.99	11.2	0	631
Electric	499,741	4.75	6.70	0	251
Chemicals	606,934	4.62	7.14	0	401
Others	641,333	4.46	5.90	0	286
Mechanical	681,378	4.17	5.71	0	411
Total	2,923,922	4.78	7.35	0	779

†Forward Citations Per Patent. *Source*: NBER 2001.

Figure 2.2 shows the means of the forward citations per patent by industry category. The industries generally rank as assumed by VOC theory: computers & telecommunications patents receive on average the most forward citations, followed by drugs & medical, electronic, chemical, others, and finally mechanical. T-tests reveal that the differences between these means are significant beyond the 99% confidence level. Even if we sharpen the level of analysis by further subdividing the industry categories into their smaller sub-categories, we again find that patent citations behave more or less as assumed by VOC theory.[58]

Of course, analyzing the data in this manner introduces a potential truncation problem: older patents have had more time to be cited than younger patents. This problem is exacerbated in the NBER dataset since it only includes citations data from 1975 onwards.[59] Therefore, patents granted before 1975 will suffer from further truncation in that a 1969 patent will contain the citations received from patents granted during 1975-1999, but not from patents granted in 1969-74. We can control for the overall truncation problem by excluding pre-1975 patents from consideration and by using multivariate regression analysis with a control for patent age.[60] The results of these regressions are reported in Figure 2.3. First, we find in all of the regressions that the coefficient for patent age is significant and generally positive; note also that the age coefficient increases in strength when pre-1975 patents are omitted from the dataset, and consistently hugs 0.3 in all regressions conducted using the 1975-1999 patent data (see also Figs. 2.5-2.7 below). This is suggestive of the truncation effects described above. We can interpret this coefficient as indicating the number of additional citations received per patent for each year of its existence. The age coefficient does turn negative in Model 5, where only the very oldest patents are used. This suggests that patented innovations may have a “lifespan” of usefulness, generating much subsequent innovation while young, then slowly fading into obsolescence as either new innovations come to replace them or their capacity to serve as the foundation for new innovations is exhausted. Second, we find in Models 1 & 2 that, even when controlling for patent age (and with the added understanding that classification errors may exist), the industry coefficients generally line up as assumed by VOC theory: computers & telecommunications patents receive the most forward citations, followed by drugs & medical, electronic, chemical, others, and finally mechanical. The coefficients here can be interpreted as the additional number of citations received per patent for patents granted to innovations in a particular industry (relative to the

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[58] Exceptions include patents in the drugs, biotechnology, food, and organic compounds sub-categories which appear to be relatively poorly cited despite the fact that these are amongst VOC’s “radically innovative” industries; in the “incremental” sub-categories, patents related to gas, power systems, resins, and coatings appear to be more highly cited than VOC theory might assume. These might be partially explained by classification problems or by differences in the legal or technical need to cite in these industries.

[59] Due to the fact that citations data were not computerized prior to 1975.

[60] All regressions reported here use a patent age based on grant year. Regressions performed using a patent age based on application year produced similar results.

Figure 2.3: OLS Testing of VOC's Industry-Innovation Assumption
(Dependent Variable = citations received per patent)

	1	**2**	**3**	**4**	**5**	**6**
Data Used:	**1963-1999**	**1975-1999**	**1975-1999 (excluding US)**	**1975-1999**	**1975-1980**	**1990-1995**
IT/Telecm	2.48 (0.02)*	3.43 (0.02)*	2.70 (0.02)*	3.52 (0.02)*	3.39 (0.06)*	5.17 (0.03)*
Drugs/Med	2.07 (0.02)*	2.29 (0.02)*	0.93 (0.03)*	2.29 (0.02)*	2.83 (0.06)*	3.02 (0.04)*
Electric	0.42 (0.01)*	0.95 (0.02)*	0.92 (0.02)*	1.07 (0.02)*	0.59 (0.04)*	1.42 (0.03)*
Chemicals	0.16 (0.01)*	0.14 (0.02)*	0.18 (0.02)*	0.24 (0.02)*	0.02 (0.04)	0.15 (0.03)*
Mechancl	-0.31 (0.01)*	-0.22 (0.02)*	0.13 (0.02)*	-0.08 (0.02)*	-0.61 (0.04)*	0.016 (0.03)*
Other						
US				1.05 (0.01)*		
patent age (yrs.)	0.08 (0.000)*	0.31 (0.001)*	0.29 (0.001)*	0.31 (0.001)*	-0.04 (0.008)*	0.65 (0.005)*
_cons	3.07 (0.01)*	1.03 (0.01)*	0.82 (0.01)*	-0.40 (0.01)*	-7.29 (0.17)*	-0.42 (0.04)*
R2	0.02	0.10	0.10	0.10	0.02	0.08
Obs	2923922	2139314	939037	2139314	384270	585758

Note: Analysis is by ordinary least squares (OLS), Huber-White estimates of standard errors reported in parentheses. *p< .001. *Source*: NBER 2001.

omitted category "Other"[61]). The mean citations received per patent in the 1975-1999 dataset is 4.9 (with a standard deviation of 7.8), therefore the size of the innovative differences between industries suggested by the coefficients is significant, but not immense.

Since my findings in subsequent sections indicate that VOC's evidence is sensitive to the US outlier, I run two regressions to consider its effects on the industry rankings. In Model 3, I omit the US data entirely, which drastically reduces the coefficient for the IT/Telecom and Drugs/Medical categories, and increases the coefficients for the Chemicals and Mechanical categories. When I instead use a US dummy (Model 4), the coefficients change significantly for only Chemicals and Mechanical patenting. The first thing to note in both these regressions is that the rankings do not change in the areas of most concern to VOC theory: chemicals, mechanical, and "other" patents receive fewer citations than those in VOC's radically innovative sectors. Second, these regressions tell us that US is in fact a powerful outlier which affects the nature of global innovation, especially in frontier sectors.

Given the time dynamics of innovation, it is also important to confirm that the findings above are not an artifact of averaging across a long time period. Models 5 & 6 address this concern, revealing that VOC's industry assumption generally holds even when I limit the dataset to either the very earliest or very latest five years of patenting activity. In these regressions, computers & telecommunications patents consistently received the most citations, again followed by drugs & medical and electronics patents; there is however some shuffling amongst the remaining categories, especially mechanical patents which may suggest a recent small surge in innovation there. But these minor shifts do not create any major problems for the VOC assumptions. Also, though not shown here, if we again further subdivide the six categories above into their 36 subcategories, we

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[61] "Other" includes innovations in miscellaneous areas such as house fixtures, furniture, pipes & joints, jewelry, cutlery, recepticals, undertaking, and amusement devices.

find that patent citations behave more or less as they do at the category level.[62] Finally, given the non-constant variance in forward citations across industries (and later, countries), I correct for heteroscedasticity using Huber-White estimators of standard errors in all regressions, but find no significant differences from the results generated by the traditional estimator. In sum, patent data generally support the VOC assumption about industry innovation characteristics.

Figure 2.4: Violations of VOC Theory for Innovation in 30 Technology Classes
(shaded squares indicate violations)

	US v. Germany			**LME's v. CME's**			**LME's (ex-US) v. CME's**		
	1983-84	**1993-94**	**1978-95**	**1983-84**	**1993-94**	**1978-95**	**1983-84**	**1993-94**	**1978-95**
Agri. Machines							▨	▨	▨
Agri., Food									
Audiovisual				▨	▨	▨	▨	▨	▨
Basic Chemical				▨			▨		
Biotechnology									
Civil Eng.							▨	▨	▨
Consumer Gds							▨	▨	▨
Control Sys.									
Electrcl Energy									
Engines							▨	▨	▨
Environment									
Handling							▨		
IT							▨		▨
Machine Tools									
Materials Procs									
Mech. Elements				▨			▨	▨	▨
Medical Eng.									
New Materials			▨	▨	▨	▨		▨	▨
Nuclear Eng.			▨		▨	▨		▨	
Optics					▨	▨	▨	▨	▨
Organic Chem.									
Pharmaceutical									
Polymers			▨	▨	▨	▨		▨	
Process Eng.					▨				
Semiconductor							▨	▨	▨
Surfaces					▨			▨	▨
Telecom.							▨		
Thermal Procs.									
Transport							▨		▨
Weapons					▨		▨		▨
Total	**0**	**0**	**3**	**5**	**8**	**5**	**14**	**12**	**13**

Source: EPO (Hall & Soskice, 2001)

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[62] With the same exceptions at the subcategory level as those found with the citations averages. See fn 17 above.

2.4.4 Testing VOC's Predictions About National Innovative Character: Simple Patent Counts

Having confirmed the industry-based innovation assumption above, we can now reconsider the evidence offered by Hall & Soskice (Figure 2.1). Again, this chart is based on EPO patent data for the United States and Germany in thirty industries during two separate two-year periods. For each industry in each time period, Hall & Soskice calculated a patent specialization index (I) which simply subtracts a country's fraction of its total patents in a particular field from the world's fraction of total global patents in the same field.[63] Hence a positive index score means greater specialization in innovation in that particular type of technology. The chart shows that the US specializes its patenting in industries typified by radical innovation, while Germany's patent specialization is in industries typified by incremental innovation. The question then is whether this finding holds true across time and space, or have Hall & Soskice inadvertently selected outlying countries or years? In order to test this possibility, I use the same EPO dataset and computational formula used by Hall & Soskice, but instead calculate the patent specialization indices across a much longer time-span (1978-1995) and compare the innovative activities of the entire set of LME and CME countries.

The results of this exercise are summarized above in Figure 2.4. Note that rather than requiring an exact quantitative match, I apply a more lenient qualitative standard for VOC theory to pass, only testing which country (or set of countries) has a higher patent specialization index in each of the thirty industries. Using Hall & Soskice's data and methodology, I was able to closely reproduce their findings for Germany and the US in 1983-84 and 1993-94. However, when I extend the time period to 1978-1995, German and US patenting fails to meet VOC predictions in polymers, new materials, and nuclear engineering. Even more discrepancies arise when we expand the dataset to compare patent specialization by the set of all LME countries versus the set of all CME countries. For example, in the 1983-84 period, the set of LME's had higher patent specialization indices than the set of CME's in three industries which Hall & Soskice describe as incremental (mechanical elements, basic materials, polymers), while CME patenting had higher specialization scores in two radical industries (new materials, audiovisual tech.). But the most striking disparity occurs when we exclude the United States from the set of LME countries; under these conditions we find that VOC theory has only marginally more predictive power than random chance.

The NBER patent data presents us with a second dataset with which to test the patent specialization indices devised by Hall & Soskice. Such a test adds value in that the NBER dataset not only spans over twice the time-period (1963-1999) as the EPO data used by Hall & Soskice, but consists of USPTO patents and is therefore a completely independent dataset. The NBER data also uses a completely independent classification scheme which allows us to control for some of the potential classification problems and idiosyncrasies discussed above. Yet, despite these differences, our results are generally the same as those found using Hall & Soskice's EPO data. I omit a graphic depiction of the results and instead explain the major findings. Of the 18 categories of innovation which I was able to map from Hall & Soskice to the NBER data, VOC's predictions were born out relatively well (approximately 70-80% of the time, depending on the time period) when applied to the US and Germany.[64] However, when we expand the dataset to test all LME countries versus all CME countries, we find that VOC theory loses a considerable amount of its predictive power, with a 72% success rate in 1983-84, but only 50% in 1993-94, and 56% over the entire 1963-1999 period. Omitting the US from the set of LME's results in further deterioration, with VOC's success rate ranging from 44-56%. Thus, after analyzing two different datasets and competing classification methods, it appears that the success of VOC theory strongly depends upon the inclusion of the United States as an LME.

2.4.5 Testing VOC's Predictions About National Innovative Character: Patent Citations

So far we have used simple patents counts in our comparisons of LME's vs. CME's, yet we know from the discussion above that forward citations of patents are an even better gauge of radical vs. incremental innovation. Therefore, in this section, I will use the forward citations data in the NBER patent dataset to test the VOC country claims directly, retaining the same techniques which I used above in testing the VOC assumptions

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[63] For example, in biotechnology: $I_{\text{US biotech}} = \text{US}_{\text{biotech}}/\text{US}_{\text{total}} - \text{World}_{\text{biotech}}/\text{World}_{\text{total}}$.

[64] Agricultural machines (a particularly difficult category to define in NBER terms) is the only category which persistently defies the VOC predictions in all time periods; while patenting in optics, pharmaceuticals, transport, organic chemistry, weapons, electrical energy, and nuclear engineering (narrowly measured) each contradicted VOC theory in different time periods.

about industries. As my dependent variable in all of the following regressions I again use citations-received per patent as a proxy for the radical vs. incremental nature of innovation. VOC theory suggests that country dummies or country-type dummies (LME, CME) are the primary independent variables of interest, as well as controls for industry-type (again we use industry category or sub-category), and of course a control for patent age should be included to address the truncation problem. Since the US outlier proved important in the simple statistical analysis above, I address it in two ways in the regressions. In some regressions a US dummy is introduced, in others the US is simply omitted from the class of LME's (creating a new dummy: LMEx). For data, we use the NBER patent dataset for all countries' patenting activity during the period 1975-1999.

We begin with regressions using controls only for patent age and country-type, the results of which (Figure 2.5) reinforce what we found previously: that LME's are more radically innovative than CME's (Model 1 v. Model 2), but that this finding depends entirely upon the inclusion of the United States as an LME (Model 3). This effect is apparent even when the CME dummy is run together with that for LME's or LMEx's (Models 4 & 5). In each of these regressions, the coefficients can be interpreted as the additional number of citations received per patent for patents granted to innovations in a particular set of nations (LME's, CME's, or LMEx's) relative to the rest of the world. Note how sharply the LME coefficient drops when we introduce a US dummy variable (Model 6) and, perhaps more interesting, that the LMEx's appear to be *less* radically innovative than the CME's (Models 7). Of equal importance is the small size of the coefficients and the differences between them. These indicate, for example in Model 4, that *even when we do not control for the US-outlier*, the innovative difference between LME's and CME's is smaller than a single citation per patent. Although this may be a statistically significant amount, it is far smaller than the innovative difference between the most vs. least innovative industries found above and does not suggest a large innovation gap.

Figure 2.5: OLS Testing of VOC Innovation Theory, by Nation Type (1975-1999)

	1	**2**	**3**	**4**	**5**	**6**	**7**
LME	0.95 (0.011)*			1.71 (0.02)*		0.65 (0.03)*	
CME		-0.59 (0.011)*		0.93 (0.02)*	-0.67 (0.01)*	0.93 (0.02)*	0.93 (0.02)*
LMEx			-0.74 (0.022)*		-0.95 (0.02)*		0.65 (0.03)*
patent age (yrs.)	0.28 (0.001)*	0.28 (0.001)*	0.29 (0.001)*	0.28 (0.001)*	0.28 (0.001)*	0.28 (0.001)*	0.28 (0.001)*
US						1.16 (0.02)*	1.81 (0.02)*
_cons	1.51 (0.01)*	2.26 (0.01)*	2.09 (0.009)*	0.76 (0.02)*	2.33 (0.01)*	0.76 (0.02)*	0.76 (0.02)*
R2	0.076	0.074	0.073	0.077	0.074	0.08	0.078
Obs	2139314	2139314	2139314	2139314	2139314	2139314	2139314

Note: Analysis is by ordinary least squares (OLS), Huber-White estimates of standard errors reported in parentheses.
*p< .001. *Source*: NBER 2001.

VOC theory also includes industry-type as a factor in determining innovative behavior. Hence a second set of regressions are run, identical to those reported in Figure 2.5 but with the addition of controls for industry (Figure 2.6). Yet we find no significant differences when the industry controls are added to the regression models. Again, the LME countries appear at first to be more radically innovative than the CME's (Model 1 vs. Model 2), but not when the United States is excluded from the group of LME's (Model 3). Note also that the industry coefficients in this regression match those found when we previously tested the VOC industry-innovation assumption above (Figure 2.3). In order to test this finding more directly we add a US-dummy, which again severely affects the coefficient of the LME dummy (Models 6 & 7). Regressions run at a finer level of analysis using industry subcategories (not shown) produce similar results.[65]

Given the broad nature of VOC theory and the complex array of causal mechanisms it hypothesizes, a fixed effects model is perhaps the best, most efficient way to conduct a statistical test of its central predictions. While the NBER dataset affords us enough degrees of freedom to use countries dummies for all 162 nations, computer memory does not. I therefore run a final set of regressions in which I include dummies for 23 of the world's highest patenting countries.[66] These countries include the aforementioned LME and CME states in addition to France, Italy, Spain, Israel, Taiwan, Singapore, and South Korea. Using only country dummies, controlling for age, and correcting for heteroscedasticity, we find that the relative strengths of the coefficients for the remaining dummies do not quite line up along the lines predicted by VOC theory (Figure 2.7). Here the coefficients can be interpreted as the additional number of citations received per patent for patents granted to innovations in a particular nation relative to those granted to the rest of the world (ROW). Though not astronomical, the size of the coefficients do indicate significant innovative differences between states, and that these innovative differences are comparable to those across different industries. All of the coefficients are

Figure 2.6: OLS Testing of VOC Innovation Theory, by Nation Type & Industry (1975-1999)

	1	**2**	**3**	**4**	**5**	**6**	**7**
LME	0.94 (0.01)*			1.66 (0.02)*		0.66 (0.03)*	
CME		-0.59 (0.01)*		0.89 (0.02)*	-0.66 (0.01)*	0.89 (0.02)*	0.89 (0.02)*
LME (excluding-US)			-0.68 (0.02)*		-0.90 (0.02)*		0.66 (0.03)*
US						1.10 (0.02)*	1.76 (0.02)*
patent age (yrs.)	0.31 (0.001)*	0.31 (0.001)*	0.31 (0.001)*	0.31 (0.001)*	0.31 (0.001)*	0.31 (0.001)*	0.31 (0.001)*
IT/Telecom	3.53 (0.02)*	3.50 (0.02)*	3.42 (0.02)*	3.49 (0.02)*	3.49 (0.02)*	3.48 (0.02)*	3.48 (0.02)*
Drugs/Med	2.28 (0.02)*	2.28 (0.02)*	2.29 (0.02)*	2.29 (0.02)	2.29 (0.02)*	2.29 (0.02)*	2.29 (0.02)*
Electrical	1.07 (0.02)*	1.02 (0.02)*	0.94 (0.02)*	1.06 (0.02)*	1.02 (0.02)*	1.05 (0.02)*	1.05 (0.02)*
Chemicals	0.24 (0.02)*	0.21 (0.02)*	0.13 (0.02)*	0.22 (0.02)*	0.20 (0.02)*	0.22 (0.02)*	0.22 (0.02)*
Mechanical	-0.09 (0.02)*	-0.14 (0.02)*	-0.22 (0.02)*	-0.11 (0.02)*	-0.13 (0.02)*	-0.11 (0.02)*	-0.11 (0.02)*
Other							
_cons	0.41 (0.02)*	1.28 (0.01)*	1.07 (0.01)*	-0.29 (0.02)*	1.25 (0.01)*	-0.29 (0.02)*	-0.29 (0.02)*
R2	0.10	0.10	0.10	0.10	0.10	0.10	0.10
Obs	2139314	2139314	2139314	2139314	2139314	2139314	2139314

Note: Analysis is by ordinary least squares (OLS), Huber-White estimates of standard errors reported in parentheses.
*p< .001. *Source*: NBER 2001.

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[65] An alternate interpretation of VOC theory suggests that in place of LME/CME/LMEx controls, we might include interaction terms (LME*industry, CME*industry, and LMEx*industry). I experimented with such interaction terms but produced the same general results as those reported above.

[66] As before, all pre-1975 patents are eliminated to control for truncation effects.

Figure 2.7: OLS Testing of VOC Innovation Theory, by Country & Industry (1975-1999)

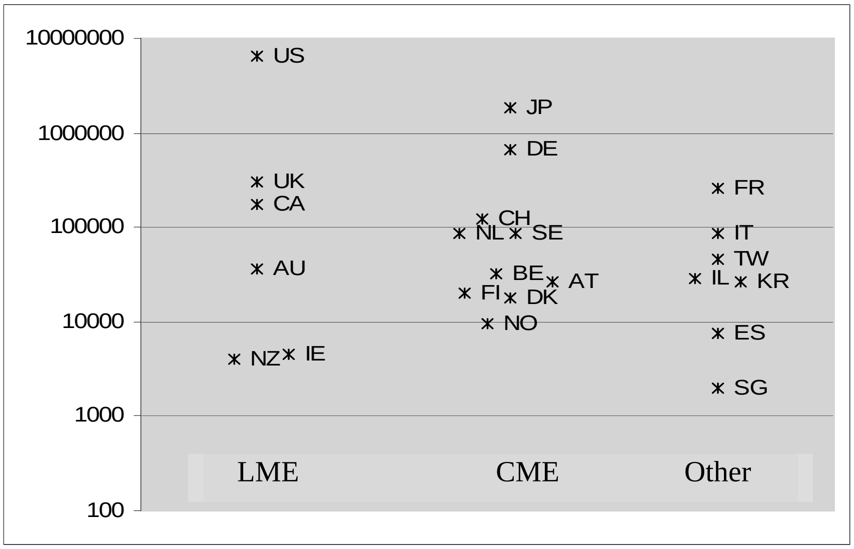
	LME's									
	patent age (yrs.)	**US**	**Ireland**	**Canada**	**UK**	**Australia**	**New Zealnd**			
1	0.29 (0.001)**	2.74 (0.03)**	2.23 (0.22)**	1.74 (0.05)**	1.55 (0.04)**	1.14 (0.06)**	0.55 (0.13)**			
2	0.32 (0.001)**	2.59 (0.03)**	1.93 (0.22)**	1.76 (0.04)**	1.35 (0.04)**	1.21 (0.06)**	0.68 (0.13)**			
	CME's									
	Japan	**Nethrlds**	**Belgium**	**Denmark**	**Sweden**	**Finland**	**Germany**	**Switz**	**Norway**	**Austria**
1	2.52 (0.04)**	1.34 (0.05)**	1.27 (0.07)**	1.07 (0.09)**	1.07 (0.05)**	1.05 (0.07)**	0.92 (0.04)**	0.77 (0.05)**	0.61 (0.10)**	0.42 (0.06)**
2	2.24 (0.04)**	1.09 (0.05)**	1.28 (0.07)**	0.98 (0.09)**	1.02 (0.05)**	1.01 (0.07)**	1.00 (0.04)**	0.81 (0.05)**	0.69 (0.10)**	0.64 (0.06)**
	Others									
	Israel	**Singapore**	**Taiwan**	**S. Korea**	**France**	**Italy**	**Spain**	**ROW**		
1	2.25 (0.09)**	1.90 (0.17)**	1.34 (0.04)**	1.21 (0.04)**	1.06 (0.04)**	0.69 (0.07)**	0.07 (0.08)			
2	1.79 (0.09)**	1.54 (0.17)**	1.56 (0.04)**	0.78 (0.04)**	0.86 (0.04)**	0.72 (0.05)**	0.18 (0.08)*			
	Industries									
	IT/Telecm	**Drugs/Med**	**Electrical**	**Chemical**	**Mechancl**	**Other**	**_cons**	**R2**	**Obs**	
1							-0.25 (0.03)**	0.08	2139314	
2	3.36 (0.02)**	2.33 (0.03)**	0.98 (0.01)**	0.23 (0.01)**	-0.14 (0.01)**		-1.14 (0.04)**	0.10	2139314	

Note: Analysis is by ordinary least squares (OLS), Huber-White estimates of standard errors reported in parentheses. **p< .001, *p< .05. *Source:* NBER 2001.

positive, indicating that patents from the rest of the world generally receive fewer forward citations than patents from our chosen countries. Patents from the US receive the most forward citations, those from Spain, Austria, and New Zealand consistently receive the least. Interestingly, Australia and New Zealand appear to deserve a place amongst the CME's, while Japan seems to be one of the most radical innovators (Model 1). And while we are not immediately concerned with Hall & Soskice's hybrid MME's, the three which appear in the regressions (France, Italy, Spain) have major differences between them and do not appear to form a cohesive group. Also, the high placement of Israel (arguably a pre-1970s CME, increasingly MME thereafter) and Taiwan (arguably an MME), not mentioned in VOC theory, further suggest that there may be more to radical innovation than the variables captured by Hall & Soskice. Adding controls for industry do not have a significant impact on the rankings, except for some minor shuffling (Model 2).

Finally, if we believe that both quality *and* quantity of patents matter, that Ireland with its relative trickle of few but highly cited patents should not necessarily be considered more radically innovative than Germany with its slightly less cited ocean of patents, then we must instead look at total citations received over time. This data is charted below in Figure 2.8. Here we have merely multiplied the mean citations received per patent by the total number of patents for each country. This will allow us to capture both the number and value of patents in one measure. The plots are split horizontally into three groups (LME's, CME's, and other countries) for comparison. Again we see the US outlier, but no strong general differences in total citations between the different VOC country types.

Figure 2.8: Total Forward Citations, 1975-1999



In sum, the VOC theory does not appear to explain innovation as measured by patenting activity. Rather, the success of VOC theory in predicting innovation appears to depend upon the inclusion of the United States, a major outlier, in the set of liberal market economies. We find this fact repeated regardless of the source of the patent data, the type of industry classification system used, or whether simple patents or forward citations are used. However, one caveat which bears repeating is that this finding depends an assumption of random error in using patents as a measure of innovation. Social scientists cannot yet completely describe the correlation between patents (an innovation output) and total innovation, nor do we fully understand how propensity to patent varies across industry, across country, and over time. We therefore briefly consider the non-patent evidence for differences in national innovation in the next section.

2.5 Additional Evidence

Patent statistics are by no means the only innovation data which paint a picture contradictory to the VOC claims, scholarly journal articles are another useful measure of innovation which reinforces the cross-national findings discussed above. Scholarly publications data offer advantages similar to those of patents, with each journal article representing a quantum of research innovation which must pass independent review and which tends to be cited in proportion to its innovative impact. More importantly, scholarly publications data are completely independent of patents: they are generally produced by a different set of innovators, affected by different incentives, and judged according to different institutional standards (McMillan & Hamilton 2000). Of course, journal articles also suffer many of the same shortcomings as patents, including difficulties in classification, problems with valuation, and uncertainty regarding to what degree journals represent the universe of innovation.[67] These difficulties are further complicated by changing journal sets, the lack of a single standardized referee process, and the relative importance of prestige and popularity in the publication process. However, just as with patents, information sciences scholars have found legitimate and rigorous applications for publications data in measuring innovative output. While this debate is better summarized elsewhere, the current consensus is that there is reasonable basis for using journal articles as a window on innovative activity in the aggregate.[68]

VOC theory does not make specific predictions regarding scholarly publications patterns, and indeed its authors may never have intended it to. Nonetheless, we might infer from VOC theory the following hypothesis: that scholarly publications by LME researchers should show specialization in fields associated with revolutionary scientific advances, while CME's should show specialization in fields associated with incremental scientific advances. Although it is not quite clear what a "radically" versus "incrementally" innovative field might be, one could simply map the typology used by Hall & Soskice for industrial sectors over to academic sectors. For example, CME's should excel in publishing in the engineering and technology journals, LME's in biology, medicine, and physics. A second hypothesis might surmise that researchers in the CME's should excel in professional journals and applied sciences publications where incremental research is more prominent, while LME researchers should publish heavily in the more academic or theoretical sciences journals where the research tends toward the revolutionary. A third, and less controversial, hypothesis would be that LME publications should simply have higher forward citation averages than CME publications.

Yet, none of the patterns hypothesized above can be found in the cross-national publications data. Consider the ISI's simple journal publication data compiled in Figure 2.9. Compare the world publication rates by field with those of the LME's and CME's. As a group, the LME's tend to consistently specialize in clinical medicine, biology, earth-space, psychology, social science, health, and professional journals; CME's tend to consistently specialize in clinical medicine, chemistry, and physics. Over time the CME's have increased their specialization in biomedical research, physics, and earth-space, but weakened in clinical medicine, chemistry, and engineering & technology; while the LME's have increased their specialization in biomedical, physics, and earth-space. Using forward citation indices (Figure 2.10) we find the LME's beating CME's in all fields. When we exclude the US from the set of LME's, the LME's appear to have higher citations than the CME's in all fields except earth & space, engineering, and physics. Relatively speaking, LME's are strongest in chemistry, physics, biomedical research, and math. CME's are strongest in chemistry, engineering, physics, and biology. None of these findings is what we might expect from VOC theory.

In Fig 2.10, each number represents the country's share of cited literature adjusted for its share of published literature. A score of 1.00 would indicate that the country's share of cited literature is equal to the country's world share of scientific literature. A score greater (less) than 1.00 would indicate that the country is cited relatively more (less) than is indicated by the country's share of scientific literature.[69]

Finally, despite problems in measuring pre-1960s innovation and diffusion, history provides researchers with some natural experiments which deserve further investigation. For example, Japan, during its first brush with democracy (1910s-1930s), was distinctively "LME-ish" but does not appear to have followed a significantly different innovation pattern than did post-war CME Japan. During this earlier period, Japan had a

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[67] the innovative "representativeness" of journal articles is more of a problem in the social sciences, and less so in the physical sciences, see Hicks 1999.

[68] Glanzel & Moed 2002, Bourke & Butler 1996, Garfield 1972.

[69] Example: $I_{\text{US biology}} = (\#\ \text{US}_{\text{biology, cited}} / \#\ \text{World}_{\text{biology, cited}}) / (\#\ \text{US}_{\text{biology, published}} / \#\ \text{World}_{\text{biology, published}})$. Data source for both tables*:* National Science Board 2002, Appendix Tables 5-43, 5-52.

Figure 2.9: Specialization in Scholarly Publications (publications per field as a % of total)

1986	**Clincl Med**	**Bio-Med**	**Bio**	**Chem**	**Physics**	**Earth Space**	**Eng-Tech**	**Math**	**Psych.**	**Soc. Sci.**	**Health**	**Prof.**	***Total***
World	29.8%	15.0	7.9	12.5	12.2	4.4	6.7	1.8	2.7	3.7	0.9	2.7	*100%*
LME	31.6%	14.6	9.1	7.7	9.1	4.9	6.4	1.8	3.9	5.1	1.4	4.4	*100%*
CME	34.2%	15.1	6.8	14.2	12.9	3.0	8.0	1.7	1.4	1.8	0.3	0.6	*100%*
LME (ex-US)	32.7%	13.8	12.2	8.6	7.9	5.3	6.3	1.7	3.1	4.8	1.0	2.6	*100%*
1999	**Clincl Med**	**Bio-Med**	**Bio**	**Chem**	**Physics**	**Earth Space**	**Eng-Tech**	**Math**	**Psych.**	**Soc. Sci.**	**Health**	**Prof.**	***Total***
World	29.0%	15.0	7.0	12.5	15.0	5.4	6.8	2.0	2.0	2.7	0.9	1.8	*100%*
LME	32.1%	16.0	7.3	8.0	10.0	6.2	5.9	1.8	3.3	4.2	1.5	3.3	*100%*
CME	32.7%	15.0	6.5	13.5	17.0	4.0	6.2	1.5	1.2	1.3	0.4	0.5	*100%*
LME (ex-US)	32.0%	14.4	10.0	8.5	9.4	6.4	6.1	1.7	3.0	4.4	1.6	2.2	*100%*

Figure 2.10: Relative Prominence of Scientific Literature by Country/Economy and Field (1999)

	All fields	Biology	Bio-med	Chem	Clincl Med	Earth Space	Eng-Tech	Math	Physics	Soc. Sci.	Psych	Health	Prof.
United States	1.35	1.16	1.40	1.50	1.27	1.31	1.20	1.24	1.47	1.28	1.12	1.14	1.16
United Kingdom	1.04	1.25	0.98	1.14	1.00	1.03	0.99	1.23	1.07	1.07	1.16	0.90	0.64
Canada	0.99	1.05	0.91	1.30	1.11	0.89	0.89	0.92	0.99	0.84	1.07	0.87	0.89
Australia	0.87	1.04	0.78	1.05	0.91	0.88	1.05	1.02	0.90	0.65	0.80	0.88	0.84
Ireland	0.82	0.99	0.57	0.98	0.87	0.67	0.85	1.02	0.93	0.56	0.76	0.67	0.47
New Zealand	0.76	0.89	0.57	1.00	0.86	0.71	0.99	0.65	1.07	0.78	1.06	0.97	0.73
LME	**1.235**	**1.136**	**1.264**	**1.381**	**1.188**	**1.190**	**1.123**	**1.193**	**1.340**	**1.167**	**1.104**	**1.055**	**1.069**
LME (ex-US)	**0.986**	**1.104**	**0.918**	**1.160**	**1.007**	**0.944**	**0.966**	**1.082**	**1.027**	**0.932**	**1.066**	**0.889**	**0.729**
Switzerland	1.37	1.41	1.40	1.45	1.08	1.16	1.77	1.07	1.36	0.66	0.59	0.48	0.86
Netherlands	1.12	1.19	0.89	1.41	1.08	1.14	1.24	0.94	1.26	0.87	1.03	1.13	0.86
Sweden	1.07	1.30	0.87	1.33	0.99	0.78	1.11	1.02	1.10	0.86	0.78	0.93	0.53
Denmark	1.04	1.21	0.77	1.20	0.94	0.85	1.34	1.36	1.35	0.55	0.63	0.70	1.17
Finland	1.02	1.17	0.86	0.94	1.03	0.63	0.95	0.92	1.01	0.72	0.89	1.38	0.73
Germany	1.01	1.08	1.00	1.07	0.83	1.11	1.06	1.08	1.27	0.42	0.72	0.48	0.31
Belgium	0.95	1.14	0.80	1.06	0.92	0.75	1.01	1.04	0.96	0.72	0.86	0.34	0.81
Austria	0.91	1.04	0.83	0.96	0.81	0.64	1.01	0.64	1.15	0.45	0.65	0.83	0.51
Japan	0.83	0.79	0.78	0.99	0.76	0.83	1.00	0.72	0.87	0.41	0.43	0.53	0.62
Norway	0.82	1.18	0.67	0.80	0.82	0.86	1.04	1.23	0.84	0.76	0.82	0.71	0.58
CME	**0.968**	**1.041**	**0.899**	**1.078**	**0.871**	**0.968**	**1.070**	**0.968**	**1.069**	**0.613**	**0.762**	**0.854**	**0.612**

strong and confrontational labor movement upon which business did not hesitate to inflict frequent and severe dislocations for the sake of technological advance. Moreover, the dependence of pre-war Japan on external trade and finance exposed even the powerful *zaibatsu* to the vicissitudes of international markets and created many LME-type incentives for economic actors. Yet the Japanese appear to have been consistent incremental innovators during this time. On the other hand, the Germans of this time period rivaled the United States in technological advance, producing wave after wave of radical innovation in multiple fields including the gas-powered automobile, the Zepplin, the Haber-Bosch process, blood-typing, aspirin, and organic chemicals to name but a few. Yet, the Germans had many of the same CME-type institutions and incentives as we find there today, including a national welfare system, national health care, and large business cartels negotiating with each other, and sometimes with workers, in a fairly CME-like manner. These stylized facts, while not conclusive, do suggest areas for deeper research and further testing of VOC claims, both as a theory of innovation and as general theory of political economy.

2.6 Implications

In sum, we have found that the predictions made by Varieties of Capitalism theory regarding national differences in technological innovation are not supported by the empirical data, and that the existing evidence depends heavily on the inclusion of a major outlier, the United States, in the class of liberal-market economies. My empirical investigation included simple patent counts, patents weighted by forward citations, and scholarly publications (both simple counts and weighted). I investigated data covering all of the VOC countries over the course of several decades, little of which revealed the patterns predicted by VOC scholars.

These findings carry significant repercussions for both VOC and innovation theory. First, insofar as patents and scholarly publications are good indices of innovation, VOC theory clearly fails to provide an accurate picture of the innovation process, and hence the trade and production patterns which follow. Whether this is a problem with the LME-CME classification system or VOC’s assumptions and causal mechanisms is not clear from the evidence presented here. However, I would suggest that while the firm may be the key actor in capitalist economies, and the primary producer of goods and services, it is difficult to ignore the role of the state in innovation as strongly as VOC’s theory and classification system do. Throughout the world, much useful innovation is the result of state-sponsored and state-managed R&D, often originating in concerns with national security. Another stream of innovative R&D in many countries comes from the public university system, or private universities benefiting from significant state-support. In still other states, innovation takes the form of incremental improvements on imported technologies, where the government has had a heavy hand in deciding which technologies will get imported. Often, the government also plays a key role as a market maker for, and main diffuser of, new innovations. However, VOC’s innovation theory omits these causal mechanisms entirely. This does not mean that VOC scholars are wrong to bring the firm onto the center-stage of political economy, but rather that in trying to get away from a hackneyed focus on government protectionism and state-ownership, they may have overcompensated. Future theorists must find a synthesis between the corporate-centered relationships emphasized by VOC and the state-centered mechanisms employed in traditional political economy.

Second, the statistical analyses above consistently point to the United States as an important factor in explaining global patterns of innovation. Furthermore, the fixed effects regressions reported in Figure 2.7 reveal that many of the world’s most innovative countries are those which also tend to have the strongest military and economic ties with the US, including Japan, Canada, the UK, Israel, and Taiwan. Together, these observations suggest that in order to better understand the political economy of comparative rates of innovation, future research should perhaps focus less on domestic institutions and more on international relations. This is not to argue that domestic institutions are insignificant, but rather that the scope and depth of a country’s relationship with the lead innovator may also carry significant weight in determining its technological profile. There is theoretical grounds for this supposition in that while the basic laws of science may be public goods, the tacit knowledge required to apply these laws to proper use and development of new technology is relatively excludable. Therefore factors such as foreign direct investment, educational exchanges, military assistance, and international flows of science and engineering labor between the lead innovator and other countries should be explored for their effects on innovation and the agglomeration patterns which interest both VOC and trade theorists.

Of course, we should recognize that the research reported above, while suggestive, does not necessarily shut the door on a Varieties of Capitalism approach to technological innovation. Innovation is a notoriously difficult phenomenon to measure quantitatively, and existing measures carry with them considerable noise, hence further progress needs to be made on method as well as theory. Nor does our critique here necessarily apply to other aspects of VOC theory. VOC is a broad approach to social behavior, consisting of myriad hypotheses regarding almost the whole spectrum of political economy including corporate governance, monetary policy, welfare programs and labor reform. These hypotheses are not necessarily interdependent and need to be considered and tested each on its own merits. Finally, as social scientists increasingly turn to institutions and international relationships in order to explain various phenomena related to cross-national variance in innovation, VOC scholars should be applauded for inserting political science into an area of research from which it has been all but absent.[70] While economists and sociologists have produced some excellent studies of the role of these variables in international technological performance, the comparative advantage which political scientists bring to the field in terms of methods and theory make this an area deserving far greater attention by students of politics. Varieties of Capitalism scholars have therefore provided a valuable and useful starting point for such an endeavor.

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[70] Notable exceptions include Edquist 1997; Samuels 1994; Lundvall 1992; Nelson 1993.

Chapter 3

Political Decentralization and Technological Innovation

3.1 Introduction

When observed over the long-run, one apparent trend is the ability of decentralized states to maintain their places at the technological frontier. Meanwhile centralized states, even when democratic, seem either unable to achieve high rates of innovation or to maintain technological leadership if achieved. Indeed, over time this observation has become a sort of conventional wisdom: centralized organizations of all sizes, from firms to nation-states, have come to be viewed as rigid and thus either hostile to the risks, costs, and change associated with new technology, or prone to cling too long to fool-hearty or outdated technological projects.[71] Recent scholarship by Daniel Drezner, as well work by Joel Mokyr, Daron Acemoglu, and other political-economists has provided a strong theoretical foundation for this intuition. In this conceptualization, technological innovation within any given nation-state is diagnosed as a combination of a public goods problem and an interest-group capture problem. Decentralization helps solve both problems: it aids in public goods production by improving the quality of information available to policymakers, while simultaneously creating conditions that reinforce property rights, markets, and increase the costs of capture.

However, a relationship between decentralization and technological innovation has never been empirically established by social scientists. While the theory is strong, the empirical evidence consists entirely of anecdotal observations and stylized case studies. This chapter therefore asks a simple empirical question: is there any aggregate evidence for a general relationship between government structure and long-run technological innovation? In an attempt to answer this question, I will examine several datasets of international patent activity, science and engineering research publications, and high-technology exports. It will be shown that, in general, firms and individuals in decentralized states are empirically no more technologically innovative than those in more centralized states.

3.2 Justification

This question of whether decentralized states are more technologically innovative than others interests scholars of comparative politics and international relations for reasons beyond those of national technological power. First and foremost, political power is currently in the process of being reallocated throughout states around the world, not only via a global shift towards greater democracy but with traditionally centralized polities in Asia, the Americas, and Europe either now decentralized or on their way to decentralization. And even while the European Union's members are engaged in a process of agglomeration in order to reap the benefits of size and the economies of scale, there is also a concurrent commitment in Europe to decentralizing their massive new political organization. While the politics of local autonomy and ethno-cultural divisions certainly play a role in the move to decentralize government in some states, part of the motivation behind this global movement is also this belief that decentralized states have a long-run competitive advantage over centralized states in promoting technological progress and in sustaining innovation-driven economic growth.[72]

Second, scholars of federalism also have an obvious interest in the outcome of this debate, especially since the theoretical consensus on the macroeconomic effects of federalism has recently broken down. A long tradition of federalism research credits decentralized political systems with everything from

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[71] See for example Smith 1988; Rosenberg & Birdzell 1985; Carroll 1993; Nam 2000; Jennergren 1981.

[72] European Commission 2003; Dresner & Gilber 2001; Barre, Gibbons, Maddox, Martin, & Papon 1997; Commission on European Communities 1988.

fiscal restraint to efficient government to preserving markets.[73] But more recently, a critical line of research has attacked this view and pointed out the detrimental affects of federalism on fiscal & monetary policy, exchange rate management, and privatization programs.[74] In an attempt at synthesis, still other scholars have criticized this dichotomy as a fallacy based upon abstract models and individual case studies. Instead, they use empirical data to show that federalism and its effects are better understood as varying along a spectrum.[75] Since most of these arguments concern the consequences of decentralization for long-run macroeconomic management and performance, and since technological innovation is both affected by, and is an important component of, the macroeconomy, it makes sense to link these research programs. That is, it is logical to ask whether the macroeconomic benefits (or costs) of decentralization identified by federalism scholars also affect technological innovation.

3.3 Definitions

For the purposes of this chapter, "decentralization" is defined as an increase in both the number and equality of centers of political power and policy-making. For many scholars, decentralization simply means federalism. However, as will be shown below, existing theories about government structure and technological change demand that I be more flexible in my definition, and allow decentralization to be either vertical or horizontal. In vertically decentralized states, authority has been shifted away from the central government and towards local governments, the classic example being federalism.[76] In horizontally decentralized states, authority is shared between an executive, legislature, judiciary, and in some cases even a powerful bureaucracy or autonomous military.[77] In practice, many states decentralize further, with power formally divided between different houses of the legislature, competing bureaucracies, or branches of the armed forces. Finally, when measuring the degree of decentralization, it is also important to consider that government structure can have both formal *de jure* components (those expressed in law or constitution) and informal *de facto* components (e.g. the extent of party alignment across different branches of government, or the extent of preference heterogeneity within each legislative branch).

3.4 Theory

In Chapter 1, it was argued that after almost two decades of research, NIS scholars have failed to produce or test any general hypotheses of national innovation rates. That is, institution or policy "X" might explain a certain country's innovation rate at a specific point in time, but not over time and not in other countries. In Chapter 2, the VOC explanation for this puzzle was tested. It was found that VOC theory did not predict variation in patents or scientific publications. Hence the problem of explaining national innovation rates remains.

According to the writings of Joel Mokyr, Daron Acemoglu et. al., and Daniel Drezner, political decentralization offers a solution to this problem.[78] The argument begins with Mokyr's realization that technological innovation is distributive and therefore creates "winners" and "losers" in the society within which it occurs. The losers created by innovation are generally holders of assets (skills, capital, land, resources, etc.) whose relative value will be hurt due to the effects of technological change. Hence technological losers can include labor groups, producers or consumers of existing technologies, or even investors. And in order to defend their assets (and their political power based on these assets), these losers will seek to influence or capture the NIS institutions and policies, or VOC's markets, that affect innovation in order to obstruct threatening technological changes. Acemoglu and Drezner subsequently

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[73] Oates 1972; Tiebout 1956; Weingast 1995.
[74] Rodden 2002; Woodruff 1999; Armijo & Shankar 2000.
[75] Rodden & Wibbels. 2002.
[76] Rodden. 2005
[77] This is much the same concept as "balance of power" or "checks and balances".
[78] The core logic of this argument emanates from Mokyr 1990, 2000; Acemoglu, Johnson, & Robinson. 2004; Drezner 2001.

point out that even the presence of markets cannot prevent this phenomena, since markets and property rights are but institutions subject to the will of captured state apparatus. The implication here is that the reason why NIS and VOC explanations fail to generalize across time and space is that NIS's mid-level institutions & policies, and VOC economic coordination, are endogenous: their technological goals, and their efficiency in achieving these goals, are determined by the ability of broader state structures to resist interest-group capture.

Put simply, more centralized governments are more vulnerable to interest-group capture because they have fewer decision-making points and veto-players to control. Therefore, ceteris paribus, more capture-able centralized governments are more likely to make policies which slow technological innovation.[79] And once made, such policies will be imposed across the entire nation due to the centralized nature of government in these states. But in decentralized states, even if similar policies arise, they can be reversed or overridden by sub-national governments. Good examples of this in the US might be AIDS research during the 1980s or environmental technologies today: in both cases powerful interest groups used their influence over the central government to slow innovation in these areas, but state and city governments were able to evade their influence and provide regulatory or budgetary support for innovation.

What if the central government is strongly pro-technology or captured by pro-technology interest-groups? Centralized government can solve coordination dilemmas that inhibit technological progress, and marshal the economic resources necessary for massive projects such as late-industrialization, space flight, or atomic weaponry. Therefore more centralized government should be good for innovation when powerful interest-groups favor it. Yet even in these cases, decentralized states still have an advantage because the sub-national provinces can act as experimental test beds for different kinds of policies and innovations. And over time, the vulnerability of centralized states to interest-group capture will outweigh any benefits, as new innovations rapidly evolve into status-quo interests and thus a drag on further technological progress. For example, although extreme cases of centralized states, such as the Soviet Union or Fascist Germany, do seem to be able to accomplish significant technological breakthroughs in some areas, these leads were neither sustainable over time nor did technological innovation in these sectors necessarily spillover into other industries.[80] If we tighten our criteria to exclude non-democratic states from consideration, centralized states still appear to trail decentralized states in long-run technological progress, with countries such as Great Britain, which used to lead the world in technological development, trailing behind the more decentralized United States, Germany, and Switzerland during the last fifty years.[81] And while Japan demonstrated a "miraculous" capacity for adaptive innovation during its Cold War catch-up with the West, it failed to innovate at the forefront of subsequent technological revolutions (e.g. software, the Internet, biotechnology) which were pioneered in more decentralized states.

Furthermore, decentralized government has additional characteristics which aid technological innovation beyond those discussed above. For example, there is Hayek's observation that much information which is helpful for economic activity cannot be usefully centralized.[82] Although Hayek was writing about the merits of decentralized markets over central economic planning, the implications for policy are clear. Local policymakers simply have superior information about local conditions than do distant national legislators or bureaucrats, and can therefore design better policy for the local environment. And better policy should mean more efficient allocation of resources towards, and proper incentives for, local innovators. This does not mean that centralized political coordination of any kind is always bad for technological innovation; but as Tiebout has shown, decentralized local public goods production is generally better at reflecting popular preferences than is centralized national public goods

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[79] Drezner 2001.
[80] Starr 1998.
[81] Mokyr 1990.
[82] Hayek 1945.

production.[83] Hence in Tiebout's economy, different sub-national governments provide a menu of different policy environments, which allows different kinds of "consumer-voters" of public goods (here innovators consuming scientific knowledge) to choose the environment that's right for them. So innovators in Massachusetts can use state government funding to pursue stem cell research, while Kansas' more rural and religious taxpayers can instead fund initiatives in agricultural sciences, and California's public universities can focus on alternative energy. In a unitary state, this type of public goods preference matching would not occur as systematically. Finally, decentralization can result in a "Delaware effect" in which sub-national governments compete with one another to attract business investment, and therefore constantly improve the legal, tax, and regulatory environments for innovators.[84] This concept has evolved into Weingast's "market-preserving federalism", in which federalism can prevent government from acting in a predatory manner towards innovators, and allow credible commitments to produce pro-market policies and public goods.[85]

3.5. Scant Empirical Evidence

Yet, despite considerable theoretical support for a relationship between government decentralization and technological innovation, the evidence remains anecdotal. Few scholars have attempted to build an empirical case for it. In separate research programs, Colleen Dunlavvy, Peter Hall, and T.J. Pempel have each tied state structure with technological progress in different case studies.[86] However their linkages are sometimes implicit or indirect, and none of them directly credit decentralization with any specific innovative advantages. Historian William McNeill has attributed China's failed brush with industrialization in the fourteenth century to its centralized governmental command structure.[87] McNeill describes how pockets of market activity developed within the ancient Chinese economy, leading first to rapid technological change, and then to entrepreneurial-based challenges to Imperial political authority. In response, the Chinese political establishment increasingly used its unified command structure to put down these threats, and redirect China's resources away from technological innovation. Although McNeill's brief sketch sounds supportive of the centralization thesis discussed above, the historical research on this period in Chinese history is too sparse to eliminate competing hypotheses, nor does a single case prove a theory.

Perhaps the only direct empirical test of a structure-innovation relationship is that performed by Daniel Drezner, who investigates two bilateral rivalries for technological leadership (UK vs. Germany, Japan vs. US) in separate time periods. Drezner points out that, in both cases, the state with the more centralized government structure fell behind the technological leader, even despite initial success.[88] However, Drezner's number of observations is too small to produce generalizeable conclusions. Nor does he explain why decentralized states such as Australia, Austria, or India have not enjoyed similar technological success to the US or Germany, while many centralized states (such as France, Sweden, Israel, and Finland) innovate at the technological frontier.

3.6 Simple Bivariate Statistical Tests

The purpose of the remainder of this chapter is not to elaborate or test a specific causal mechanism by which government structure might affect national innovation rates. Rather, I ask a more fundamental empirical question here: is there a general relationship between government structure and technological innovation? The causal stories outlined above dovetail with some widely held stereotypes about national differences in innovation. However, little empirical data has yet been produced to verify

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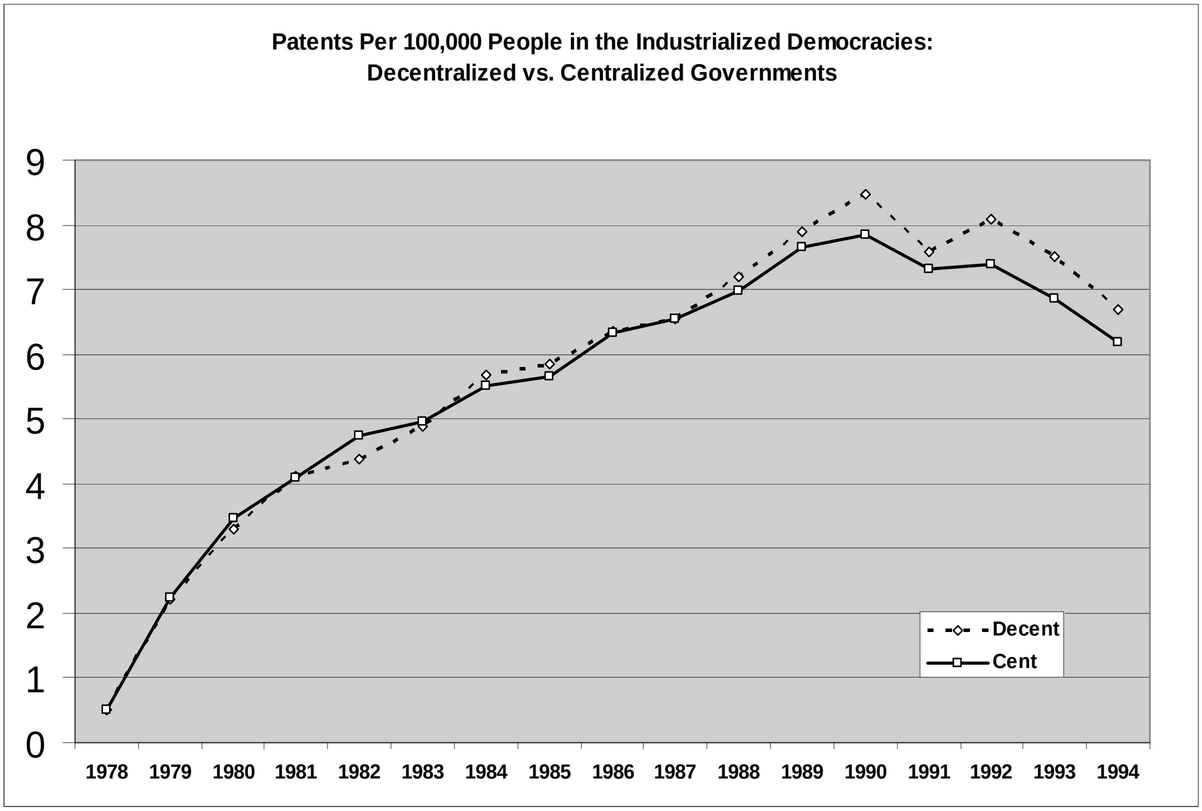
[83] Tiebout, 1956.
[84] Cary 1974. For both the improved information and principal-agent arguments favoring federalism, Oates 1972 is still considered core scholarship.
[85] Weingast, 1995; Qian and Weingast. 1997.
[86] Dunlavy 1994; Hall 1986; Pempel 1998.
[87] McNeill 1982.
[88] Drezner 2001.

the assumption that decentralized states have some sort of comparative institutional advantage that promotes technological innovation. And the empirical data which does exist is either limited to anecdotal evidence and stylized facts, or does not directly bear on the question of innovation rates. Therefore it is unclear whether any government structure-innovation relationship exists in the first place, either in the aggregate or over the long-run.

One fairly straightforward and traditional way to test for such a relationship is to simply compare national patent rates. The results of such a test are presented below in Figure 3.1. Here, using seventeen years of international patent data from the European Patent Office (EPO), the combined per capita patenting activity of the five of the most decentralized industrialized democracies (Australia, Canada, Germany, Switzerland, and the United States) has been plotted alongside that of the five of the most centralized industrialized democracies (Finland, France, Great Britain, New Zealand, Sweden). I do not use any formal measure of decentralization in these comparisons, but have instead selected countries which are widely characterized throughout the literature as being either highly decentralized or centralized. Between 1978-88, the graph reveals no clear innovative advantages to either type of government structure; but from 1989-95 the decentralized states do indeed patent more than the centralized states. However, the gap between the two groups is always less than 10 percent and shows a pattern of reversing itself repeatedly over time, hence there is no way to tell if this apparent patenting superiority of decentralized states is a significant long-run phenomena. Given the prevalence of the "accepted wisdom" about the benefits decentralization for innovation, one would not expect such mild and transitory results.

Figure 3.1: Innovation in Advanced Democracies: Decentralized vs. Centralized States



Source: European Patent Office.[89]

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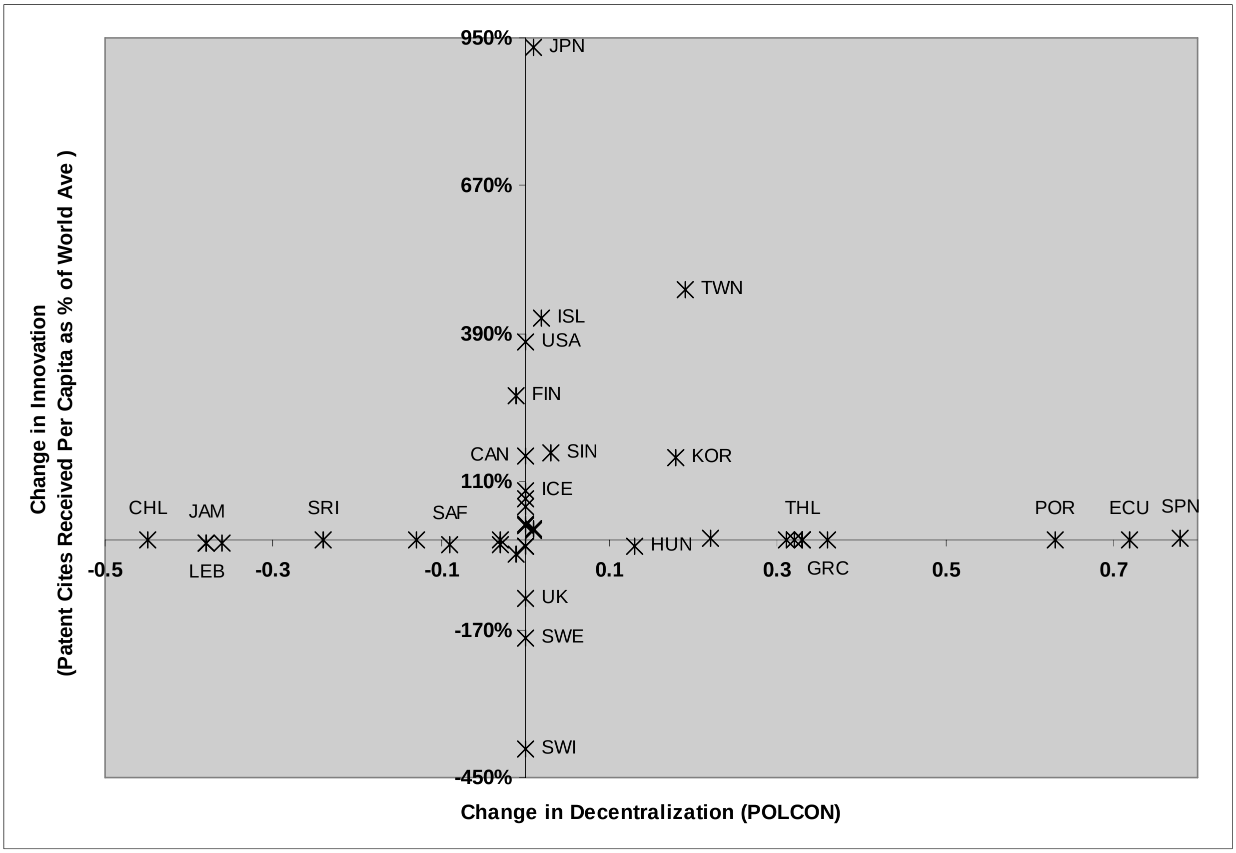
[89] EPO patent data obtained through the cooperation of Thomas Cusak, David Soskice, and Peter Hall. See also Hall & Soskice 2001.

Ideally, one would want to perform a natural experiment, in which observed changes in government structure can be followed by observations of changes in innovative activity, with all other factors held constant. While no empirical situation fits this ideal, we do have a number of cases in which governments have decentralized over time, and where we can also collect some quantitative data on innovative outputs. These are reported in Figure 3.2 (below). This graph plots changes in decentralization versus changes in innovation in the twenty-nine countries which underwent the largest changes in government decentralization from 1975-95. In addition, I also plotted the results for the twenty-five countries with the largest changes in relative innovation rates.[90]

Figure 3.2: Innovation vs. Decentralization in 45 Countries (1975-95)



Source: United States Patent & Trademark Office, NBER (2001)

As my measure of overall decentralization in this graph, I employ the POLCON Index developed by Witold Henisz (U. Penn).[91] The POLCON Index is a 0-1 measure which takes into account the number of independent branches of government with veto power over policy, modified by the extent of party alignment across branches of government and the extent of preference heterogeneity within each legislative branch. The inclusion of party alignment and legislative preferences means that POLCON is not a pure measure of structural decentralization. However, unlike measures which rely purely on formal institutional structure, the POLCON measure allows me to control for states which may be formally decentralized but which may suffer ineffective *de facto* checks and balances. It also provides a finer gauge than the traditional technique of using “dummies”. Moreover, the POLCON index has been shown

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[90] Overlap between the two sets of countries and missing POLCON data for Hong Kong and the Bahamas brings the total number of countries to forty-five.

[91] Henisz 2000.

to be statistically and positively significant in affecting both business investment decisions and technological diffusion in various countries, therefore it is natural to ask whether it holds similar significance for innovation rates.[92]

For my measure of innovation in Figure 3.2, I look at changes in relative innovation rates. Specifically, my measure is a country's change in patent citations received (per capita) as a share of the world average, based on international patent data from the United States Patent & Trademark Office (USPTO).[93] This second database of patents adds value in two ways. First, it provides a separate and independent set of patent data by which to index innovation.[94] Second, forward citations data are available for all USPTO patents granted between 1975-99. Simple patent counts only measure how much innovation is being produced, but weighting patents by their forward citations allow us to control somewhat for the quality, as well as the quantity, of the innovations being patented.

If decentralization is as overwhelming an influence on innovation as is assumed in the literature, then those states which have decentralized the most should enjoy significant improvements in innovation rates. However, as Figure 3.2 reveals, only Taiwan and South Korea appear have experienced significant increases in both variables. Otherwise, the countries that decentralized most (Spain, Ecuador, Portugal, Greece, and Thailand), experienced little change in innovation rates; while the countries which had major shifts in innovative performance (Japan, Israel, Switzerland, US, Finland) underwent little change in government structure. Of course, "decentralization" in many of these countries was more horizontal and informal, and is perhaps better described as a move from autocracy or single-party government towards genuine multi-party democracy. But this is precisely the point: even using the broadest definition and least formal measure of decentralization, it is difficult to find a correlation with innovation.

Using the same measure of innovation, Figure 3.3 selects out those countries with the largest increases in relative innovation rates from 1975-95. The first thing that should strike us here is how little change in relative innovation rates there is at all. Few of the 74 countries sampled registered any significant shift in their relative rankings, and those with less than a 7.5 percent change have been left off of the graph altogether. Secondly, even a cursory examination reveals that the decentralized states appear to have had little innovative advantage over other states, regardless of size or wealth. The decentralized US and Canada both experienced large relative gains in forward patent cites per capita; meanwhile the federalist states of Germany and Switzerland suffered significant relative declines. Amongst the biggest gainers are countries like Japan, Taiwan, Israel, Singapore and South Korea, all relatively centralized states. One major new innovator, Finland, even marginally increased its centralization (as measured by POLCON). But before we credit centralization with this achievement, we must also note that three of the most centralized European states (France, Great Britain, and Sweden) are amongst the largest decliners in relative innovation rates. More interesting is the nation that does not appear in Figure 3.3, Spain, which significantly decentralized by almost any measure one can calculate. Spain's negative change in relative innovative performance (a mere -0.01 percent) is too small to register on this graph, despite the fact that its government continuously decentralized, both horizontally and vertically, formally and informally, throughout the entire time period sampled. Hence, even if I "cheat" by selecting on the dependent variable, I cannot substantiate a relationship between structure and innovation!

Of course, these simple statistical tests do not allow us to simultaneously control for important conditional variables which might also affect innovation rates. These include such factors as overall economic resources, base level of technical development, military spending, and openness to trade. These control variables will be considered in greater detail in the regressions below.

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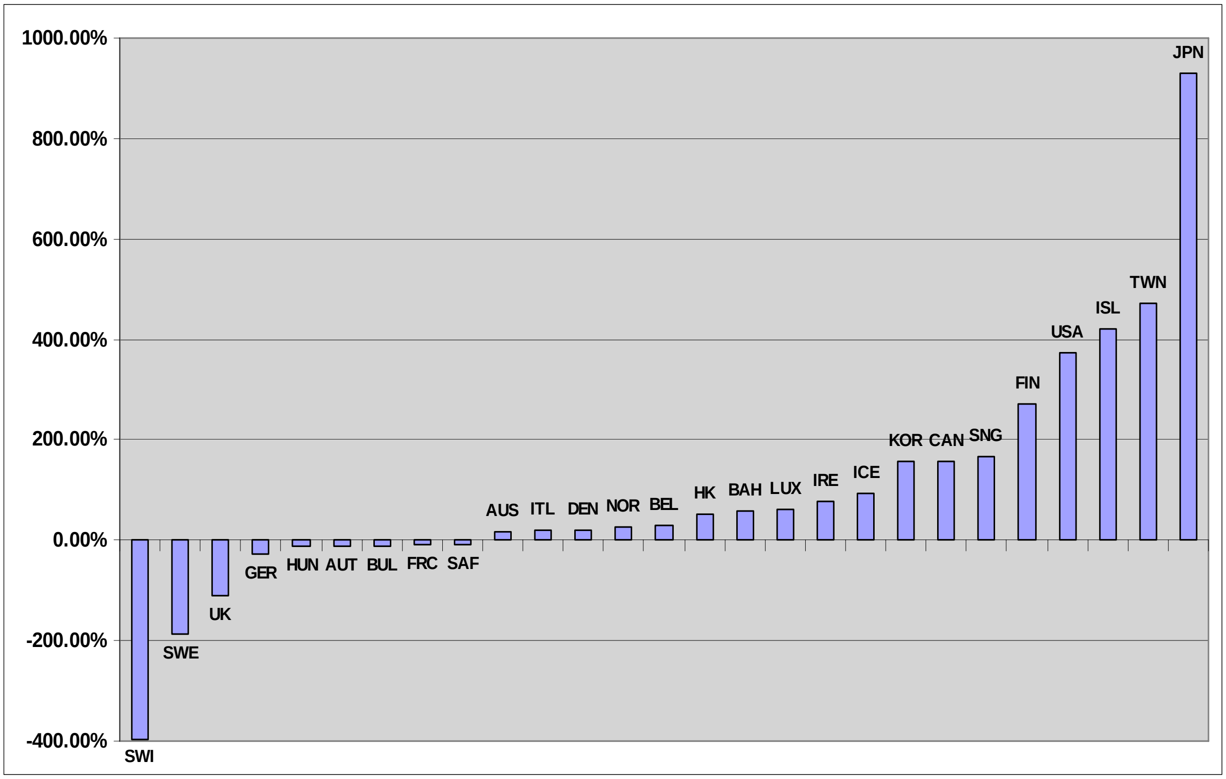
[92] Delios and Henisz. 2000; Henisz 2002; Henisz & Zelner. 2001.

[93] For example: ($[X_{US}/X_{world}]_{t=1990\text{-}1995} - [X_{US}/X_{world}]_{t=1970\text{-}1975}$), where X=forward patent cites/population.

[94] Hall, Jaffe, & Trajtenberg 2001.

Figure 3.3: Change in Patent Cites Received Per Capita as Percent of World Ave. (1970-75 vs. 1990-95)



Note: n=74, countries not shown had a change of <7.5%. Source: United States Patent & Trademark Office, NBER (2001). Countries shown: Switzerland, Sweden, Great Britain, Germany, Hungary, Austria, Bulgaria, France, South Africa, Australia, Italy, Denmark, Norway, Belgium, Hong Kong, Bahamas, Luxembourg, Ireland, Iceland, South Korea, Canada, Singapore, Finland, United States, Israel, Taiwan, Japan.

3.7 Multivariate Statistical Tests

3.7.1. Methods & Data

In order to strengthen my statistical analysis by controlling for additional variables, I turn in this section to multiple regressions. Here again, the goal is not to test a particular strand of theory, since the existing theoretical mechanisms are vague. Rather purpose of the regressions is to find evidence for the existence of an assumed, but unsubstantiated, empirical relationship between government structure and technological innovation in the aggregate. In order to test for the existence of such a relationship, I conduct cross-sectional statistical analysis of innovation rates across some 70 countries during the 1975-95 period.[95] Although setting up the data for time-series cross-sectional regressions would be ideal, the presence of rarely changing independent variables over time would create multicollinearity issues, especially when used with country fixed effects. Therefore I stick with ordinary least squares (OLS), with Huber-White estimates of the standard errors. But since there are significant changes in some of the independent variables during these two decades, I later split the dataset into four consecutive five-year sub-periods and test each separately. And since a lag likely occurs between the activity of innovation and

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[95] Poisson regression is not used because the data neither follows, nor satisfies the assumptions for, a Poisson distribution.

the patent application, I lag the independent variables 1, 5, and 10 years in separate regressions wherever possible.

3.7.2. Dependent Variable: Innovation

In order to triangulate on the dependent variable, I use three independent and distinct measures of innovation: citations-weighted patents (per capita), citations-weighted scientific publications (per capita), and high-technology exports (per GDP). The proper use of patents and publications as quantitative measures of innovation, and the practice of weighting these measures by forward citations as a control for quality, have already been discussed in Chapter 2 (Section 4.2). In this chapter, in order to increase confidence in my results, and to accommodate different perspectives on the phenomena and measurement of technological innovation, I corroborate the regressions of citations-weighted patent and publications data (per capita) with similar regressions of an additional measure of innovation: high-technology exports as a percentage of GDP. High-technology exports as a share of GDP is a measure that allows me to better get at undocumented innovation, while further stressing economically valuable innovative capacity. Of course, some high-technology exports can represent purely locational moves by high-technology firms into low-cost labor countries, but researchers have found this not to be the case in the aggregate or over the long-run. That is, in order for high-technology exports to constitute a significant share of a nation's GDP over several decades, the exporting country must have a meaningful and rapidly improving degree of technological capability.[96]

The patent data comes from the same National Bureau of Economic Research (NBER) Patents Database used in the previous chapter. The scientific publications data comes from a subset of the Thomson-ISI National Science Indicators database and includes data on over 9.4 million articles published in scientific journals by researchers in over 170 countries during 1981-95, and the 164.2 million citations made to these articles during the 1981-2002 period. The high-technology exports data comes from the United Nations *Comtrade* database and consists of trade data on total exports in those industry classes defined by the OECD as "high-technology". This OECD definition of "high technology industries" is based on R&D intensity, and has been used widely by academic researchers and major government institutions for almost two decades.[97] Its sectors include aircraft, spacecraft, pharmaceuticals, office machinery (includes accounting and computing), telecommunications equipment (including radio and television), and medical & scientific instruments.[98]

3.7.3 Independent Variable: Government Decentralization

In order to test the decentralization-centralization hypothesis, various different measures of government structure are used alternately. The first follows the standard convention used by comparativists and consists of dummies for federal systems.[99] Federalism dummies have been used in this manner by researchers to test for links between government structure and macroeconomic performance, corruption, inflation, fiscal responsibility, etc.[100] The second measure is the index of federalism devised by Arend Lijphart (UCSD) which ranks countries on a five point scale (Lijphrt Fed).[101] Note that both the

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[96] Yamashita, 1991; Blomstrom & Wolff 1994; United Nations Conference on Trade and Development 2003.

[97] See OECD 1986, 2003.

[98] Specifically, SITC (rev.2) codes 54, 75, 76, 77, 87, and 792.

[99] In this case the dummies are coded (1 =federal, 0 =non-federal) according to Watts, Ronald L. 1999. *Comparing Federal Systems* Kingston, ONT: McGill-Queens Univ. Press. The dummy federal states include: Arab Emirates, Argentina, Australia, Austria, Brazil, Canada, Germany, India, Malaysia, Mexico, Nigeria, Pakistan, Spain (1978 onwards), Switzerland, USA, Venezuela, and Yugoslavia

[100] Wibbels 2000; Treisman 2000a, 2000b; Escobar-Lemmon 2001.

[101] Lijphart 1999. The twenty-nine countries measured by Lijphart's indices include: Australia, Austria, Belgium, Canada, Columbia, Costa Rica, Denmark, Finland, France Germany, Greece, India, Ireland, Israel, Italy, Jamaica, Japan, Mauritius, Netherlands, New Zealand, Norway, Portugal, Spain, Sweden, Switzerland, Trinidad & Tobago, UK, USA, Venezuela. While Lijphart also provides measure for Bahamas, Barbados, Iceland, Luxemborg, Malta,

dummies and Lijphart ranks are measures of vertical decentralization (federalism) and do not take into account horizontal decentralization. This should not pose a problem for those theories which attribute much or all of the innovative benefits of decentralization to federalism. However, in order to cover all the theoretically possibilities, I also want to test the relevance of horizontal decentralization (division of powers) and total combined decentralization. Again, Lijphart's indices are of use here. Specifically, I alternately sum and average Lijphart's measures of executive dominance (inverse), bicameralism, and judicial review to construct two different measures of horizontal decentralization. I further combine these newly constructed horizontal measures with Lijphart's federalism measure to construct two measures (summed and average) of total decentralization (Sum Lijphrt and Ave Lijphrt).[102] I also experiment with the one of the constructed horizontal measures (Sum Lijphrt Horiz) separately. As a third independent measure of overall decentralization, I employ the POLCON Index discussed above.[103]

3.7.4. Additional Control Variables

The basic question asked here is: given a nation with a particular set of economic resources, at a particular stage of development, does decentralized government somehow result in more technological innovation than does centralized government? Hence the additional control variables I focus on are found in the World Bank's *World Development Indicators* database: *GDP* (to control for the amount of economic resources upon which innovators can draw), and per capita electric power consumption (to control for base-level of economic development).[104] Also, since it is widely assumed that a certain amount of political freedom is required for innovative activity, a measure of Democracy (Polity2, from the Polity IV database) is included.[105] Finally, since the United States is a technological outlier by almost any measure, a US-dummy is added.

The regressions are based on log-log specification, except for the political variables (decentralization and democracy) and those variables expressed in percentages. The estimates are therefore less sensitive to outliers and can be interpreted in terms of elasticities; log-log models are also consistent with much of the prior work in this type of research.[106] This results in a primary regression model along the following lines:

$$\begin{aligned}\text{Ln}(\text{Innovation}_{t=0 \text{ thru } 1}) = {} & B_0 + B_1 * (\text{Govt. Decentralization}_{t=0}) + B_2 * \text{Ln}(\text{Economic Resources}_{t=0}) \\ & + B_3 * \text{Ln}(\text{Level of Econ. Development}_{t=0}) + B_5 * (\text{Democracy}_{t=0}) \\ & + B_6 * (\text{US dummy})\end{aligned}$$

where patenting activity in period t =0 through t=1 is a function of the independent variables at time t =0. The model is identical when publications are used as the measure of innovation. However, when high-technology exports per GDP is the dependent variable, the control for economic resources (log of GDP) is replaced with a control for total population (log of population). This allows me to match the per capita patents and publications regressions as closely as possible.

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and New Guinea, the Polity4 database does not, hence these countries do not appear in the regressions reported below.

[102] E.g *Sum Lijphrt = Lijphrt Fed* + 1/executive dominance (inverse) + bicameralism + judicial review; *Sum Lijphrt Horiz* = 1/executive dominance (inverse) + bicameralism + judicial review

[103] To control for annual fluctuations, I use lagged 4-year period averages of *POLCON* such that, for example, the average *POLCON* 1980-84 index is used when testing patenting during the 1985-90 sub-period.

[104] Per capita electric power consumption (kilowatt-hours per capita) makes theoretical sense as an indicator of development for the time period under consideration since the more developed a country is, the more its populace will conduct electricity-based activities. It also correlates well empirically with other development measures, specifically GDP per capita and lagged innovation, either of which produce high variance inflation factors (and hence high multicollinearity) when used alongside GDP.

[105] Marshall, Jaggers, & Gurr 2003.

[106] Furman, Porter, & Stern 2002; Jones 1998.

This model will doubtless arouse some criticism for its narrow approach. Economists, sociologists, and policy-analysts often take a more encompassing view when performing statistical analysis of innovation at the national level, and include a myriad of policy variables, financial controls, and education measures alongside the primary independent variables of interest. Given the large potential number of causal lines feeding into national innovation rates, this temptation is understandable. Why not control for, say, education spending or those factors identified by Furman, Porter, & Stern (2002) as contributing to national innovative capacity?[107] The answer is that this approach would be atheoretical. Recall that these mid-level institutions and policies are exactly those studied by NIS scholars, and the theory tested here holds that they are either endogenous to government structure, or are overwhelmed by their causal effects. Also, some of the policy or mid-level political institutions mentioned in the economics literature as affecting innovation appear to be driven by anecdotal observations or poorly developed political theory. Since adding control after control to a regression model can blur into data-mining, I prefer here to adhere as closely as possible to core theoretical assumptions and widely reported observations.

Nonetheless, in some regressions, I do experiment with controls for three variables which are specifically cited by NIS scholars as important causal factors, and which are arguably not endogenous to government structure. First, openness to trade (defined as exports plus imports as a share of GDP) is generally considered to provide competitive motivation for long-run innovation.[108] Second, military spending is too considered by many to be a major source of technological progress, and is included in the regressions as a percentage of gross national product.[109] Third, natural resources are considered an obstacle to innovation, “cursing” otherwise innovative countries into a cycle of dependence on exports of oil, metals, raw materials, and agricultural products.[110] I therefore experiment with three alternate measures of natural resource base (as a percent of total, alternately: arable land, fuel exports, or metal/ore exports) in my regressions.[111]

3.7.5 Regression Results

The first and most important finding of the regressions is that government decentralization is consistently insignificant. With but a single exception, no regression yielded a significant coefficient for any measure of decentralization used in any combination with any of the innovation measures or conditional variables. This result occurred regardless of the time period tested, the measure of decentralization used, the conditional variables included, and whether patents, publications, or high-technology exports were employed as the regressand. Representative results of the main set of regressions are tabulated in Tables 3.1 and 3.2.

The lone case in which the null hypothesis can be rejected occurs when I sub-divide countries by wealth, but here the affect is fairly small (Table 3.3). In this case, regression analysis suggests that decentralization may foster innovation, but only for one measure of decentralization, and only when the dataset is constrained to a small subset of wealthy countries. Here a 0.1 increase in the POLCON scale is associated with a 33.6 percent increase in patent citations, 12.8 percent rise in publication citations (for OECD members), and a 0.003 percentage point rise in high-technology exports per GDP (for high GDP-per-capita countries). Note however that the mean POLCON score for either sub-group of wealthy

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[107] Furman, Porter, & Stern 2002.

[108] Daniels 1997; Grossman & Helpman. 1995, 1991; data source for regressions is World Bank 2002.

[109] Smith 1985; McNeil 1982; data source for the regressions is United States Arms Control and Disarmament Agency 1975-1996.

[110] Ross 1999; Sachs & Warner 1995; Gelb 1988.

[111] World Bank 2002.

Table 3.1: Primary Regressions of Technological Innovation (1975-95)

	DV = Log of Patent Citations Received Per Capita					DV = Log of Pub Citations Received Per Capita					DV = High-Tech Exports as % of GDP				
	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5
Sum Lijphrt	-0.01					0.01					0.00				
	[0.07]					[0.06]					[0.001]				
Ave Lijphrt		-0.03					0.03					0.00			
		[0.27]					[0.22]					[0.004]			
Lijphrt Fed			0.06					0.09					-0.003		
			[0.15]					[0.13]					[0.004]		
Sum Lijphrt Horizntl			-0.06					-0.07					0.002		
			[0.12]					[0.09]					[0.004]		
Federalism Dummies				-0.36					-0.25					0.004	
				[0.34]					[0.26]					[0.01]	
POLCON					1.13					0.38					-0.02
					[1.07]					[0.64]					[0.05]
Log GDP	**0.42**	**0.42**	**0.43**	**0.32**	**0.29**	0.14	0.14	0.16	**0.18**	**0.16**					
	[0.15]**	**[0.15]****	**[0.16]****	**[0.11]****	**[0.11]****	[0.12]	[0.12]	[0.12]	**[0.08]***	**[0.08]***					
Log Popultn											-0.001	-0.001	-0.001	-0.003	-0.002
											[0.003]	[0.003]	[0.004]	[0.004]	[0.003]
Log KwH/cap	**1.59**	**1.59**	**1.55**	**1.33**	**1.26**	**1.30**	**1.30**	**1.25**	**1.09**	**1.07**	0.004	0.004	0.005	0.004	0.006
	[0.31]***	**[0.31]*****	**[0.36]*****	**[0.17]*****	**[0.19]*****	**[0.22]*****	**[0.22]*****	**[0.21]*****	**[0.09]*****	**[0.11]*****	[0.003]	[0.003]	[0.003]	[0.003]	[0.007]
Democracy	**0.13**	**0.13**	**0.13**	0.05	0.02	0.02	0.02	0.02	**0.03**	0.02	0.001	0.001	0.001	0.00	0.001
	[0.03]***	**[0.03]*****	**[0.03]*****	[0.03]	[0.04]	[0.02]	[0.02]	[0.02]	**[0.02]***	[0.02]	[0.001]	[0.001]	[0.001]	[0.001]	[0.001]
US Dummy	-0.13	-0.13	0.03	**0.98**	0.71	-0.54	-0.54	-0.33	-0.01	-0.17	-0.009	-0.009	-0.02	-0.01	-0.01
	[0.59]	[0.59]	[0.68]	**[0.44]***	[0.42]	[0.45]	[0.45]	[0.52]	[0.32]	[0.3]	[0.01]	[0.01]	[0.01]	[0.01]	[0.01]
constant	**-31.1**	**-31.1**	**-30.7**	**-25.9**	**-25.0**	**-16.6**	**-16.6**	**-16.2**	**-16.0**	**-15.5**	0.002	0.002	-0.01	0.04	0.03
	[2.51]***	**[2.51]*****	**[2.74]*****	**[2.36]*****	**[2.34]*****	**[2.23]*****	**[2.23]*****	**[2.45]*****	**[1.76]*****	**[1.83]*****	[0.07]	[0.07]	[0.06]	[0.05]	[0.04]
R-squared	0.86	0.86	0.86	0.83	0.83	0.79	0.79	0.80	0.81	0.82	0.09	0.09	0.11	0.03	0.04
max VIF	1.93	1.93	2.5	2.2	4.15	1.93	1.93	2.50	2.17	4.02					
# obs	28	28	28	70	69	28	28	28	74	73	28	28	28	78	76

Note: Analysis is by ordinary least squares (OLS), Huber-White estimates of standard errors reported in brackets. All independent variables are 1974 values, all dependent variables are overall value of the 1975-95 period. *p< .05, **p< .01, ***p<.001

Table 3.2: Secondary Regressions of Technological Innovation (1975-95)

	DV = Log of Patent Citations Received Per Capita					DV = Log of Pub Citations Received Per Capita					DV = High-Tech Exports as % of GDP				
	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5
Sum Lijphrt	-0.03					0.02					-0.0001				
	[0.06]					[0.05]					[0.001]				
Ave Lijphrt		-0.13					0.08					-0.003			
		[0.24]					[0.19]					[0.003]			
Lijphrt Fed			0.03					0.06					-0.003		
			[0.12]					[0.1]					[0.004]		
Sum Lijphrt Horizntl			-0.09					-0.02					0.001		
			[0.13]					[0.08]					[0.003]		
Federalism Dummies				-0.25					-0.08					0.007	
				[0.35]					[0.25]					[0.01]	
POLCON					1.32					0.93					-0.02
					[0.99]					[0.65]					[0.03]
Log GDP	0.65	0.65	0.68	0.38	0.35	0.09	0.09	0.1	0.2	0.18					
	[0.20]**	[0.20]**	[0.23]**	[0.12]**	[0.12]**	[0.12]	[0.12]	[0.13]	[0.08]*	[0.08]*					
Log Popultn											0.005	0.005	0.005	0.02	0.02
											[0.002]*	[0.002]*	[0.003]	[0.004]***	[0.004]***
Log KwH/cap	1.27	1.27	1.21	1.22	1.14	1.38	1.38	1.34	1.01	0.94	0.003	0.003	0.004	0.0003	0.002
	[0.33]**	[0.33]**	[0.40]**	[0.16]***	[0.18]***	[0.23]***	[0.23]***	[0.26]***	[0.1]***	[0.11]***	[0.003]	[0.003]	[0.003]	[0.003]	[0.004]
Democracy	0.12	0.12	0.12	0.05	0.01	0.03	0.03	0.03	0.04	0.02	0.0005	0.0005	0.0005	0.0004	0.0009
	[0.03]**	[0.03]**	[0.03]**	[0.03]	[0.04]	[0.02]	[0.02]	[0.02]	[0.01]**	[0.02]	[0.0004]	[0.0004]	[0.0005]	[0.0006]	[0.0006]
US Dummy	0.33	0.33	0.52	1.28	1.07	-0.44	-0.44	-0.32	0.01	-0.09	0.003	0.003	-0.003	0.0009	0.007
	[0.52]	[0.52]	[0.64]	[0.49]*	[0.47]*	[0.52]	[0.52]	[0.55]	[0.34]	[0.31]	[0.01]	[0.01]	[0.01]	[0.01]	[0.009]
Miltry Spnding	0.08	0.08	0.07	-0.01	0.003	0.07	0.07	0.07	0.05	0.06	0.0002	0.0002	0.0002	-0.0009	-0.001
	[0.02]**	[0.02]**	[0.02]**	[0.05]	[0.05]	[0.01]***	[0.01]***	[0.01]***	[0.025]*	[0.02]*	[0.0005]	[0.0005]	[0.0004]	[0.0007]	[0.0006]
Trade per GDP	0.02	0.02	0.02	0.01	0.01	0.008	0.008	0.008	0.007	0.007	0.0005	0.0005	0.0005	0.001	0.001
	[0.01]*	[0.01]*	[0.01]*	[0.003]**	[0.003]***	[0.007]	[0.007]	[0.007]	[0.003]**	[0.002]**	[0.0002]*	[0.0002]*	[0.0002]*	[0.0003]***	[0.0002]***
Arable Land	-0.001	-0.001	-0.002	0.01	0.02	0.03	0.03	0.02	0.01	0.02	0.0002	0.0002	0.0002	0.00	-0.0001
	[0.01]	[0.01]	[0.02]	[0.01]	[0.01]	[0.01]**	[0.01]**	[0.01]**	[0.01]	[0.01]	[0.0001]	[0.0001]	[0.0002]	[0.0002]	[0.0002]
_cons	-35.8	-35.8	-35.6	-27.5	-26.7	-17.3	-17.3	-17.2	-16.8	-16.4	-0.12	-0.12	-0.12	-0.30	-0.31
	[3.33]***	[3.33]***	[3.47]***	[2.78]***	[2.73]***	[2.06]***	[2.06]***	[2.09]***	[1.84]***	[1.91]***	[0.05]*	[0.05]*	[0.05]*	[0.08]***	[0.07]***
R-squared	0.92	0.92	0.93	0.85	0.86	0.91	0.91	0.91	0.85	0.86	0.30	0.30	0.31	0.70	0.71
max VIF	4.01	4.01	4.23	2.89	4.91	4.01	4.01	4.23	2.84	4.76					
# obs	28	28	28	68	67	28	28	28	72	71	28	28	28	70	69

Note: Analysis is by ordinary least squares (OLS), Huber-White estimates of standard errors reported in brackets. All independent variables are 1974 values, all dependent variables are overall value of the 1975-95 period. *p< .05, **p< .01, ***p<.001

countries is around 0.7, with a maximum of 0.88 and a standard deviation of ~0.25. Hence the effect of POLCON on innovation, while statistically significant, is not very large. And interestingly, neither centralization nor decentralization appeared to affect the pace of technological change in non-wealthy countries, by any measure. These results are discussed further below.

The coefficients of the other independent variables should be interpreted with caution. Since the regressions presented here were designed specifically to test the relationship between decentralization and innovation, firm conclusions cannot be drawn from them about the other independent variables. I therefore prefer to treat them as hypotheses in need of further direct testing.

One of these tentative findings is that trade matters. Trade as a percentage of GDP is significant and positive in most regressions that include it as an independent variable, and across each measure of innovation. The coefficients suggest that, cross-nationally, a 10 percent increase in trade as a percentage of GDP is associated with a 10-20 percent increase in citations-weighted patents per capita, a 7-8 percent increase in citations-weighted publications per capita, and a 0.005-0.01 percentage point increase in high-technology exports as a percent of GDP. The relatively larger effect of trade on patenting could reflect a greater concern for intellectual property protection by trading nations. Also the seemingly small effect of trade openness on high-tech exports is not quite so minor when we realize that the sample mean for high-tech exports per GDP is only 0.023 percent (with a standard deviation = 0.056 percent). Overall, this finding that trade-openness fosters innovation dovetails with much of the trade-innovation literature, and I view it as an additional piece of confirmatory evidence to that debate.[112]

A second tentative finding is that level of development matters for innovation. The per capita development measure carried high levels of significance and large coefficients in every patents or publications regression which included it as an independent variable. In simple bivariate regressions with either patents or publications as the dependent variable, logged KwH per capita accounted for over 72 percent of the variance (though this dropped to 10 percent when high-technology exports was used as the measure of innovation). This makes level of development a likely suspect as a primary source of the high R^2's in the multiple regressions of patents and publications.[113] Of course, high multicollinearity amongst the regressors might also be to blame. In order to test this, the variance inflation factors (VIF's) were calculated and the highest individual VIF is reported for each regression with an R^2 of 0.75 or above.[114] The low VIF's suggest that high multicollinearity is not a problem. Substitution of GDP per capita as the development measure yielded no significant differences in the results reported. Nor do these coefficients change significantly across different regression models. Where high-technology exports are concerned, level of development does not seem to be significant. This could reflect both the rise of less developed innovators such as South Korea, Taiwan, and Ireland, as well as the out-sourcing of high-technology manufacturing by Western firms to Southeast Asia and Eastern Europe during the 1980s and 1990s. Hence you do appear to need to be developed in order to patent and publish, but not necessarily to make your economy a hub for high-technology exports.

Likewise GDP carried high levels of significance in many of the regressions which included it as an independent variable. However, these coefficients were at best only half as large as those for economic development. This implies that a percentage change in the size of the economy has only half the effect on innovation of a percentage change in economic development.

There are a few other results worth noting. Interestingly, democracy is significant in for a minority of the regressions, a subset of those involving patents or publications. And the coefficients for democracy are very small, implying a mere 3-13 percent increase in patents or publications for a full 1-

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[112] Grossman & Helpman 1991; Dosi, Pavitt, & Soete 1990.

[113] Simple bivariate regressions of innovation on logged GDP per capita (as an alternate development measure) produced results nearly identical to those on logged electricity consumption per capita. For comparison, I further note the next highest R^2's for the simple bivariate regressions of patents or publications are found on logged GDP (0.34) or democracy (0.39).

[114] According to Klein's rule, when an individual variable's VIF is greater than $1/(1-R^2)$ of the overall regression then problematic multicollinearity may exist. See Klein 1962; Green 2000.

point increase on the Polity IV scale. Second, the effect of military spending on both patents and scientific publications stands out across many of the regressions. The coefficients suggest that a 10 percent increase in military spending is associated with 70-80 percent increase in citations-weighted patents and a 50-70 percent increase in citations-weighted publications. Whether this reflects direct military research or a more nuanced correlation between security and innovation is unclear, and requires further investigation.

Also, various different measures of natural resource base were experimented with producing mixed results. Arable land as a percentage of total occasionally had an unexpected positive association with innovation, but either fuel exports or metals exports (as a percentage of total exports) occasionally had a negative association with innovation. While this finding may become the subject of future research, it does not cause problems here; no measure of natural resource base affected the significance of government structure, nor did omitting the measure altogether have any substantive affect on the regression results.

Finally, various lagged measures of the dependent variable (citations-weighted patents citations, simple & per capita) were experimented with in each of the regressions, but with little change in the results except to drive up the variance inflation factors to more worrisome levels. And since a high correlation (r = 0.87) exists between lagged innovation and electric power consumption, it was felt that the latter measure sufficiently captured the control one would seek in the former. This also allows me to avoid many of the methodological and interpretational problems surrounding lagged dependent variables.[115]

One possible explanation for the null results reported for government structure is that decentralization may take time to have its effect on technological innovation. After all, in order for government structure to affect the conditions and incentives for innovation, it must first alter the political, economic, and policy environments within which innovators operate. This might take several election or business cycles to be realized in full. In order to test this possibility, I used the 1974 values for my independent variables and regressed the later five-year sub-periods of innovation on them (1975-80, 1980-85, 1985-90, 1990-85). These regression results closely resemble those for the entire time period, though interestingly with generally larger coefficients for GDP and (for patents) smaller coefficients for level of development. Hence economic size seems to affect innovation more strongly over longer time-periods, development less so. Also, military spending in these regressions appears significant for both patenting and publishing across all models tested, while arable land appears significant in many models. But each of these findings is peripheral to my main concern with decentralization. The fact remains that, even after a decade or two, government structure is still insignificant for innovation rates regardless of the model tested. This dovetails with what we saw in Figures 3.2 and 3.3 above: countries which increased their decentralization during the 1975-95 period did not appear to improve their innovative performance. Admittedly, this test only covers a 15-20 year time lag, therefore I must remain agnostic as to the effects of decentralization over longer periods of time.

A second alternate explanation for the null results above is that decentralization might benefit innovation in the advanced economies, while centralization might help lesser developed countries in Gerschenkronian fashion.[116] That is, with their luxury of having the advanced economies as models, backward economies may benefit more from a powerful central authority that can force actors down a well-trodden economic path towards technological development. Conversely, this kind of centralized power might be a handicap for the advanced economies, which by nature of their position at the economic frontier must find their way forward more by experiment than by government direction. I experiment with two tests for this hypothesis, and the results merit further study. First I split the data into OECD and non-OECD subgroups and re-ran the regressions above. Second I repeated this exercise, instead splitting the data into “wealthy” and “non-wealthy” subgroups, where “wealthy” is defined as being in the top 10

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[115] Achen 2000; Kelly 2002; Keele & Kelly 2006.

[116] Gerschenkron 1962.

percent of GDP per capita.[117] In both instances, the POLCON measure showed small but positive and significant coefficients, but not any of the other decentralization measures. It is possible that this result is due to selection bias based on the small and overlapping samples. Alternately, it may suggest that not only does decentralization matter for wealthy countries, but that informal decentralization (which only the POLCON measure captures) may be more important than structural decentralization. In other words, structural decentralization does not matter if all actors in the structure belong to the same political party and have similar political-economic preferences. (extent of party alignment across branches of government and the extent of preference heterogeneity within each legislative branch).

Table 3.3: Regressions of Technological Innovation in Rich Nations (1975-95)

	Dependent Variable:					
	Pat Cites	Pub Cites	HT Exprts	Pat Cites	Pub Cites	HT Exprts
OECD Member	X	X	X			
Wealthy Country				X	X	X
POLCON	**3.36** **[0.76]*****	**1.28** **[0.55]***	0.05 [0.028]†	**3.36** **[0.52]*****	0.95 [1.04]	**0.03** **[0.009]***
Log GDP	**0.46** **[0.11]****	0.23 [0.17]		**0.58** **[0.12]****	0.45 [0.34]	
Log Popultn			-0.003 [0.006]			0.0003 [0.002]
Log KwH/cap	**1.14** **[0.41]***	**0.75** **[0.29]***	-0.01 [0.01]	**2.11** **[0.53]****	0.35 [0.95]	**0.016** **[0.007]***
Democracy‡						
US Dummy	-0.23 [0.47]	-0.42 [0.50]	0.0004 [0.017]	**-1.52** **[0.64]***	-0.73 [1.41]	**-0.02** **[0.009]***
Constant	**-29.9** **[4.99]*****	**-15** **[4.59]*****	0.14 [0.17]	**-40.6** **[6.51]*****	-17.3 [11.4]	-0.14 [0.06]
R-squared	0.89	0.62	0.19	0.94	0.5	0.66
max VIF	1.96			1.86		
# obs	24	24	23	12	12	11

Note: Analysis is by ordinary least squares (OLS), Huber-White estimates of standard errors reported in brackets. All independent variables are 1974 values, all dependent variables are overall value of the 1990-95 period.
† p<.10, *p< .05, **p< .01, ***p<.001, ‡ omitted due to high multicollinearity.

3.7.6 Potential Problems

The regressions reported here do have drawbacks which somewhat restrict, but by no means eliminate, their usefulness as tests of the government structure-innovation relationship. First, a need to conserve degrees of freedom prevents me from adding country and year fixed effects. The concern over country fixed affects is somewhat ameliorated by the fact that other researchers have used pure fixed-effects models in regressions on patent data, and produced results which show no significant innovative differences between decentralized and centralized states.[118] Likewise, the separation of the dataset into

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[117] The "wealthy" countries for the period starting 1975-1995 include: Austria, Belgium, Denmark, France, Japan, Kuwait, Netherlands, Sweden, Switzerland, United Arab Emirates, United States.
[118] Taylor 2004.

temporal subperiods should mitigate some of the concerns over year fixed effects. Also, it is tempting to suspect that endogeneity may be at play. However there currently exists neither theoretical justification nor empirical evidence to suspect that somehow technological change affects government structure. Nor is there reason to suspect that an uncontrolled variable affects both government structure and innovation.

Second, at least two scenarios were not tested here. Non-linear relationships were not tested for lack of sufficient data. For example, there may be diminishing returns to decentralization such that extremely decentralized or centralized governments may hinder innovation, but that a happy medium exists. A second possibility is that diminishing returns may occur over time. The Spanish case and the subdivision into of time periods would seem to rule out this possibility. However, to be fair, one could theorize a situation whereby decentralization might result in few gains in innovation as the country initially moves to a new political-economic equilibrium, followed by a rapid increase in innovation as the new structural incentives take hold, and then diminishing returns after the new equilibrium solidifies. In other words, although the assumption of a simple linear relationship between government structure and innovation can now be seriously called into question, this does not eliminate the possibility of a more complex model.

While these issues reveal the limitations of statistical analysis in testing the government structure-innovation relationship, they do not invalidate the results reported here. Certainly, the results produced above are robust enough to allow us to question the hypothesized innovative advantages of government decentralization. They also point to the importance of case studies as the next step in research on this question. Case studies are important for resolving whether there are truly no significant lines of causality between government structure and innovation, or whether wealth and government structure might interact to affect the policy environment for innovators; whether broad structural forces exist but are obscured or overwhelmed by other factors, or are conditional on some omitted variable. Case studies would also allow us to go beyond patent data, and judge with greater scrutiny the pace and degree of innovation being performed. Of course, such case studies should be careful to fully randomize across technologies, and to maximize variation across cultures and time periods, in order to compensate for the constraints of small-N analysis.

3.8 Conclusions and Implications

In sum, I have examined two separate sets of patent evidence, along with data on scientific publications and high-technology exports, and found that, contrary to the conventional wisdom, decentralized states are generally no more technologically innovative than centralized states. The only exception to this finding was a minor effect, which appeared only amongst a small subset of wealthy countries and only when using the broadest measure of decentralization. Of course no single statistical test or dataset is by itself conclusive, but the compounding of the several alternate measures and methods used above establishes a firm basis for questioning the accepted wisdom that decentralization leads to higher innovation rates.

Perhaps most provocative were the secondary findings, such as the relatively minor influence of democracy, and relatively large effect of lagged military spending, on innovation over time. These results deserve some attention in future research since they contradict much of the endogenous-growth literature which puts a heavy emphasis on civilian democratic institutions for explaining long-run innovation-driven economic growth and efficiency. It suggests that, rather than being a natural product of institutional reform, innovation could instead be a rational solution to a perceived security problem. In other words, long-run technological innovation may find better explanations in international relations theory rather than comparative political institutions. This is an aspect almost totally ignored by the economists and sociologists who study innovation, and deserves greater attention from political scientists. Of course it is important not to get ahead of ourselves here, since the various tests reported here were not specifically designed to examine causal relationships between democracy and innovation. A useful next step in testing, therefore, would be for researchers to conduct in-depth qualitative analysis of individual technological case studies in order to confirm and refine each of the findings above.

Chapter 4

International Relationships and Technological Innovation

4.1 Introduction

In this chapter it will be argued that international relationships may be the missing piece to the national innovation rate puzzle. I note that anecdotal observations, both from my own research and within the evidence provided by domestic institutionalists, suggests that certain kinds of international relationships might have a role in determining national innovation rates. In order to test this possibility, regression analysis will be performed on various measures of innovation, domestic institutions, and international relationships. These regressions suggest that certain kinds of international relationships (e.g. capital goods imports, foreign direct investment, educational exchanges) with the lead innovator (the United States) strongly affect countries' innovation rates, even when controlling for domestic institutions. In other words, explaining national innovation rates is not so much a domestic institutions story as it is an international story.

4.2 Anecdotal Observations

Thus far I have shown how none of the dozens of NIS institutions or policies explain national innovation rates across time and space, nor does VOC economic coordination, nor political decentralization; however, an interest in international relationships as an explanatory variable emerges out of anecdotal observations generated by some of this research. For example, in Chapter 2, the statistical analysis of the VOC theory of technological innovation consistently pointed to the United States as an important factor in explaining global patterns of innovation. It was also observed that many of the world's most innovative countries are those which also tend to have the strongest military and economic ties with the US, including Japan, Canada, the UK, Israel, and Taiwan. My prior research on comparative innovation rates in East Asia also revealed the importance of linkages between international relationships and innovation, though specifically in the cases of Japan vis-a-vis the US during the Cold War, and Southeast Asia vis-a-vis Japan during the mid-1980s through mid-1990s.[119] Might these anecdotal observations be indicative of a more general causal relationship?

There are also strong indications of an important role for international relationships within the empirical evidence put forward by domestic institutionalists.[120] For example, although Alice Amsden emphasizes institutional explanations in her studies of industrialization in East Asia, her evidence also consistently reports the vital role of foreign technical assistance in helping South Korea, Taiwan, China, etc. to approach the technological frontier. Similarly, in a 2000 collection of case studies on innovation in the developing world assembled by lead NIS researcher, Richard Nelson, scholars repeatedly mentions the importance of joint ventures, contacts with foreign suppliers and consumers, and other forms of international contacts.[121] Meanwhile, atheoretical histories of technological development and industrialization in 18th, 19th, and 20th century Europe and the United States are replete with instances of national innovation rates being affected by international relationships.[122] And this phenomenon is not necessarily limited to technological catch-up by lesser developed states, since even advanced industrialized nations seem to benefit technologically from ties to lead innovators.[123]

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[119] Taylor 1995.

[120] Amsden 1989, 2001; Amsden & Chu 2003; Yamashita 1991.

[121] Kim & Nelson 2000.

[122] Jeremy 1991; Cowan 1997.

[123] Nobel & Birkinshaw 1998; Keller 2004; Cantwell 1995.

Together, these observations suggest that in order to better understand the political economy of comparative rates of innovation, research should perhaps focus less on domestic institutions and more on international relations. This is not to argue that domestic institutions are insignificant, but rather that the scope and depth of a country's relationship with the lead innovator may also carry significant weight in determining its technological profile. Therefore factors such as those listed below in Figure 4.1 between the lead innovator and other countries should be explored for their effects on innovation.

Figure 4.1: International Relationships Important for National Innovation Rates

- **overseas training & education in science-engineering**
- **use of foreign consultants & technical assistance**
- **overseas plant visits**
- **consultations with foreign capital goods & high technology suppliers/consumers**
- **inward FDI in production and R&D facilities from more advanced countries**
- **mergers & acquisitions**
- **joint R&D projects**
- **immigration of scientists, engineers, and highly skilled labor**
- **establishing R&D facilities in high-tech countries**
- **attendance to international expositions, conferences, & lectures**
- **technology licensing**
- **imports of capital goods & high technology products**

4.3 Methods and Data

If the international relationships listed in Figure 4.1 are important for explaining differences in national innovation rates, then their effects should be evident in the empirical data. That is, countries with more of the international relationships such as in Figure 4.1, and higher levels of them, should be observed to innovate relatively more than countries that are less well connected, regardless of the quality of their domestic institutions. In order to test for this in the empirical data, we turn in this section to regression analysis of empirical data on national innovation rates, international relationships, and domestic institutions.

The goal here is to find evidence for, or against, the existence of a causal relationship between the international relationships and long-run national innovation rates. More importantly, we want to see if such a relationship holds even when we control for the quality of domestic institutions. In order to test for the existence of such an IR-innovation relationship, I conduct ordinary least squares regression analysis of innovation rates across several dozen countries during the 1980-1995 period. The OLS regressions are conducted on three consecutive five-year sub-periods (1980-1985, 1985-1990, 1990-1995).[124] And since a time lag may occur between the activity of independent variables and their effects on innovation rates, I lag my independent variables 1, 5, and 10 years in the OLS regressions wherever possible.

4.3.1 Dependent Variable: Innovation

As my measure of innovation, I continue the practice established in prior chapters of using citations-weighted patents (per capita). The patent data comes from the same National Bureau of

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[124] Scholars who specialize in the empirical measurement of innovation report that patent and publication measures suffer increasing construct-validity problems when they are disaggregated into smaller time and space units. That is, patent and publications data are acceptable measures of innovation when used in the aggregate (e.g. as a rough measure of national levels of innovation across long periods of time), but are not appropriate when used as a measure of micro-level innovation (e.g. to compare the innovativeness of individual firms or specific industries from year to year). While my aggregation of patent and publication data at the national level certainly meets these requirements, annual comparisons of these national innovation rates may not. Rather, five-year aggregates provide more reliable estimates of relative national innovation rates.

Economic Research (NBER) Patents Database used in previous regressions.[125] For those scholars who remain skeptical of citations-weighted patents as a measure of innovation, I also corroborated the results reported below with regression using as its measure of innovation: a factor analysis of three independent and distinct measures of innovation: citations-weighted patents (per capita), citations-weighted scientific publications (per capita), and high-technology exports (per GDP).

4.3.2 Independent Variables: International Relationships

Unfortunately, there is no single variable which captures the myriad international relationships listed in Figure 4.1. Also, different countries appear to have different combinations of international relationships with the lead innovators. For example, discussions of innovation in Japan have highlighted that country's reliance on the reverse-engineering of imports, licensing, and the use of foreign consultants;[126] while Israel has depended heavily on the immigration of scientists and high-skilled labor;[127] and many Finnish firms prefer to establish ties with major foreign research universities.[128]

While this diversity of transfer mechanisms handicaps empirical research, we can as a "first cut" look at some of the most likely, and best measured, indices of international relationships to see if there is any macro-level evidence at all to support an international relationships hypothesis of technological change. These measures include (each vis-a-vis the United States): graduate students sent to study science or engineering in US universities, imports of capital goods from, inward FDI received from, and outward FDI into the US. Clearly, these measures only capture an imperfect subset of the many international relationships listed in Figure 4.1, and therefore the results should be interpreted as a step in a larger research program. But they are worth examining since they should be amongst the most likely to provide evidence for, or against, an international relationships mechanism of technological change.[129]

Also, each of these measures focuses specifically on countries' relationships with the lead innovator, the United States. Although this is done primarily for purposes of data availability and cost, it also has several desirable properties. First, the international relationships described in the last section should ideally be geared towards relatively more innovative countries, preferably the lead innovator. In other words, Mexico (or any other country) should gain far more by establishing multiple strong ties with the world's lead innovator as opposed to creating these same ties with say Spain. Second, by limiting some of our observables to relationships with the US we actually strengthen the test of these relationships. For example, Mexico sends its students to study science and engineering in US, Spain, Britain and several other advanced countries. Ideally we would want data on all of these student flows. And by restricting measurement of student flows to those destined only for the US, I create a potential bias *against* finding evidence supporting an international relationships hypothesis, and thus a stronger test.[130] On the other hand, focusing only on relationships with the US also introduces the possibility of selection bias: there may be some variable specific to US relations which affects national innovation rates. Note that this would not nullify a positive finding of the significance of international relationships, but rather particularize it to the US. Such a hypothesis is theoretically intriguing, but beyond the scope of this paper and will be more fully developed in future research.

As for the specific observables used to measure international relationships, first I use science and engineering PhD's awarded by United States' graduate schools to foreign students. This data is collected annually by the National Science Foundation in their Survey of Earned Doctorates (SED).[131] Second, I use United Nations on imports of capital goods, which Alice Amsden emphasizes as being important for

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[125] Although data availability for some independent variables may limit the number of countries considered in each regression, the remaining countries consistently account for at least 98% of the USPTO patent dataset.

[126] Morris-Suzuki 1994.

[127] Toren 1994; Anonymous 1989; Gandal, Hanson, & Slaughter 2000.

[128] Steinbock 2001.

[129] Coe & Helpman 1995; Klevorick, Nelson, & Winter 1987; Mansfield 1985; Griliches 1992; Henderson, Jaffe, & Trajtenberg 1998.

[130] Future research might consider tracking student flows to the top schools (or countries) tracked in Liu 2004.

[131] National Science Foundation.

technical development both for their ability to directly transfer technology,[132] but also knowledge in the form of international consultants and technical advice from the exporting firm.[133] Finally, FDI, in either direction, is a major conduit of tacit knowledge and here I use United Nations (UNCTAD) data. Inward FDI not only brings in plant, equipment, and research facilities, but along with it expertise and training from the investing firms.[134] For outward FDI, I focus on FDI into the US, which often represents foreign firms setting up shop to capture spillovers of tacit knowledge from US domestic R&D.[135]

These measures of student flows, capital goods imports, and FDI are combined by means of factor analysis into a single "international relationships" factor , which is then used as an independent variable in the regressions. The summary statistics and factor analysis of the international relationships data (capital goods imports, FDI flows, student flows) are presented below in Figure 4.2. Note the relative size of the eigenvalues, which strongly suggests that a single factor is appropriate, with its heaviest weighting in capital goods imports, slightly less weightings in inward and outward FDI, and a relatively minor weighting in students sent to obtain science-engineering PhD's in US graduate schools.

Figure 4.2: IR-Factor

Summary Stats of Components:

Variable	Description	Obs	Mean	Std. Dev.	Min	Max
infdius	Inward FDI from US[†]	434	2431	13607	0	243797
capim	Capital goods imports (US)[†]	450	1840	6750	0	22600
usphds	US PhDs in science	486	200	638	0	6989
outfdi	FDI into US[†]	489	2253	11740	-204.76	132041

Factor Analysis:

Factor	Eigenvalue	Difference	Cumulative
1	2.15	2.11	1.10
2	0.04	0.15	1.12
3	-0.10	0.03	1.07
4	-0.14	.	1.00

Creation of IR-Factor as a New Variable:

Scoring Coefficients: (based on unrotated factors)

Variable	New "International Relationships" Factor
Infdius	0.31
Capim	0.42
Usphds	0.03
Outfdi	0.27

[†] Millions of $US, (previous 5 years)

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[132] Including: power generating machinery and equipment, machinery specialized for particular industries, metalworking machinery, general industrial machinery and equipment, office machines and automatic data processing equipment, telecommunications, sound recording and reproducing equipment, electric machinery, apparatus and appliances.

[133] Amsden 2001.

[134] Yamashita 1991.

[135] US Dept. of Commerce. 1992, 1987.

4.3.3. Independent Variables: Domestic Institutions

To control for domestic institutions, I focus on those most invoked by the conventional wisdom as having a positive effect on innovation: democracy and free markets. As my measure of democratic institutions, I employ Polity2 from the University of Maryland's *Polity IV Database*, which ranks nations on a -10 to +10 scale of democracy.[136] I alternately use the POLCON Index developed by Witold Henisz (U. Penn).[137] The POLCON Index is a 0-1 measure which takes into account the number of independent branches of government with veto power over policy, modified by the extent of party alignment across branches of government and the extent of preference heterogeneity within each legislative branch. POLCON is therefore a measure of what both Acemoglu and Keefer describe as decentralized democracy or "democracy *cum* checks and balances".[138] The inclusion of party alignment and legislative preferences means that POLCON is not a pure measure of structural decentralization. However, unlike measures which rely purely on formal institutional structure, the POLCON measure allows us to control for states which may be formally decentralized but which may suffer ineffective *de facto* checks and balances. The POLCON index correlates highly with Polity2 (depending on the time period, from 0.72 to 0.85), and has been shown to be statistically and positively significant in affecting both business investment decisions and technological diffusion in various countries, therefore it is natural to ask whether it holds similar significance for innovation rates.[139] I also experiment with the Freedom House measures (1-7 scale) of "political rights", "civil liberties", and "Free" (1-3 scale).

As my measure of market quality, I use the "Economic Freedom of the World Index" produced by the Fraser Institute which ranks the strength of nations' market institutions on a 1-10 scale. This index is a composite measure which attempts to quantify and combine: size of government sector in the national economy, legal structure & security of property rights, access to sound money, free trade, and degree of government regulation of finance, labor, and private business. Triangulation of this measure is difficult because most quantitative indices of market institutions began during the 1990s, which is towards the close of my innovation time-series. However, I can use dummies for "liberal market economies" (LME's) and "coordinated market economies" (CME's) as described by Hall & Soskice in their research on Varieties of Capitalism.[140] The former represent economies where economic actors tend to coordinate their activities via market arrangements (US, UK, Canada, Australia, New Zealand); in the latter market institutions are restrained, and instead actors coordinate via political agreements and private collaborations (Austria, Belgium, Denmark, Finland, Germany, Japan, Netherlands, Norway, Sweden, and Switzerland).

These institutional measures are frequently used by social scientists who study comparative institutions, and therefore allow me to conduct my probe with relative confidence. The summary statistics are provided in Figure 4.8. If the domestic institutions hypothesis is correct, then those nations with higher levels of democracy and free markets should be more innovative than others, regardless of their degree of international relationships.

4.3.4 Additional Control Variables

The basic question I wish to ask here is: given a nation with a particular set of economic resources, at a particular level of development, do its international relationships or domestic institutions determine its innovation rate? Hence the additional control variables I focus on are found in the World Bank's *World Development Indicators* database: *GDP* (to control for the amount of economic resources upon which innovators can draw), *population* (to control for the number of potential innovators) and either *per capita electric power consumption* or *GDP per capita* (to control for base-level of economic

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[136] Marshall, Jaggers, & Gurr 2003.

[137] Henisz 2000.

[138] Keefer 2004.

[139] Delios & Henisz. 2000; Henisz 2002; Henisz & Zelner 2001.

[140] Hall & Soskice 2001.

development).[141] Finally, if a country's ability to absorb new knowledge depends in part on its existing stocks of knowledge, then it is important to control for local science and engineering education. While level of development or a lagged dependent variable may partially control for this, in some regressions I also experiment a control for *local science and engineering undergraduate students per capita*.

The regressions are based on log-log specification, except for the domestic institutions variables (democracy, decentralization, and markets). The estimates are therefore less sensitive to outliers and can be interpreted in terms of elasticities; log-log models are also consistent with much of the prior work in this type of research.[142] This results in a primary regression model along the following lines:

$$\begin{aligned}\text{Innovation Factor}_{t=0 \text{ thru } 1} = {} & B_0 + B_1 * (\text{IR Factor}_{t=0}) + B_4 * (\text{Domestic Insts}_{t=0}) \\ & + B_2 * \text{Ln}(\text{Economic Resources}_{t=0}) + B_3 * \text{Ln}(\text{Level of Econ. Development}_{t=0}) \\ & + B_5 * \text{Ln}(\text{Domestic Sci-Eng students})\end{aligned}$$

where innovation in period t =0 through t=1 is a function of the independent variables at time t =0. Questions about multicollinearity naturally arise with this combination of observables. Therefore I not only report the maximum variance inflation factor in each regression result, but also experiment with omitting some of the worst potential offenders.

4.4 Regression Results

The first and most important finding of the regressions is that international relationships strongly affect national innovation rates. Almost every regression yielded a significant and positive coefficient for the IR-factor, regardless of regression technique employed, lag structure used, or control variable included (or omitted). Representative results of these regressions are tabulated in Figures 4.3 through 4.7. Note that in the regressions the coefficients for the IR-factor are relatively robust to changes in the regression model, though they do change significantly across different time periods and lag structures. The regressions suggest that in the 1990-95 period, a unit increase in the IR-factor results in a 20-30% increase in innovation rates. Earlier time periods show an even greater effect of international relationships on innovation rates, as do longer lag structures. These effects are considerable when one considers that the mean IR-factor for the entire dataset is approximately 0.0, with a standard deviation of 0.9. The time dependence of the IR factor could reflect a decrease in knowledge flows out of the US over time, either due to the rise of Japan and Western Europe as competing sources of technical knowledge, or to a decline in demand due to countries such as Japan, South Korea, Finland, and Israel reaching the technological frontier.

How do we know that international relationships affect innovation rates, rather than the reverse? In other words, perhaps an increasing innovation rate is a pre-requisite to receiving increased flows of FDI, capital goods imports, etc, rather than an effect of them. I attempted to answer this question in several ways. First, I ran time-series cross-section regressions, which corroborated the OLS findings. Second, in a more transparent approach, I re-ran the OLS regressions above, but with increasing time lags between the independent and dependent variables (Figure 4.3, middle columns). Again, I found that the coefficients for the IR Factor are consistently positive and significant, and match the values of the coefficients produced in the non-lagged regressions fairly well. Third, the measure for economic development (either per capita electric power consumption or GDP per capita) should likewise control for countries' base level of technological capability. However, in order to be sure, in some regressions I add a control for the earliest level of national innovation rate possible with the data: citations-weighted patents

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[141] Per capita electric power consumption (kilowatt-hours per capita) makes theoretical sense as an indicator of development for the time period under consideration since the more developed a country is, the more its populace will conduct electricity-based activities. It also correlates well empirically with other development measures, specifically GDP per capita and lagged innovation, either of which can produce high variance inflation factors (and hence high multicollinearity) when used alongside GDP.

[142] Furman, Porter, & Stern 2002; Jones 1998.

received in 1970 (Figure 4.3, rightmost columns). This observable allows me to control for each country's base innovation rate a full decade or two prior to the observed international relationships. Note that the while the 1970 patent measure is significant and positive in many regressions, its effect is small and its inclusion has little impact on the coefficients for the IR Factor, except for the sole case of the 1980-1985 time period.

The second, and perhaps more interesting, result is that the coefficients for domestic institutions are generally small and often insignificant. The coefficients for the Polity 2 measure of democracy suggest that a unit increase in democracy results in a mere 2-7% increase in innovation. And these coefficients are only rarely significant, and even then just barely at the $p<0.05$ level. The substitution of Freedom House's measures of "political rights" or "civil liberties" for the Polity 2 measure produces similarly insignificant coefficients (Figure 4.5); however the use of "Free", "Partly Free", and "Not Free" (1-3 scale) does produce strong and significant results, with a unit increase in "Free" corresponding to a ~60% increase in innovation. However the mean value of the "Free, Partly Free, Not Free" measure is approximately 2.0 with a standard deviation of 0.8, thus this is a particularly dull tool with which to measure democracy.[143] Its coefficient may merely suggest that large shifts in democracy matter far more for innovation than do smaller shifts (such as those measured by Polity 2).

As with the democracy measures, the Economic Freedom measure is also generally insignificant throughout the regressions. The coefficients here are somewhat larger however, generally suggesting a ~20% increase in innovation rates (and sometimes as high as a ~50% increase) for a unit increase in economic freedom. However, this effect is not so large when one considers that mean for Economic Freedom is 5.6 with a standard deviation of 1.1, again a somewhat dull measure of institutions. Furthermore, in those rare cases where Economic Freedom is significant, it is just barely so (at the $p<0.05$ level). Thus while markets seem to perform better in my regressions than does democracy, their performance does not match the strong expectations of the ability of markets to affect innovation generated by free market theorists.

Throughout the regressions, the variance inflation factors suggest that high multicollinearity is not to blame for the poor performance by domestic institutions. This a conclusion supported by the low correlation of the two main institutional measures, Polity 2 and Economic Freedom Index, with each other (ranging 0.34 - 0.43 depending on the time period). Unfortunately there are few similar institutional measures available for the time-series in question, hence I cannot triangulate further. Attempts were made using dummies for "liberal market economies" vs. "coordinated market economies" according to Varieties of Capitalism theory, the results of which matched the other regressions. However, the number of observations was too low ($n = 12\text{-}14$) to provide a high level of confidence.

Interestingly, neither the strength of the IR Factor nor the relative weakness of the domestic institutions measures is much affected by each other's presence or absence in the regression models (Figure 4.6). That is, the coefficients for the IR Factor remain relatively unchanged when the domestic institutions controls are omitted from the model. Likewise, the domestic institutions coefficients do not gain much strength or significance when the IR Factor is omitted. This is not to say that there is *no* effect at all, since there clearly are some mild changes in values and significances. However, the regression results are fairly robust and reveal that we do not need to hold domestic institutions constant in order for international relationships to have their effects, nor does the IR Factor absorb significance away from the domestic institutions.

Since there is considerable missing data on local education of scientists and engineers, I tend to omit it from many of the regressions reported here, except for those in Figure 4.4. Theoretically, this local education variable should be important. Note however that its inclusion does not have a major effect on the other variables. Nor does the control for local science and engineering undergraduate students per capita show up as significant. This is likely due to variation in the quality and depth of science education programs across countries. Unfortunately we have no way of consistently controlling for the quality or

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[143] In that 100% of the observations fall within just over 1 standard deviation from the mean.

depth of different national education programs during the time period covered here, and therefore must remain agnostic on this issue until more data comes available.[144]

Indeed, quantitative data on several of my variables is missing for some countries, therefore we have to ask how representative is the sample included in the regressions? For example, the regression most limited by data constraints (Figure 4.4, first column) has only 51 observations, and is missing countries which should most strongly support an international relationships hypothesis (e.g. Taiwan, Japan, Germany, Singapore). However, despite these omissions, T-tests reveal that the regressed sample does not select on the dependent variable: countries included in even the most restricted regressions are no more innovative than those which are excluded. However, the sample does appear to be somewhat biased on several independent variables. The countries included in the regressions tend to be slightly more developed, and have larger economies, larger populations, stronger democracies, more domestically trained undergraduates in science & engineering, and stronger international relationships (in educational exchanges, capital goods imports, but *not* inward or outward FDI) than those countries not included in the regressions. Interestingly, T-tests of the measure of economic freedom reveal no significant different between those countries included in the regressions and those omitted. Hence overall, we have to be careful when generalizing the findings in these regressions, however I would argue that the biases here are common to the large-N datasets analyzed throughout the comparative political economy literature.

An alternate explanation for the results above is that domestic institutions might benefit innovation more in the advanced economies, while international relationships might be more helpful to lesser developed countries in a somewhat Gerschenkronian fashion.[145] That is, with their luxury of having the advanced economies as models, backward economies may benefit more from international flows of technical knowledge which can be used by them to leap ahead, down a well-trodden path towards technological development. Conversely, advanced economies, by nature of their position at the economic frontier, must find their way forward more by experiment than by government direction. In these advanced economies, domestic institutions may be of more relative benefit, helping to alleviate the risks and information costs associated with experimentation; and since they are already innovating near the technological frontier, these economies may have relatively less to gain from international ties with other lead innovators. I experiment with two tests for this hypothesis (Figure 4.7), and the results merit further study. First I controlled for OECD membership and interaction of OECD membership with the IR Factor. Second I repeated this exercise, instead splitting the data into “wealthy” and “non-wealthy” subgroups, where “wealthy” is defined as being in the top 10 percent of GDP per capita.[146] The control for OECD membership is not statistically significant, nor is the “OECD-IR” interaction term; though adding the latter to the model does noticeably alter the coefficients for the IR factor, which is likely a result of high collinearity between the two (note the high VIF’s). The “wealth” control is statistically significant, but its inclusion in the model does not noticeably affect the coefficients for domestic institutions or the IR factor. Adding a “wealth-IR” interaction term has little additional effect in the 1990-1995 period but, as with the lone IR Factor, the effect of the interaction term increases in significance and size in earlier time periods. Thus the benefits for innovation from international relationships are neither particular to, nor higher for, lesser developed states.

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[144] The OECD’s “Program for International Student Assessment” was begun in 2000; the NEA’s “Trends in International Math and Science Study” started testing in 1995; and while the US Department of Education has carried out the “National Assessment of Educational Progress” for over thirty years, it only covers students in the United States.

[145] Gerschenkron 1962.

[146] The “wealthy” countries for the period starting 1975-1995 include: Austria, Belgium, Denmark, France, Japan, Kuwait, Netherlands, Sweden, Switzerland, United Arab Emirates, United States.

4.5 Conclusions

In sum, I have examined quantitative data on innovation, democratic and market institutions, and four types of international relationships, and found that, contrary to the conventional wisdom, international relationships are as important as, and perhaps more important than, domestic institutions in determining national innovation rates. This conclusion is admittedly tentative, and considerable work remains to be done in establishing the importance of international relationships relative to domestic institutions. However, the *prima-facie* evidence reported here confirms what economic historian Eric Hobsbawm wrote almost forty years ago: “It is often assumed that an economy of private enterprise has an automatic bias towards innovation, but this is not so. It has a bias only towards profit.”[147] One might now add that the inhabitants of democracies are likewise not automatically biased towards technological progress, but perhaps only towards their personal pursuit of happiness. The next and final chapter will put these findings into context with the research reported in the preceding chapters, suggest possible explanations for what has been observed, and posit the implications of this research for the debate on national innovation rates.

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[147] Hobsbawm 1969, p. 40

Figure 4.3: Basic Models

		Dependent Var = Log (Citations-Weight Patents Per Capita)							
					w/time lag		**w/lagged DV**		
Time for Dependent Var:		1990-1995	1985-1990	1980-1985	1990-1995	1990-1995	1990-1995	1985-1990	1980-1985
Time for Indep. Vars:		1989	1984	1979	1984	1979	1989	1984	1979
Level of Develpmt	Lagged DV (1970)						**0.003**	**0.004**	**0.01**
							[0.002]*	**[0.002]***	**[0.003]****
	log (gdppc)	**1.51**	**1.53**	**1.47**	**1.46**	**1.43**	**1.43**	**1.44**	**1.30**
		[0.22]***	**[0.16]*****	**[0.15]*****	**[0.19]*****	**[0.22]*****	**[0.22]*****	**[0.15]*****	**[0.15]*****
Domestic Institutions	democracy	0.06	0.03	**0.06**	**0.07**	0.05	0.06	0.03	0.04
		[0.04]	[0.03]	**[0.03]***	**[0.03]***	[0.03]	[0.03]	[0.02]	[0.03]
	econ freedom indx	0.19	0.27	0.2	0.2	**0.54**	0.18	0.2	0.24
		[0.22]	[0.16]	[0.21]	[0.16]	**[0.26]***	[0.21]	[0.15]	[0.18]
International Relationships	IR-factor	**0.28**	**0.64**	**1.16**	**0.69**	**0.96**	**0.20**	**0.48**	0.08
		[0.10]**	**[0.16]*****	**[0.27]*****	**[0.19]****	**[0.29]****	**[0.10]***	**[0.17]****	[0.35]
	_cons	**-9.38**	**-8.95**	**-8.02**	**-8.63**	**-9.91**	**-8.76**	**-7.97**	**-7.33**
		[1.17]***	**[1.19]*****	**[1.27]*****	**[1.30]*****	**[1.41]*****	**[1.21]*****	**[1.17]*****	**[1.16]*****
	R-squared	0.85	0.85	0.82	0.84	0.82	0.86	0.86	0.85
	Number of obs	74	72	65	74	68	74	72	65
	Max VIF	2.52	1.90	1.56	2.12	1.59	2.67	2.03	2.89

$*p<0.05$, $**p<0.01$ $***p<0.001$

Figure 4.4: Expanded Model

		Dependent Var = Log (Citations-Weight Patents Per Capita)				
Time for Depndt Var:		1990-1995	1985-1990	1980-1985	1990-1995	1990-1995
Time for Indep. Vars:		1989	1984	1979	1984	1979
Level of Develpmt	log (gdppc)	**1.61**	**1.42**	**1.43**	**1.36**	**1.21**
		[0.29]* **	**[0.24]*** **	**[0.23]*** **	**[0.29]*** **	**[0.30]*** **
	log (sci-eng undergrads/pop)	-0.01	0.28	0.02	0.29	0.40
		[0.24]	[0.23]	[0.31]	[0.24]	[0.29]
Size	log (GDP)	-0.006	-0.03	0.07	-0.05	0.05
		[0.13]	[0.15]	[0.13]	[0.17]	[0.17]
Domestic Institutions	democracy	0.05	0.02	0.05	0.05	0.05
		[0.04]	[0.03]	[0.03]	[0.04]	[0.03]
	econ freedom indx	0.09	**0.36**	0.17	0.30	0.51
		[0.28]	**[0.18]***	[0.24]	[0.17]	[0.30]
International Relationships	IR-factor	**0.21**	**0.59**	**1.04**	**0.68**	**0.86**
		[0.11]*	**[0.21]****	**[0.30]****	**[0.29]***	**[0.39]***
	_cons	**-9.28**	-6.08	-9.08	-5.41	-7.01
		[3.19]**	[4.23]	[4.98]	[4.40]	[4.73]
	R-squared	0.87	0.84	0.80	0.84	0.81
	Number of obs	51	60	54	62	57
	Max VIF	4.35	3.11	2.34	3.36	2.40

***p<0.05, **p<0.01 ***p<0.001**

Figure 4.5a: Basic Model (experiments with additional institutional measures)

		Dependent Var = Log (Citations-Weight Patents Per Capita)					
Time for Depndt Var: 1990-1995							
Time for Indep. Vars: 1989							
Level of Develpmt	log (gdppc)	1.51	1.50	1.60	1.75	1.48	1.59
		[0.22]***	[0.23]***	[0.17]***	[0.16]***	[0.23]***	[0.18]***
Domestic Instituions	democracy	0.06	0.06			0.06	
		[0.04]	[0.04]			[0.04]	
	econ freedom indx	0.19	0.21			0.20	
		[0.22]	[0.23]			[0.23]	
Freedom House Measures	political rights		0.01	0.17	0.20		
			[0.09]	[0.1]	[0.11]		
	civil liberties					0.06	0.21
						[0.12]	[0.12]
	Free						
World Bank	Checks2a						
International Relationships	IR-factor	0.28	0.27	0.25		0.27	0.25
		[0.10]**	[0.10]**	[0.09]**		[0.10]**	[0.09]**
	_cons	-9.38	-9.43	-9.47	-10.6	-9.44	-9.56
		[1.17]***	[1.18]***	[1.02]***	[0.93]***	[1.18]***	[1.00]***
	R-squared	0.85	0.85	0.82	0.81	0.85	0.82
	Max VIF	2.52	2.9	1.77		2.83	
	Number of obs	74	73	80	83	73	80

***p<0.05, **p<0.01 ***p<0.001**

Figure 4.5b: Basic Model (experiments with additional institutional measures)

Time for Depndt Var: 1990-1995 Time for Indep. Vars: 1989		**Dependent Var = Log (Citations-Weight Patents Per Capita)**					
Level of Develpmt	log (gdppc)	**1.73**	**1.46**	**1.51**	**1.57**	**1.72**	**1.45**
		[0.17]***	[0.22]***	[0.21]***	[0.14]***	[0.13]***	[0.21]***
Domestic Instituions	democracy		0.04				0.05
			[0.04]				[0.03]
	econ freedom indx		0.20	0.20			0.22
			[0.23]	[0.23]			[0.21]
Freedom House Measures	political rights						
	civil liberties	0.25					
		[0.13]					
	Free		0.39	**0.62**	**0.66**	**0.73**	
			[0.26]	[0.25]**	[0.23]**	[0.26]**	
World Bank	Checks2a						0.20
							[0.12]
International Relationships	IR-factor		**0.26**	**0.25**	**0.25**		**0.28**
			[0.10]**	[0.09]**	[0.09]**		[0.10]**
	_cons	**-10.7**	**-9.44**	**-9.93**	**-9.27**	**-10.4**	**-9.50**
		[0.91]***	[1.13]***	[0.94]***	[0.95]***	[0.86]***	[1.14]***
	R-squared	0.81	0.86	0.85	0.83	0.82	0.86
	Max VIF		2.61	2.52			2.56
	Number of obs	83	73	75	80	83	73

***p<0.05, **p<0.01 ***p<0.001**

Figure 4.6: Basic Model (with vs. without Institutions or IR Factor)

		Dependent Var = Log (Citations-Weight Patents Per Capita)								
Time for Depndt Var:		1990-1995	1990-1995	1990-1995	1985-1990	1985-1990	1985-1990	1980-1985	1980-1985	1980-1985
Time for Indep. Vars:		1989	1989	1989	1984	1984	1984	1979	1979	1979
Level of Develpmt	log (gdppc)	1.51	1.58	1.65	1.53	1.63	1.71	1.47	1.59	1.61
		[0.22]***	[0.22]***	[0.12]***	[0.16]***	[0.16]***	[0.13]***	[0.15]***	[0.16]***	[0.14]***
Domestic	democracy	0.06	0.07		0.03	0.04		0.06	0.07	
Institutions		[0.04]	[0.04]		[0.03]	[0.03]		[0.03]*	[0.03]*	
	econ freedom indx	0.19	0.37		0.27	0.43		0.20	0.37	
		[0.22]	[0.23]		[0.16]	[0.16]*		[0.21]	[0.21]	
International	IR-factor	0.28		0.36	0.64		0.64	1.16		1.41
Relationships		[0.10]**		[0.12]**	[0.16]***		[0.19]**	[0.27]***		[0.32]***
	_cons	-9.38	-10.83	-9.32	-8.95	-10.5	-8.92	-8.02	-9.97	8.00
		[1.17]***	[1.11]***	[0.93]***	[1.19]***	[1.12]***	[1.03]***	[1.27]***	[1.25]***	[1.10]***
	R-squared	0.85	0.85	0.77	0.85	0.84	0.82	0.82	0.82	0.77
	Number of obs	74	77	93	72	75	78	65	69	73

*p<0.05, **p<0.01 ***p<0.001

Figure 4.7: Basic Model (with wealth dummies & interaction terms)

	Dependent Var = Log (Citations-Weight Patents Per Capita)						
Time for Depndt Var:		1990-1995	1990-1995	1990-1995	1990-1995	1990-1995	1990-1995
Time for Indep. Vars:		1989	1989	1989	1989	1989	1989
Level of Develpmt	log (gdppc)	**1.38**	**1.37**	**1.53**	**1.51**	**1.48**	**1.52**
		[0.26]***	**[0.26]*****	**[0.23]*****	**[0.28]*****	**[0.27]*****	**[0.23]*****
Domestic Institutions	democracy	0.06	0.06	0.07	0.06	0.07	0.06
		[0.03]	[0.03]	[0.04]	[0.03]	[0.03]	[0.04]
	econ freedom indx	0.20	0.19	0.32	0.19	0.12	0.25
		[0.23]	[0.23]	[0.23]	[0.22]	[0.23]	[0.22]
International Relationships	IR-factor	**0.29**	**0.31**		**0.28**	**0.77**	
		[0.09]**	**[0.19]***		**[0.11]***	**[0.32]***	
Wealth 1	Wealthy Dummy	**1.02**	**1.20**				
		[0.43]*	**[0.53]***				
	Wealthy*IR		-0.11	**0.31**			
			[0.16]	**[0.13]***			
Wealth 2	OECD Dummy				-0.03	0.19	
					[0.66]	[0.73]	
	OECD*IR					-0.52	**0.23**
						[0.34]	**[0.08]****
	_cons	**-8.51**	**-8.44**	**-10.17**	**-9.41**	**-8.85**	**-9.77**
		[1.30]***	**[1.33]*****	**[1.17]*****	**[1.50]*****	**[1.57]*****	**[1.16]*****
	R-squared	0.86	0.86	0.84	0.85	0.86	0.85
	Number of obs	74	74	74	74	74	74
	Max VIF	1.87	3.00	2.56	3.14	**19.59†**	2.42

***p<0.05, **p<0.01 ***p<0.001 † high multicollinearity**

Figure 4.8: Summary Statistics

Total Sample

Variable	Obs	Mean	Std. Dev.	Min	Max
Cite-Weighted Patents Per Capita	720	0.00028	0.000952	0	0.0086
GDP	563	1.59E+11	5.81E+11	7.85E+07	6.25E+12
Population	735	3.01E+07	1.02E+08	30000	1.12E+09
per cap GDP	563	6963.21	9192.50	101.6	50081
Democracy	587	-0.09	7.94	-10	10
Econ Freedom	412	5.61	1.16	2.30	8.64
Free	486	1.04	0.82	0	2
US SE PhDs	810	164.74	557.67	0	6989
IR Factor	416	0	0.92	-0.42	11.09
Domestic SE Undergrads Per Captia	434	0.004168	0.003971	0	0.020472

1990-1995 period

Variable	Obs	Mean	Std. Dev.	Min	Max
Cite-Weighted Patents Per Capita	145	0.000203	0.000678	0	0.005817
GDP	133	1.83E+11	6.97E+11	9.17E+07	6.25E+12
POP	148	3.51E+07	1.19E+08	42170	1.12E+09
per cap GDP	133	7273.07	9605.19	101.5772	44725.5
Democracy	117	1.95	7.73	-10	10
Econ Freedom	99	5.68	1.21	2.937	8.219
Free	124	1.12	0.83	0	2
US SE PhD	162	241.85	741.23	0	6989
IR Factor	139	0.22	1.40	-0.34367	11.09433
Domestic SE Undergrads	70	0.006672	0.005271	0.000184	0.020472

1985-1990 period

Variable	Obs	Mean	Std. Dev.	Min	Max
Cite-Weighted Patents Per Capita	145	0.000318	0.00106	0	0.008396
GDP	122	1.66E+11	6.09E+11	1.27E+08	5.34E+12
POP	148	3.24E+07	1.10E+08	35000	1.04E+09
per cap GDP	122	7081.07	8992.11	114.64	40514.42
Democracy	118	0.03	8.01	-10	10
Econ Freedom	99	5.49	1.21	2.296	8.371
Free	124	1.10	0.79	0	2
US SE PhD	162	184.77	580.84	0	5244
IR Factor	139	-0.05	0.62	-0.38071	3.917559
Domestic SE Undergrads	92	0.004482	0.003801	0	0.013831

1980-1985 period

Variable	Obs	Mean	Std. Dev.	Min	Max
Cite-Weighted Patents Per Capita	145	0.000299	0.00098	0	0.007649
GDP	109	1.65E+11	5.81E+11	9.91E+07	4.92E+12
POP	148	2.98E+07	1.01E+08	30000	9.69E+08
per cap GDP	109	7443.47	9837.56	160.2024	50080.53
Democracy	118	-0.54	8.00	-10	10
Econ Freedom	93	5.46	1.14	2.932	8.644
Free	118	1.01	0.80	0	2
US SE PhD	162	175.17	581.24	0	5177
IR Factor	138	-0.17	0.36	-0.41768	2.388347
Domestic SE Undergrads	92	0.004803	0.003997	0	0.015736

Chapter 5

Conclusion: A Change in the Debate

5.1 Summary

This dissertation has asked the question: why are some countries more technologically innovative than others? The conventional wisdom amongst many social scientists is that domestic institutions determine national innovation rates. However, while research on domestic institutions has brought to light the complexity of the innovation process and the diversity of factors involved in it, it has failed to produce any general explanation of how domestic institutions determine national innovation rates. That is, although specific domestic institutions or policies might appear to explain particular instances of innovation, they fail to explain national innovation rates across time and space.

Despite these shortcomings, the domestic institutions thesis has to date received little challenge from innovation scholars in political-economy; therefore, in this dissertation, I have tested the ability of domestic institutions to explain differences in national innovation rates. I have examined quantitative data on innovation, various domestic institutions, and four types of international relationships. First, I tested the Varieties of Capitalism explanation of innovation, which predicts that societies with liberal-market economies will direct their inventive activity towards radical technological change, while societies with coordinated-market economies will direct their inventive activity towards incremental technological change. I found that these predictions are not supported by the empirical data, and that the evidence offered by VOC proponents depends heavily on the inclusion of a major outlier, the United States, in the class of liberal-market economies. If the US is taken out of the equation, then empirically the other LME's and CME's innovate almost exactly alike. Next, I tested the political-decentralization theory of innovation. I used regressions which alternately employed three different measures of innovation, six different measures of decentralization, and with controls for size of the economy, population, level of development, democracy, and a US dummy. I even experimented with bi-variate analysis in which I explicitly selected on the dependent variable, a technique which usually results in false-positive findings. Yet none of these approaches provided any significant evidence for a general relationship between decentralized government and technological innovation. Finally, I noted that anecdotal observations, both from my own research and within the evidence provided by domestic institutionalists, suggests that certain kinds of international relationships might have a role in determining national innovation rates. In order to test this possibility, I performed regression analysis on various measures of innovation, domestic institutions, and international relationships. These regressions suggested that countries' relationships with the lead innovator (the United States) strongly affect their innovation rates, even when controlling for domestic institutions. In other words, explaining national innovation rates is not so much a domestic institutions story as it is an international story.

These findings suggest a change in the debate over national innovation rates. The research presented here suggests that scholars should move away from pure domestic institutions hypotheses, and towards explanations based at least in part on international relationships. As discussed below, I do not argue that my findings are definitive or without potential problems. But I do argue that the results are strong enough to merit further study, and to constitute a legitimate critique of the domestic institutions school of thought. Though tentative, the tests reported here have never been performed before, use aggregate data that has not been used before, and examine the roles of several independent variables which have either not previously been considered or at least not simultaneously controlled for in single tests. Thus, this dissertation should be viewed as a useful first step in challenging the conventional wisdom that domestic institutions determine national innovation rates.

5.2 Alternate Explanations

I propose three possible explanations of the empirical findings presented in this dissertation, and recommend them as avenues to be more fully developed and explicitly tested in future research. As with all statistical analyses, one potential explanation has to be methodological. Issues of construct validity and measurement error affect several of the measures used, and omitted variable bias is always a potential problem in macroeconomic regression analysis such as that reported here. Hence, the findings in this chapter could always be spurious, the result of bad data or a missing control variable. Or of course, we may have simply not yet identified the right institutions, or combination of institutions, that affect innovation rates. However, I contend that the data and models employed in this dissertation contain no more potential errors or biases than are found in similar statistical analyses routinely performed by economic growth scholars or comparative political economists. Moreover, extensive use of data triangulation where possible, and experimentation with different model specifications, should establish an acceptable level of confidence in the general results reported here. This is not to say that my data and methods cannot be improved upon, but rather that there is ample justification for accepting the general results presented here. Therefore I suggest that future scholars should focus on *both* improving research methods and data, *and* examining other, competing explanations for the findings I have presented, such as those suggested below.

A second possible explanation for the findings reported here is that a nation's innovation rate may be determined by its access to the superior tacit scientific and technical knowledge possessed by the lead innovators. According to this view, institutional theories fail to explain innovation because they focus almost entirely on the public goods nature of scientific and technical knowledge, and ignore its private goods aspects. Since technological innovation is a knowledge-based activity, the costs of acquiring useful knowledge necessarily affect national innovation rates. If knowledge is a public good, then acquiring existing knowledge is practically cost free. The problem then lies with creating the right incentives for people to generate new knowledge. And this is exactly how most institutions theories tend to treat scientific and technical knowledge, as if it were merely an accumulated stockpile of data to which everyone has free access. However, if innovation also depends on tacit knowledge (the aspect of all knowledge that cannot be, or is not, codified),[148] then international relationships with the lead innovators may provide the best conduits for this tacit knowledge. That is, since tacit knowledge is not codified, it is rival and largely excludeable, therefore it cannot be treated like a public good.[149] Hence in order to get it, one must either create it anew through experimentation and trial-and-error learning, or acquire it from others via a process of apprenticeship. The extremely high costs and risks of generating new-to-the-world tacit and embedded knowledge suggest that innovators should prefer to transfer existing tacit and embedded knowledge wherever possible. Or put more simply, innovators should prefer not to re-invent costly wheels. And since this particular good exists in the minds, actions, and technologies of scientists and engineers in other countries, we need to focus on international relationships such as those listed previously in Figure 4.1. Thus differences in national innovation rates might be explained by differences in access to tacit knowledge that has been developed by lead innovators.

A third possible explanation for the findings of this dissertation is that innovation is a community-based activity. While the tacit knowledge transfer explanation assumes that knowledge is relatively objective, this third explanation springs from the opposite assumption. Researchers such as Thomas Kuhn, Loren Graham, and Ian Hacking have shown that social factors such as culture, politics, and national histories can affect the ways in which scientists and engineers frame scientific problems and construct theories in different countries.[150] In other words, the intellectual and social community to which people belong can affect how scientific "commonsense" and what is "natural" are construed within that community. This will in turn affect the ways in which scientists, policymakers, and perhaps even the general public think about science, technology, and the ways in which scientific and technical

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[148] Though some prefer: "unlikely to be codified". See Spender 1996.

[149] Von Hippel 1994.

[150] Graham 1998; Kuhn 1962; Hacking 1990.

explanations are interpreted locally. Some scholars even argue that all scientific rationality, methods, and truths are subjective.[151] If knowledge is socially constructed, then we get very different picture of innovation; one in which innovation rates are a function of, and in part defined by, the community to which a nation belongs. In this view, for example, when Japanese firms reverse-engineer American technology and consult US technical advisors, they are not just acquiring new knowledge but joining the Western knowledge community. Therefore one could describe Japan's rapid rise in innovation rates during the 1960s-1990s as a natural result, or perhaps indicator of, its increased membership in the Western knowledge-based economy. This view of innovation would give causal emphasis to the same international relationships, and predict very similar results to, those discussed in Chapter 4.

5.3 Potential Problems

Other issues for future research include potential problems and criticisms of this dissertation. I would argue that there are two important criticisms worth noting: one methodological, the other theoretical. First, amongst all of my quantitative measures, those of domestic institutions are the most problematic. They are often necessarily broad, and occasionally highly subjective, which means that they can fail to capture significant differences in institutions, or non-quantifiable characteristics. Hence there are limits on what can be established on the basis of statistical analysis. And while qualitative analysis may have its drawbacks in terms of generalizeability and potential for subjective analysis, well-designed case-studies may well offer value here. And although there are a plethora of case-studies of national innovation rates, few if any are designed to probe the comparative effects of domestic institutions versus international relationships.

Indeed, statistical analysis can produce only a limited amount of evidence towards causality of any sort. If we wish to more fully prove the hypothesis argued in this paper, then future research must get beyond opaque measures such as factors, and high-level aggregations of domestic institutions and international relationships. Perhaps industry-level, firm-level, or university-level analysis is the next step. Here, the patent data would still provide good measures of innovation, and allow for qualitative analysis as well. And since industries, firms, or universities share the same general national institutional environment, one could more precisely gauge the degree to which differences in international relationships affect innovation rates. Complementing such a cross-sectional study with a temporal analysis of change in domestic institutions and international relations, and doing so in both "more innovative" and "less innovative" states (such as South Korea and Taiwan, Portugal and Spain) may provide the leverage and specificity to further test the hypothesis argued here.

Second, even if one were to fully accept the empirical findings described in this dissertation, they still would not completely explain why some countries are more innovative than others. Rather, international relationships or domestic institutions are only the vehicles or techniques by which nations become more innovative. They tell us more about "how", rather than "why", some countries become more innovative than others. For if establishing international relationships with lead innovators is the key, then how do we explain the lead innovators themselves? The innovation data may hint at the answer. If we observe change in technological patent and scientific publication behavior over time, we can see the rapidly and increasingly innovative countries (Taiwan, Israel, South Korea, Japan, etc.) are each typified by conditions in which the perceived security threat is external rather than internal. That is, the material benefits of technological change to national military or economic security outweigh the costs imposed by the redistributive aspects of technological change. This is arguably even the case in Finland, whose Cold War security depended on keeping internal tensions low so as to prevent Soviet or NATO interventions, but whose post-Cold War security depends on being economically competitive.[152] Meanwhile in countries such as Spain, Italy, Norway, and Sweden, there is relatively little focus on external threats to national security, and relatively more focus on maintaining good relations between disparate domestic interest groups. This is admittedly mere conjecture driven by stylized facts. But it does point to a possible

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[151] Latour 1987; Berger & Luckmann 1966; see also Friedman 1998 for a recent summary of this view.

[152] Jakobson 1998.

research program which would consider the hypothesis that national innovation rates are driven by the balance of internal vs. external security concerns; by the redistributive consequences of technological innovation for domestic interest groups versus the need for technological change in order to maintain military or economic competitiveness.

5.4 Contributions

Finally, I would assert that the theoretical contribution of my overall research program is two-fold. First it points to the necessity for a better understanding of micro-level innovation processes. Domestic institutions theories of innovation may be built on inaccurate and inconsistent assumptions of what innovation is and how it works. It may be that they ignore the creation and sharing of tacit knowledge, or that they neglect the social construction of knowledge, but the overall implication is that there is a political component of knowledge that is being overlooked. And I would argue that failure to appreciate this shortcoming, failure to question the assumptions upon which domestic institutions theories are based, is what tends to force scholars into a never-ending search for the “right” institutions which determine national innovation rates and economic growth. Absent a proper understanding of the fundamental political-economy of technological innovation, this search may yield little in the way of productive or generalizeable results.

Second, my research program suggests that a single-minded focus on finding an institutional explanations can blind scholars to important political variables, such as international relationships, that play powerful roles in affecting technological change. I am not suggesting that institutions do not matter at all (though this may yet prove to be the case). But I am arguing that my research implies that existing institutional theories have been over-stated and over-simplified in the literature. I contend that there is sufficient empirical evidence for social scientists to say that institutions are not causal in-and-of themselves, or at least they are not necessary and sufficient causes of differences in innovation. Achieving sustained technological innovation is not as simple as “set up democracy and free markets”. It is more complicated than that. In fact, as speculated above, there may even be some sort of causal interaction going on between domestic institutions, security issues, and innovation that needs to be explored. In other words, this dissertation should be seen as an attempt to change the debate over the sources of technological innovation, not to end it.

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