Political Decentralization and Technological Innovation: Testing the Innovative Advantages of Decentralized States

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Abstract

Are politically decentralized states better at fostering long-run technological innovation than centralized states? Societies with decentralized governments are widely seen as agile, competitive, and well structured to adapt to innovation's gale of creative destruction. Meanwhile, centralized states, even when democratic, have come to be viewed as rigid and thus hostile to the risks, costs, and change associated with new technology, or prone to cling too long to foolhardy or outdated technological projects. Therefore government decentralization is often perceived as a necessary institutional foundation for encouraging long-run technological innovation. However, in this article, I 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.

KEY WORDS: decentralization, federalism, government, innovation, politics, political, technological, technology

Introduction

Is political decentralization good for national innovation rates? In empirical studies of national competitive advantage, observers consistently note the ability of politically decentralized states to maintain their places at the technological frontier. On the other hand, centralized states, even when democratic, seem unable either to achieve high rates of innovation or to maintain technological leadership if achieved. This observation has over time become a sort of "accepted wisdom" among social scientists: decentralized governments are widely seen as agile, competitive, and well structured to adapt to innovation's gale of creative destruction. Meanwhile, 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hostile to the risks, costs, and change associated with new technology, or prone to cling too long to foolhardy or outdated technological projects (Acemoglu et al., 2006; Carroll, 1993; Jennergren, 1981). These sentiments can be found both in the popular press (Surowiecki, 2004) and throughout the academic literature (Drezner, 2001; Mokyr, 1990, 2002; Rosenberg & Birdzell, 1985).

However, despite broad theoretical support, a general correlation between political decentralization and technological innovation has yet to be empirically established by social scientists. While the popular association between the two phenomena is strong, the empirical evidence consists mostly of anecdotal observations and stylized case studies. This article 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, this article quantitatively tests the argument that government decentralization is positively correlated with innovation. It examines several

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datasets of international patent activity, science, and engineering research publications, and high-technology exports. This analysis reveals that, in general, innovators in decentralized states are empirically no more technologically innovative than those in more centralized states. Although this research does not address issues of technological diffusion, or meso-level sociological or business arguments concerning industry or firm decentralization, it does suggest that the conventional wisdom regarding political decentralization aiding innovation is incorrect and in need of modification. In the concluding section, indications of more fruitful avenues of research are inferred from the data.

Justification

This question of whether decentralized states are more technologically innovative than others should interest scholars of comparative politics and international relations for reasons beyond that of national technological capability. First and foremost, political power is currently in the process of being redistributed throughout states around the world, not only via a global shift toward greater democracy, but with traditionally centralized polities in Asia, the Americas, and Europe either now decentralized or on their way to decentralization. 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 (Barre et al., 1997; Commission on European Communities, 1988; European Commission, 2003).

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 fiscal restraint to efficient government to preserving markets (Oates, 1972; Tiebout, 1956; Weingast, 1995). More recently, a critical line of research has attacked this view and pointed out the detrimental affects of federalism on fiscal and monetary policy, exchange rate management, and privatization programs (Armijo & Jah, 2000; Rodden, 2002; Woodruff, 1999). 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 (Rodden & Wibbels, 2002). 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.

Literature Review

Definition

Political decentralization (a.k.a. government decentralization) is defined here as an increase in both the number and equality of centers of political power and policy making. Many scholars interpret "decentralization" to simply mean federalism. However, as will be shown below, existing theories concerning 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 toward local governments, the classic example being federalism (Rodden, 2005). In horizontally decentralized states, authority is shared between an executive, legislature, judiciary, and in some cases even a powerful bureaucracy or autonomous military.[1] In practice, many states decentralize even further, with power formally divided between different houses of the legislature, competing bureaucracies, or branches of the armed forces. Finally, as will be further discussed below, 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).

Theory

Political decentralization proponents emphasize four primary mechanisms by which government structure should affect national innovation rates. First, they argue that both horizontal and vertical decentralization increase the number of political and economic units participating in, funding, and demanding innovative activities. This not only multiplies technological search and experimentation efforts (Acemoglu, Johnson, & Robinson, 2005; Drezner, 2001; Mokyr, 1990, 2002; Nelson, 2005; Weingast, 1995), but can also increase the diversity of these research efforts and the information acquired through them (Acemoglu, Johnson, & Robinson, 2005; Drezner, 2001; Mokyr, 1990, 2002; Rosenberg & Birdzell, 1985; Surowiecki, 2004).

Second, scholars assert that, by increasing the number of units, decentralization increases competition, thus increasing the incentives for innovation. This theme recurs throughout much of innovation research, but is perhaps best specified in the federalism literature. Federalism scholars point out that decentralization can result in a "Delaware effect" in which subnational governments compete with one another to attract business investment, and therefore constantly improve the legal, tax, and regulatory environments for innovators (Cary, 1974; Oates, 1972). This concept has evolved into Weingast's "market-preserving federalism," in which federalism can prevent government from acting in a predatory manner toward innovators, and allow credible commitments to produce pro-market policies and public goods (Qian & Weingast, 1997; Weingast, 1995).

Third, it is also argued that decentralization provides superior information for both policy makers and innovators (Mokyr, 1990, 2002). Hayek (1945) observed

that much information which is helpful for economic activity cannot be usefully centralized (e.g. tacit knowledge). Although Hayek was writing with regard to the merits of decentralized markets over central economic planning, the implications for political decentralization are clear: local policymakers simply have superior information concerning local conditions than do distant national legislators or bureaucrats, and can therefore design better policy for the local environment. Better policy should in turn mean more efficient allocation of resources toward, 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 (1956) has shown, decentralized local public goods production is generally better at reflecting popular preferences than is centralized national public goods production. Hence in Tiebout's economy, different subnational governments provide a menu of different policy environments, which allows different kinds of "consumer-voters" of public goods (here innovators consuming scientific knowledge, investors looking for R&D opportunities, high-tech labor seeking employment, and so forth) to choose the environment that is right for them. So, for example, 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. Surowiecki (2004) describes this as a form of decentralization-driven specialization which makes innovators more productive and efficient, or which alternately could be interpreted as conducive to producing Richard Florida's (2002) "creative cities."

Fourth, several scholars argue that political decentralization aids national innovation rates by making the state less vulnerable to capture by *status quo* interest groups (Acemoglu, Johnson, & Robinson, 2005; Drezner, 2001; Mokyr, 1990, 2002; Rosenberg & Birdzell, 1985; Weingast, 1995). 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 that slow technological innovation (Drezner, 2001). Once made, such policies will be imposed across the entire nation due to the centralized nature of government in these states. Conversely, in decentralized states, even if similar policies arise, they can be reversed or overridden by subnational governments. A good example of this in the United States might be AIDS research during the 1980s when powerful interest groups exerted their influence on the federal executive branch to slow innovation in these areas. However, the federal legislature, as well as state and city governments, were able to override the objections of the executive branch and provide regulatory or budgetary support for research; while the courts served as an additional point of entry for supporters of technological progress (Shilts, 1987).

This fourth aspect of government structure might also help to explain why other institutional explanations have failed to generalize across different countries and time periods. For example, national systems of innovation (NSI) scholars have long probed the effects of dozens of national institutions and policies on the innovation rates of a wide spectrum of nations, but with few generalizeable results (Edquist, 1997; Lundvall, 1992; Nelson, 1993). The NSI's approach has been to use case

studies to identify the domestic institutions and policies that best solve the extraordinary public goods problems associated with technological innovation (Arrow, 1962). The NSI scholars have therefore examined the interactions and effects on innovation rates of different education policies, science policies, trade regimes, legal frameworks, financial institutions, anti-trust laws, and so forth. However, after almost 20 years of research, NSI scholars have failed to produce any general theory 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.

Government decentralization offers a possible explanation for this conundrum. According to decentralization proponents, technological innovation poses not just a public goods dilemma, it also suffers from an interest-group capture problem. *Status quo* interest groups are those whose assets (e.g. skills, capital, land) are hurt by technological change. In order to obstruct threatening technological changes, these interest groups will often seek to influence or capture precisely those institutions and policies that NSI scholars use to explain innovation rates. Even the presence of markets cannot prevent this phenomena, argue Acemoglu, Johnson, & Robinson (2005) and Drezner (2001), since markets and property rights are but institutions subject to the will of captured state apparatus. Thus NSI explanations fail to generalize across time and space because the mid-level institutions and policies they prescribe are endogenous to government structure: their technological goals, and their efficiency in achieving these goals, are determined by the ability of broader state structures to resist interest-group capture.

What if a centralized government is strongly pro-technology or captured by pro-technology interest groups? After all, centralized government can better 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 Drezner (2001) points out that, even in these cases, decentralized states still have an advantage because the subnational provinces can act as experimental test beds for different kinds of policies and innovations. 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.

Finally, the arguments posited above should be qualified in that scholars differ in the degree to which they believe political decentralization matters, relative to other causal variables, for innovation. On the one hand, evolutionary economics suggests the possibility that, at least in the long run, government decentralization alone might do much of the work toward fostering innovation. In evolutionary theory, variation (i.e. search efforts) and selection (i.e. competition for limited resources) are necessary and sufficient for sustained technological change (Nelson, 2005). Since decentralization is both necessary for competition and fosters variation, in the very long run it could be a primary causal factor for technological change. Granted, evolutionary economists generally theorize how firms foster innovation within an industry, but there is no reason why this dynamic should not operate in other institutional settings. For example, the literature on why Europe innovated rapidly during the last half millennium, while Asia stagnated, often posits this stronger

evolutionary version of the decentralization hypothesis (Mokyr, 1990, 2002; Rosenberg & Birdzell, 1985). It is therefore not a major leap to suggest that subnational units fostering innovation within a national system might also obey an evolutionary dynamic, and therefore be strongly affected by political decentralization. A somewhat weaker version of the decentralization hypothesis is exemplified by Drezner (2001), who argues that decentralization is necessary, but not sufficient, for innovation. While Drezner sees government decentralization as being generally helpful, he also invokes conditional variables such as factor endowments, level of development, size, and just plain luck, in order to explain outlier cases. Yet perhaps the weakest version of the decentralization argument is made by Mokyr, who states that decentralization is neither necessary nor sufficient for innovation. He notes that when political decentralization manifests itself as severe fragmentation and Balkanization, it can lead to a complete lack of cooperation, violent competition, and physical conflict. Thus government decentralization should hurt innovation as it approaches the extremes of breaking apart a nation or causing civil war.

In sum, however, despite all the conditions put forward by different theorists, and regardless of the specific mechanism emphasized, the core of the decentralization argument remains. Or as Mokyr (2002) puts it, after a lengthy discussion of caveats and provisos:

> All the same, some measure of decentralization is probably desirable . . . it seems that too much coordination can be unhealthy. The need to retain some political diversity, coupled with openness and freedom of both ideas and the people in which they are embedded, seems to be undiminished even as knowledge itself has become more mobile . . . (p. 2822)[2]

Scant Empirical Evidence

The causal mechanisms outlined above dovetail with some widely held stereotypes of national differences in innovation rates. However, little empirical data has yet been produced to verify the assumption that decentralized states have some sort of comparative institutional advantage that promotes technological innovation. The empirical data which does exist is either limited to anecdotal evidence and stylized case studies, 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.

This is not to suggest that case-study research is unscientific or inappropriate to this research question. Indeed, one of recommendations which follows from the findings below is that more qualitative research is necessary in order to better specify the causal mechanisms and conditional variables involved. That is, the critique here is not that case-study research is somehow inadequate, but that not enough has been done and that existing case studies tend to take too high-level of an approach. Case studies are strongest when used to resolve or test causal mechanisms at the micro-level, and the existing case studies on the decentralization-innovation linkage do not provide this degree of resolution. Hence, I suggest that future researchers follow the example of more penetrative case-study research such as that exemplified by Richard Samuels (1987) and Jeff Hart (1992), or Danny Breznitz (2007).

In fact, few scholars have attempted to build an empirical case for the decentralization-innovation hypothesis. In separate research programs, Colleen Dunlavy (1994), Peter Hall (1986), and T. J. Pempel (1998) have each tied state structure with technological progress in different case studies. However their linkages are sometimes implicit or indirect, and none of them directly credit decentralization with any specific innovative advantages. Historian William McNeill (1982) has attributed China's failed brush with industrialization in the fourteenth century to its centralized governmental command structure. McNeill describes how pockets of market activity developed within the ancient Chinese economy, leading first to rapid technological change and later 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 decentralization 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 Drezner (2001), who investigates two bilateral rivalries for technological leadership (the United Kingdom vs. Germany, Japan vs. the United States) 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. However, Drezner's number of observations is too small to produce generalizeable conclusions. Nor does he probe the puzzle of why decentralized states such as Australia, Austria, or India have not enjoyed similar technological success to the United States or Germany, while many centralized states (e.g. France, Sweden, Israel, and Finland) innovate at or near the technological frontier.

Methodology

The purpose of the remainder of this article is to ask a fundamental empirical question. Is there any evidence to support a general relationship between government structure and technological innovation? Note that I am not testing here for the presence of a specific causal mechanism. This is because decentralization scholars collectively, and sometimes individually, describe multiple causal mechanisms by which decentralized government should affect innovation. Also, different researchers posit different combinations of mechanisms. Therefore I will test only for the presence of a general macro-correlation. In so doing, my approach is similar to that used by researchers who have sought to test for general correlations between smoking and cancer (Cutler, 1955), or industrialization and climate change (IPCC, 2001), but did not know the precise causal mechanism involved. That is, no matter which mechanism is in operation (i.e. increased competition, superior information, greater experimentation, limitations on *status quo* interests), or even if the specific mechanism(s) remains unidentified, the regression models employed below should reveal a correlation between decentralization and innovation if a causal relationship actually exists. Hence my regressions constitute a Van Everan "hoop" test: flunking the test provides strong evidence *against* the hypothesized relationship, though

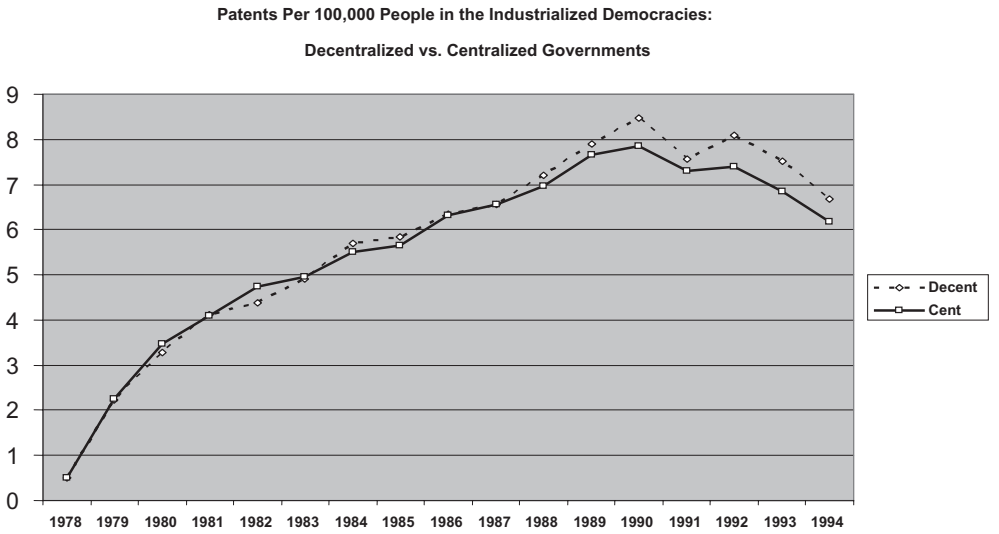

Figure 1. Innovation in Advanced Democracies: Decentralized versus Centralized States
Source: European Patent Office (2003).[19]

passing test may only produce little support for it (Van Evera, 1997). This empirical section of this article will suggest that the political decentralization hypothesis flunks such a "hoop" test.

Simple Bivariate Tests

One fairly straightforward and traditional way to test for the strongest version of a decentralization-innovation relationship is to simply compare national patent rates. The results of such a test are presented below in Figure 1. Here, using 17 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 those political systems which are widely characterized throughout the literature as being either highly decentralized or highly 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% 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" regarding the benefits of decentralization for innovation, one would not expect such mild and transitory results.

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

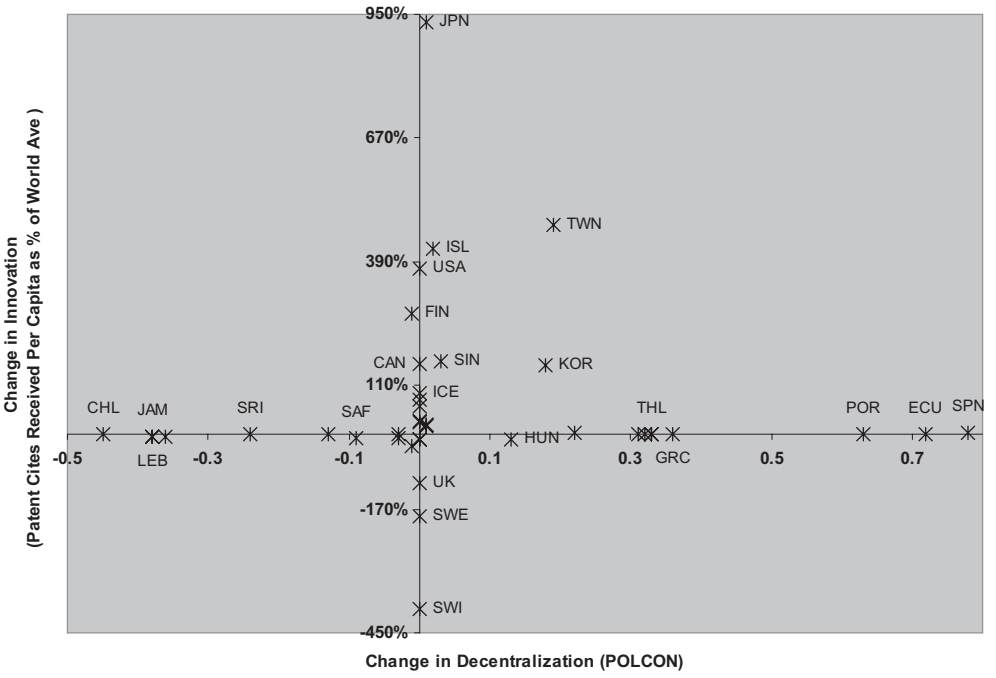

Figure 2. Innovation versus Decentralization in 45 Countries (1975–95)
Source: United States Patent, Trademark Office, and NBER (2001).

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 2. This graph plots changes in decentralization versus changes in innovation in the 29 countries that underwent the largest changes in government decentralization from 1975–95. In addition, I also plotted the results for the 25 countries with the largest changes in relative innovation rates.[3]

As my measure of overall decentralization in this graph, I employ the POLCON Index developed by Witold Henisz (2000). The POLCON Index is a 0–1 measure that 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 that rely purely on formal institutional structure, the *POLCON* measure allows me to control for states that 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 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 (Delios & Henisz, 2000; Henisz, 2002; Henisz & Zelner, 2001).

As my measure of innovation in Figure 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

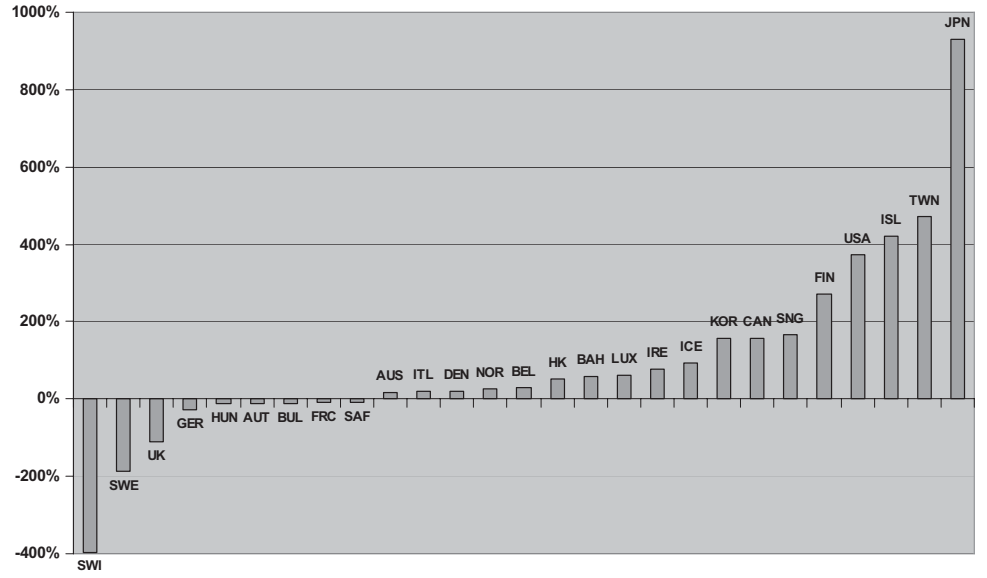

Figure 3. Change in Patent Cites Received Per Capita as Percent of World Ave. (1970–75 vs. 1990–95)
Note: n = 74, countries not shown had a change of <7.5%.
Source: United States Patent and others (2001).
Countries shown: Switzerland, Sweden, Great Britain, Germany, Hungary, Austria, Bulgaria, France, South Africa, Australia, Italy, Denmark, Norway, Belgium, Hong Kong, Bahamas, Luxembourg, Ireland, Iceland, South Korea, Canada, Singapore, Finland, United States, Israel, Taiwan, Japan.

United States Patent & Trademark Office (USPTO).[4] 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 (Hall, Jaffe, & Trajtenberg, 2001).[5] 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 allows us to control somewhat for the quality, as well as the quantity, of the innovations being patented. The use of citations-weighted patents as a measure of innovation is discussed at greater length in the next section.

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 2 reveals, only Taiwan and South Korea appear to 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 that had major shifts in innovative performance (Japan, Israel, Switzerland, the United States, and 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 toward genuine multi-party democracy. Note that this only strengthens the claim being made here: 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 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% change have been left off of the graph altogether. Second, 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 United States 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. Among 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*). Yet 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 among the largest decliners in relative innovation rates. More interesting is the nation that does not appear in Figure 3, Spain, which significantly decentralized by almost any measure one can calculate. Spain's negative change in relative innovative performance (a mere –0.01%) 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 the strongest version of the decentralization hypothesis.

Of course, these simple bivariate tests do not allow us to control for additional control variables invoked by weaker versions of the decentralization hypothesis. According to Drezner, Mokyr, and others, these conditional variables should include such factors as democracy, overall economic resources, base level of technical development, factor endowments, military spending, and openness to trade. These control variables will be considered in greater detail in the regressions below.

Multivariate Statistical Tests

Methods and Data—In order to test weaker versions of the decentralization-innovation hypothesis, I turn in this section to multivariate regressions. I conduct cross-sectional statistical analysis of innovation rates across some 70 countries during the 1975–95 period.[6] Although time-series cross-sectional regressions would be ideal here, the presence of rarely changing independent variables over time creates 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. 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 subperiods and test each separately. Also, since a lag likely occurs between the activity of innovation and the patent application, I lag the independent variables one, five, and ten years in separate regressions wherever possible.

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). By far, the most frequently used quantitative measure of national innovation rates is patents. Patents are by definition related to innovation. Each patent represents an individual "quantum" of invention which has passed the scrutiny of trained specialists, and gained the support of investors and researchers who must dedicate time, effort, and significant resources to research and legal protection. Given these qualities, patents have been used as a basis for the economic analysis of innovative activity for 40 years, starting with the pioneering work of economists Frederic Scherer (1965) and Jacob Schmookler (1966) who used patent statistics to investigate the demand-side determinants of innovation.

Of course, patents do have weaknesses as a quantitative measure of innovation. First, simply adding up patents does not take into consideration that most are for minor innovations, while a few represent extremely valuable and far-reaching innovations. Also, simple patent counts have been found empirically to correlate well with innovation inputs (e.g. R&D spending), but they are too noisy to serve as anything but a very rough measure of innovation output (Griliches, 1984). I address these issues by weighting patents by their forward citations. The idea here is that minor 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 (Hall, Jaffe, & Trajtenberg, 2000; Jaffe, Trajtenberg, & Fogarty, 2000; Lanjouw & Schankerman, 1999; Trajtenberg, 1990).

A second potential weakness is that it is often unclear what fraction of a nation's innovation is actually patented, or to what degree selection bias exists in any given set of patent data. This problem is exacerbated when we consider that different countries may exhibit significant variance in their propensity to patent. However, at the national level, citations-weighted patents have also been found to correlate highly with other measures that we generally associate with aggregate innovation rates, including GDP growth, manufacturing growth, exports of capital goods, R&D spending, capital formation, Nobel Prize winners (Amsden & Mourshed, 1997). Thus, even though patents do not capture all technological innovation, they do appear to capture a representative sample of it when weighted by forward citations and used in large aggregates.

Still, 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 data (per capita) with similar regressions of two additional measures of innovation: scientific publications weighted by forward citations (per capita), and high-technology exports as a percentage of GDP. Scholarly scientific publications offer advantages similar to those of patents, with each journal article representing a discrete piece 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 (Bourke & Butler, 1996; Glanzel & Moed, 2002; McMillan & Hamilton, 2000). 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 (Blomstrom & Wolff, 1994; UNCTAD, 2003; Yamashita, 1991).

The patent data comes from a subset of the National Bureau of Economic Research (NBER) Patents Database and includes data on over 1.7 million utility patents granted by the USPTO to applicants from the United States and 146 other countries during 1974–95, and the 9.7 million citations made to these patents during the same time period.[7] 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" (UN COMTRADE Database, 2006). 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 (OECD, 1986, 2003). Its sectors include aircraft, spacecraft, pharmaceuticals, office machinery (includes accounting and computing), telecommunications equipment (including radio and television), and medical and scientific instruments.[8]

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.[9] Federalism dummies have been used in this manner by researchers to test for links between government structure and macroeconomic performance, corruption, inflation, and fiscal responsibility (Escobar-Lemmon, 2001; Treisman, 2000a, 2000b; Wibbels, 2000). The second measure is the index of federalism devised by Arend Lijphart (1999), which ranks countries on a five-point scale (*Lijphrt Fed*).[10] Note that both the 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 that 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*).[11] 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.[12]

Additional Control Variables—In order to test the weaker versions of the decentralization hypothesis, we also need to include controls for those variables specified by decentralization theorists as conditioning the effects of government decentralization on innovation. For example, almost universally, these researchers assume that the size of a country's economy and its level of development affect innovation rates. The idea here is that larger economies will have more resources upon which innovators can draw, and that innovators in more advanced economies should be able to draw on these resources more effectively. Hence the primary 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).[13] Also, since most decentralization scholars, especially Mokyr, require a certain amount of political freedom for innovative activity, a measure of *Democracy* (Polity2, from the Polity IV database) is included (Marshall, Jaggers, & Gurr, 2003). Finally, since the United States is a technological outlier by almost any measure, a U.S. 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 (Furman, Porter, & Stern, 2002; Jones, 1998). This results in a primary regression model along the following lines:

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

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.

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, those factors identified by Furman and others (2002) as contributing to national innovative capacity? The answer is that the decentralization hypothesis holds that such policies are either endogenous to government structure, or are overwhelmed by its causal effects. Although this may sound like an extreme interpretation of the decentralization argument, recall that these mid-level

institutions and policies are exactly those that NSI scholars have failed to generalize as causal explanations after almost two decades of research.

Take as an example the recent debate over the promotion of "Intelligent Design" in the United States. A decentralization theorist would argue that, if the United States had a centralized government structure, then the Bush Administration or a Republican-controlled congress could have required U.S. public schools to teach Intelligent Design as science, and even deemphasized the teaching of evolution. Depending on the extremes to which this policy were taken, private schools might also have felt a need to join this movement in order to be "competitive," or to meet government certification requirements. However, since the United States is decentralized, the decision over Intelligent Design was left up to the states and the local school boards. Most of these school districts opted to omit Intelligent Design, others chose to place warning stickers on biology textbooks, still others actively promoted the teaching of Intelligent Design as science. The courts then got involved to thwart the teaching of Intelligent Design as science in some states, while voters changed outcomes in local elections in others. Thus decentralized government, both horizontal and vertical, has arguably played an important role in virtually eliminating Intelligent Design, and continuing the support for teaching evolution, in science classrooms. A very different outcome might have occurred in a centralized American democracy.

Decentralization proponents argue that similar types of policy battles are regularly fought over R&D spending, science policy, education budgets, high-technology procurement, teaching and testing standards, and so forth. These fights take place between different interest groups at both the federal and local levels, as well as between the executive, legislative, and judicial branches. Hence, all sorts of policies important for innovation are arguably endogenous to government structure, and in very much the ways described by decentralization scholars (i.e. policy responds to competition between different branches and levels of government; is made better by superior information available to voters and policy makers at the local level; decentralization creates a menu of different policy environments for consumers of public goods to choose from). Note that we need not necessarily agree nor disagree with this; rather the purpose of this article is merely to test the decentralization-innovation thesis as given.

Nonetheless, for those who are not fully convinced by the endogeneity argument, in some regressions I do experiment with four additional controls. Three of these are variables which are specifically cited by innovation and some decentralization scholars as important causal factors for innovation, 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 (Daniels, 1997; Grossman & Helpman, 1991, 1995).[14] 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 (McNeill, 1982; Smith, 1985).[15] 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 (Gelb, 1988; Ross, 1999; Sachs & Warner, 1995). 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 (World Bank, 2002). Finally, although the importance of aggregate education is overstated according to some proponents of the decentralization hypothesis (Mokyr, 2002, pp. 274, 291), and arguably endogenous to government structure, I experiment with its inclusion in the regressions. I alternately included controls for undergraduates in science and engineering (total and per capita), literacy (as percent of population), and government expenditure on education (as percent of total and percent of GNP) (World Bank, 2002).

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 1–2.

The lone case in which the null hypothesis can be rejected occurs when I subdivide countries by wealth, but here the affect is fairly small (Table 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% increase in patent citations, 12.8% 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 subgroup of wealthy 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. 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 regarding 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% increase in trade as a percentage of GDP is associated with a 10–20% increase in citations-weighted patents per capita, a 7–8% 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

Table 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]
U.S. 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 < 0.05 **p < 0.01 ***p < 0.001.

Table 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[0.1]					–0.003		
			[0.12]										[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[0.13]	0.2	0.18					
	[0.20]**	[0.20]**	[0.23]**	[0.12]**	[0.12]**	[0.12]	[0.12]		[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]
U.S. 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 < 0.05 **p < 0.01 ***p < 0.001.

Table 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	1.28	0.05	3.36	0.95	0.03
	[0.76]***	[0.55]*	[0.028]†	[0.52]***	[1.04]	[0.009]*
Log GDP	0.46	0.23		0.58	0.45	
	[0.11]**	[0.17]		[0.12]**	[0.34]	
Log Popultn			–0.003			0.0003
			[0.006]			[0.002]
Log KwH/cap	1.14	0.75	–0.01	2.11	0.35	0.016
	[0.41]*	[0.29]*	[0.01]	[0.53]**	[0.95]	[0.007]*
Democracy‡						
U.S. Dummy	–0.23	–0.42	0.0004	–1.52	–0.73	–0.02
	[0.47]	[0.50]	[0.017]	[0.64]*	[1.41]	[0.009]*
Constant	–29.9	–15	0.14	–40.6	–17.3	–0.14
	[4.99]***	[4.59]***	[0.17]	[6.51]***	[11.4]	[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.
†$p < 0.10$ *$p < 0.05$, **$p < 0.01$, ***$p < 0.001$.
‡Omitted due to high multicollinearity.

high-tech exports is not quite so minor when we realize that the sample mean for high-technology exports per GDP is only 0.023% (with a standard deviation = 0.056%). 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 (Dosi, Pavitt, & Soete, 1990; Grossman & Helpman, 1991).

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% of the variance (though this dropped to 10% 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^2s in the multiple regressions of patents and publications.[16] Of course, high multicollinearity among the regressors might also be to blame. In order to test this, the variance inflation factors (VIFs) were calculated and the highest individual VIF is reported for each regression with an R^2 of 0.75 or above.[17] The low VIFs 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 outsourcing 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 that 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 only for a minority of the regressions, a subset of those involving patents or publications. Also, the coefficients for democracy are very small, implying a mere 3–13% increase in patents or publications for a full one-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% increase in military spending is associated with 70–80% increase in citations-weighted patents and a 50–70% increase in citations-weighted publications. Whether this reflects direct military research or a more nuanced correlation between security and innovation is unclear.

Also, the experiments with different measures of natural resource base produced 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. Likewise, experiments with controls for science and engineering undergraduates, literacy, and education spending also failed to substantively affect the coefficients or significance levels for decentralization. These regressions suggested that, even when we control for education, government structure has little overall effect on national innovation rates.

Finally, various lagged measures of the dependent variable (citations-weighted patents citations, simple and 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. Also, 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 (Achen, 2000; Keele & Kelly, 2006; Kelly, 2002).

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 subperiods 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. However, 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 2 and 3 above: countries that 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 results reported above is that government decentralization might have a bell-shaped relationship with innovation. That is, there may be diminishing returns to decentralization such that highly decentralized or highly centralized governments may hinder innovation, but that a happy medium exists. I therefore conducted tests using a "bell" constructed on the *POLCON* index, but they too failed to produce significant results.

A third possible 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 (Gerschenkron, 1962). 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 toward 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% of GDP per capita.[18] 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).

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 (Taylor, 2004). Likewise, the separation of the dataset into temporal subperiods should mitigate some of the concerns over year fixed effects.

It is tempting to imagine that endogeneity may be at play. However there currently exists neither theoretical justification nor empirical evidence to suspect that an uncontrolled variable affects both government structure and innovation. Nor is there reason to suspect that somehow technological change affects government structure. History shows us both democratic and totalitarian states that have taken advantage of technological change to strengthen the power of central government, as well states that have used it to devolve power out to the subnational level.

Also, to some, these regressions may resemble data-mining or seem cavalier. They are not. The inclusion of the different control variables above (trade, military spending, etc.) both have solid theoretical basis and were prompted by the specific recommendations of innovation scholars and reviewers. However, so much the better if the regressions *had* been data-mining or cavalier. Data-mining is indeed problematic when it finds correlations that are then used to prove a theory; but if one goes to the extreme of data-mining and still *cannot* find a correlation between two variables, then the likelihood that a relationship exists between them becomes highly suspect, which is what I argue here. Likewise, if I had found a statistically significant relationship between decentralization and innovation, then questions of whether the regressions were overly casual and cavalier would have been an issue; but here it would only further support the argument against decentralization hypothesis. Indeed, it seems that no matter how cavalier one gets with the data, one still cannot find a relationship between decentralized government and innovation. The non-correlation is quite robust.

Another possibility is that there may be changing returns to decentralization 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, or the need to consider far longer time periods than are analyzed above.

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 innovative advantages of government decentralization, especially the stronger versions of the decentralization hypothesis. They also point to the importance of case studies as the next step in research on this question. Case studies are important for confirming the statistical results produced here. They can resolve,

at close range, 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.

Conclusions

In sum, I have examined two separate sets of patent evidence, along with data on scientific publications and high-technology exports, and found that decentralized states are generally no more technologically innovative than centralized states. These findings were robust to the inclusion of several conditional variables, including controls for democracy, development, size, natural resources, military spending, trade openness, and even education. The only exception to this finding was a minor effect, which appeared only among a small subset of wealthy countries and only when using the broadest measure of decentralization.

The conventional wisdom is therefore incorrect. Political decentralization may have other benefits, but it appears to be neither necessary nor sufficient for explaining or predicting national innovation rates. Certainly 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 assumption that government decentralization leads to higher innovation rates. If we believe that what matters most for long-run aggregate technological change is a competitive environment, then the implication of these findings for policy making is that government decentralization is but one way to achieve this, if at all.

What should the next steps be for innovation researchers? Here I would take as clues the more provocative secondary findings above, such as the relatively minor influence of democracy, and relatively large effect of lagged military spending, on innovation over time. These results deserve 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. More specifically, there are two hypotheses that researchers may want to consider more closely: 1) whether certain types of international relationships (e.g. strategic alliances, capital goods imports, foreign direct investment, educational exchanges) are more important than domestic institutions in determining national innovation rates; 2) whether the political decision to pursue technological change is driven by security concerns, rather than by forces inherent in domestic institutions.

Of course it is important not to get too far ahead of ourselves here, since the various tests reported above were not specifically designed to examine causal

relationships between democracy or military expenditure and innovation. Another 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 statistical findings above. Here I would recommend a micro-level comparative analysis of how government structure affected the innovation process for a given set of technologies. Or alternately, given the productivity of Florida's (2002) recent research, case studies might also probe whether a causal linkage exists between national government structure and increases in the innovation index of particular "creative cities." Regardless, case studies add value here in that they would allow researchers to observe the causal mechanisms, and their effects, in action; something which cannot be distinguished so readily via regression analysis.

Notes

1 This is much the same concept as "balance of power" or "checks and balances."
2 A virtually identical conclusion can also be found in his prior essay on the same subject. See Mokyr (1990, p. 180).
3 Overlap between the two sets of countries and missing POLCON data for Hong Kong and the Bahamas brings the total number of countries to 45.
4 For example: $([X_{US}/X_{world}]_{t=1990–1995} - [X_{US}/X_{world}]_{t=1970–1975})$, where X = forward patent cites/population.
5 Database available at http://www.nber.org/patents.
6 Poisson regression is not used because the data neither follows, nor satisfies the assumptions for, a Poisson distribution.
7 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.
8 Specifically, SITC (rev.2) codes 54, 75, 76, 77, 87, and 792.
9 In this case the dummies are coded (1 = federal, 0 = non-federal) according to Watts (1999). The dummy federal states include: Arab Emirates, Argentina, Australia, Austria, Brazil, Canada, and others (1978 onwards), Switzerland, the United States, Venezuela, and Yugoslavia
10 The 29 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, the United Kingdom, the United States, Venezuela. While Lijphart also provides measure for Bahamas, Barbados, Iceland, Luxemborg, Malta, and New Guinea, the Polity4 database does not, hence these countries do not appear in the regressions reported below.
11 E.g *Sum Lijphrt* = *Lijphrt Fed* + 1/executive dominance (inverse) + bicameralism + judicial review; *Sum Lijphrt Horiz* = 1/executive dominance (inverse) + bicameralism + judicial review
12 To control for annual fluctuations, I use lagged four-year period averages of *POLCON* such that, for example, the average *POLCON* 1980–84 index is used when testing patenting during the 1985–90 subperiod.
13 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.
14 Data source for the regressions is World Bank (2002).
15 Data source for the regressions is USACDA (1975–96).
16 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^2s for the simple bivariate regressions of patents or publications are found on logged GDP (0.34) or democracy (0.39).

17 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) and Green (2000).
18 The "wealthy" countries for the period starting 1975–95 include: Austria, Belgium, Denmark, France, Japan, Kuwait, Netherlands, Sweden, Switzerland, United Arab Emirates, the United States.
19 EPO patent data obtained through the cooperation of Thomas Cusak, David Soskice, and Peter Hall. See also Hall and Soskice (2001).

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