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State structure, technological leadership and the maintenance of hegemony

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Abstract. The importance of technological innovation to economic growth and state power is generally acknowledged in international relations. Less attention has been paid to the state's precise role in fostering innovation. This article argues that, contrary to realism, a centralized state is ill-suited to fostering innovation, particularly for technological leaders. Centralized states are more likely to make errors in crafting policy, and those errors cannot be reversed at the regional or local level. Decentralized states are better suited for the required tasks in fostering innovation. These hypotheses are tested against the Anglo–German rivalry for technological leadership in the late nineteenth century, and the US–Japanese rivalry of the last twenty years. In both cases the more centralized regime—Great Britain and Japan—faltered after initial successes. This suggests a tension within great powers. Policymakers prefer a strong, centralized state to facilitate policymaking. However, the evidence suggests that a decentralized state structure is a necessary condition for states to sustain themselves at the technological frontier.

Introduction

The importance of economic growth to state power is undisputed by international relations scholars.[1] The importance of technological innovation to economic growth is similarly undisputed by economists.[2] Logically, technological leadership is a linchpin of great-power status in the world, a fact recognized by long-cycle theorists.[3] However, despite the obvious importance of innovation to power, and despite a large literature on how the state should be organized to maximize the extraction of societal resources, there has been very little written in international political economy on the state's role in fostering technological leadership.

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1 See Robert Gilpin, *War and Change in World Politics* (Cambridge: Cambridge University Press, 1981), and Paul Kennedy, *The Rise and Fall of the Great Powers* (New York: Vintage Press, 1987).

2 Nathan Rosenberg and L.E. Birdzell, *How The West Grew Rich* (New York: Basic Books, 1985); Joel Mokyr, *The Lever of Riches* (New York: Oxford University Press, 1990); Michael Boskin and Laurence Lau, 'Capital, Technology, and Economic Growth', in Nathan Rosenberg, Ralph Landau, and David Mowery (eds.), *Technology and the Wealth of Nations* (Stanford, CA: Stanford University Press, 1992).

3 William Thompson, 'Long Waves, Technological Innovation, and Relative Decline', *International Organization*, 44 (Spring 1990), 201–33; and George Modelski and William Thompson, *Leading Sectors and World Powers: The Coevolution of Global Politics and Economics* (Columbia, SC: University of South Carolina Press, 1996).

The relationship between innovation and the nation-state has been discussed in international relations, but the debates that touch on the subject mention it only in passing. In the late seventies, there was a great deal of discussion about state 'strength' *vis-à-vis* society as a way of determining foreign economic policies, including industrial policies.[4] One of the implicit arguments in this literature was that strong states would pursue more enlightened economic policies. However, the strong state/weak state typology has been criticized as vague, and this literature has moved away from the study of economic issues, focusing more on security policies.[5]

In this decade, proponents of globalization argue that because information and capital are mobile, the location of innovation has been rendered unimportant.[6] While this notion has some popular appeal, the globalization thesis lacks theoretical or empirical support. Theoretically, even in a world of perfect information and perfect capital mobility, economists have shown that the location of technological innovation matters.[7] Empirically, the claims of globalization proponents have been far-fetched. Capital is not perfectly mobile, and increased economic exchange does not lead to a seamless transfer of technology from one country to another.[8] The location of innovation still matters.

Long-cycle theorists have paid the most attention to the link between technological innovation, economic growth, and the rise and fall of hegemons.[9] They argue that the past five hundred years of the global political economy can be explained by the waxing and waning of hegemonic powers. Countries acquire hegemonic status because they are the first to develop a cluster of technologies in leading sectors. These innovations generate spillover effects to the rest of the lead economy, and then to the global economy. Over time, these 'technological hegemons' fail to maintain the rate of innovations, leading to a period of strife until a new hegemon is found. While this literature has done an excellent job at describing the link between

4 Peter Katzenstein, *Between Power and Plenty* (Madison, WI: University of Wisconsin Press, 1978).

5 Michael Desch, 'War and Strong States, Peace and Weak States?', *International Organization*, 50 (Spring 1996), pp. 237–68.

6 Susan Strange, 'States, Firms, and Diplomacy', *International Affairs*, 68 (January 1992), pp. 1–15; Walter Wriston, *The Twilight of Sovereignty* (New York: Scribner's, 1992); Benjamin Barber, *Jihad vs. McWorld* (New York: Times Books, 1995); Dani Rodrik, *Has Globalization Gone Too Far?* (Washington: Institute for International Economics, 1997).

7 Paul Romer, 'Endogenous Technological Change', *Journal of Political Economy*, 98 (1990), pp. S71–S102. W.W. Rostow, *The Stages of Economic Growth* (Cambridge: Cambridge University Press, 1960); Moses Abramovitz, 'Catching Up, Forging Ahead, and Falling Behind', *Journal of Economic History*, 46 (1992), pp. 385–406; AnnaLee Saxenian, *Regional Advantage: Culture and Competition in Silicon Valley and Route 128* (London: Oxford University Press, 1994), p. 16; Robert Reich, *The Work of Nations* (New York: Vintage Books, 1991); Robert Lucas, 'On the Mechanics of Economic Development', *Journal of Monetary Economics*, 22 (1988).

8 Clive Crook, 'The Future of the State', *The Economist*, 20 September 1997; Richard Nelson and Gavin Wright, 'The Rise and Fall of American Technological Leadership: the Postwar Era in Historical Perspective', *Journal of Economic Literature*, 30 (1992), pp. 195–6; Herbert Kitschelt, 'Industrial Governance Structures, Innovation Strategies, and the Case of Japan', *International Organization*, 45 (Autumn 1991), pp. 453–93; Louis Pauly and Simon Reich, 'National Structure and Multinational Corporate Behavior: Enduring Differences in the Age of Globalization', *International Organization*, 51 (Winter 1997), pp. 1–30; Mark Taylor, 'Dominance Through Technology', *Foreign Affairs*, 74 (November/December 1995), pp. 14–20; Mitchell Bernard and John Ravenhill, 'Beyond Product Cycles and Flying Geese: Regionalization, Hierarchy, and the Industrialization of East Asia', *World Politics*, 47 (January 1995), pp. 171–209.

9 Beyond the citations in fn. 3, see George Modelski (ed.), *Exploring Long Cycles* (Boulder, CO: Lynne Reiner, 1987); Modelski and William Thompson, *Seapower in Global Politics, 1494–1993* (Seattle, WA: University of Washington Press, 1988).

innovation, economic growth, and global stability, it cannot explain *why* technological hegemons lose their lead over time.

This article argues that the governance structure of the nation-state is crucial to determining the effectiveness of national innovation policies, and that a decentralized state structure is a necessary (but far from sufficient) condition for a nation-state to maintain technological leadership. For countries at the technological frontier, a centralized state structure will lead to policies that retard innovation.[10] A centralized state can play a positive role for technological late-comers as a way to accelerate economic growth.[11] However, centralized decision-making at the frontier increases the chances for technological leaders to decline over time. If a unitary, central actor is responsible for public investments into innovation, the decisions will be biased towards *status quo* interest groups. Furthermore, centralized states face a greater handicap in the natural tendency of governments to stick with policies even as their utility declines over time. Centralized states are more likely to maintain flawed policies rather than engage in reform. This problem is endemic to all levels of government, but errors by centralized states are felt across the entire country and difficult to reverse. Decentralized states are more likely to create an environment that fosters experimentation and rewards innovation. Errors by one region are not replicated across the country.

It should be stressed at the outset that there are myriad factors affecting the ability of nations to innovate. Market factors such as industrial organization, the absolute size of the marketplace, entrepreneurial culture, and factor endowments matter. The role of *fortuna* should not be underestimated. A decentralized state structure is hardly a sufficient condition for technological leadership. However, it is argued here that in the modern era it is a necessary condition. Given that the relationship between the two has not been discussed in the international political economy literature, this is not a minor point.[12]

If true, the relationship between state structure and technological leadership has serious ramifications for theory and policy. It suggests that the United States, a decentralized state, has the capability to maintain its technological and economic primacy for the foreseeable future. This prediction stands in sharp contrast to the forecasts of American decline made in the past two decades.[13] It also suggests a tension that great powers face in managing the international system. On the one hand, foreign policymakers need a robust economy in order to advance their

[10] Although there is some minimal overlap between the distinction between centralized and decentralized state structures and the strong state/weak state typology, the differences are more significant. State strength is a function of a bureaucracy's relative autonomy from societal pressures. State centralization is a function of a bureaucracy's relative autonomy *from other bureaucracies*. Thus, state structures are decentralized if many bureaucracies are capable of funding and implementing policies without the need for negotiation with other government organizations. State structures are centralized if only a few government organizations possess this capability. See also Thomas Risse-Kappen (ed.), *Bringing Transnational Relations Back In* (Cambridge: Cambridge University Press, 1995), pp. 20–2.

[11] Alexander Gerschenkron, *Economic Backwardness in Historical Perspective* (Cambridge, MA: Harvard University Press, 1962).

[12] It should also be stressed that the arguments here are neither an endorsement nor a critique of neoclassical economic theory. Indeed, one of the reasons for the upcoming discussion of the nineteenth century chemicals sector is that Germany, which pursued much more interventionist policies with regards to its domestic economy, overtook Great Britain, the classic *laissez-faire* state.

[13] See Kennedy, *The Rise and Fall of the Great Powers*; Samuel Huntington, 'The Lonely Superpower', *Foreign Affairs*, 78 (March/April 1999).

interests. On the other hand, in order to do this, governments must weaken their autonomous decision-making power at the centre. In terms of policy, the argument presented here suggests that the predicted rise of Asian economies to economic primacy is far from assured, and that the role of the state in Asian economic development has a limited practicality.

This article is divided into five sections. The next section develops an explanation for why decentralized government structures are a necessary condition for maintaining a healthy pace of innovation at the technological frontier. Centralized governments are more vulnerable to political pressures to distort innovation policies, and centralized structures prevent other institutions from pursuing alternative policies. Section 3 provides a case study of Great Britain's loss of technological hegemony in the chemicals sector to Germany in the late nineteenth century. The British state erred in not supplying enough public goods to foster innovation; its centralized structure compounded the error. Section 4 sketches the recent rivalry in information technologies between Japan and the United States. Japan's errors in its technology policy are quite different from those of the United Kingdom in the last century, but the causes and effects of the errant policies are quite similar, due to the likeness in state structures. The final section summarizes and concludes.

The role of the state in fostering innovation

I define innovation as one of three types of activities:[14] (1) The introduction of a new product, or a new quality of an established good; (2) The introduction of a more efficient production process; (3) The introduction of a new organizational type for production and/or distribution. The first two activities, product and process innovation, are traditionally associated with technological improvements. Economic historians place a great deal of emphasis on changes in organizational form as an engine for economic growth. Without innovations in organizational form, technological change may not be exploited to the fullest extent.

Nation-states have enormous incentives to encourage innovation. Innovation is the most important source of economic growth. There are other ways to increase economic output: investment in capital, an increase in the supply of labour, or the extraction of resources from occupied lands.[15] These are examples of increasing output through the introduction of more inputs, and such steps are impossible to continue indefinitely. Innovation is the holy grail of economic growth because it raises the level of output while using the same number of inputs, thus increasing productivity. As noted, economists agree that innovation is the most important source of economic growth among the advanced industrial states.[16]

Long cycle theorists have observed that innovation in 'leading sectors' has a disproportionate influence upon economic growth and state power. Leading sectors

[14] This is a truncated version of Joseph Schumpeter's definition in *A Theory of Economic Development* (Cambridge: Harvard University Press, 1934). Schumpeter also includes the opening of new markets and the development of new sources of supply.

[15] On the latter, see Peter Liberman, *Does Conquest Pay?* (Princeton, NJ: Princeton University Press, 1996).

[16] Most recently, see Boskin and Lau, 'Capital, Technology, and Economic Growth'.

possess a bundle of closely related characteristics: high growth rates *vis-à-vis* the rest of the economy, a significant investment in research and development activities, low price elasticities of demand, and spillover effects that improve labour productivity across the entire spectrum of the economy. Historically, a great power has acquired hegemon status through a near-monopoly on innovation in leading sectors.[17]

Although there is no sure-fire formula for increasing the rate of innovation, there are three accepted functions for the state in fostering technological innovation. First, it can reduce the risks of innovative activity by providing a steady source of initial demand. Advocates of this 'demand-pull' hypothesis argue that innovators will focus on ideas that have a receptive market.[18] The larger the potential market, the greater the incentive for innovative activity. For leading-edge technologies, the state can play a critical role in guaranteeing the initial demand for a product or process. A long-term government contract can provide innovators with a reduction of Schumpeterian risk that nascent markets cannot. There are several twentieth-century examples of the state's role in demand-pull technological change: the German demand for ersatz materials in World War I, the British development of radar in World War II, and the United States demand for military and aerospace goods during the Cold War.[19]

Second, governments can invest in public goods related to innovative activity. This would include spending on education and basic science. Public investments in innovation are not substitutes for private sector investment, but rather a complement to such investments. The provision of more public inputs, such as basic science or general education, gives firms an incentive to invest more in private inputs such as specific training or research and development.[20] Historically, firms have invested more of their own resources into R&D activities in response to government investments.[21] Private firms have a greater incentive to invest in their own innovative resources if these public goods are well-supplied.

The state's third function is to establish the rules of the game so that innovation is a profitable activity. Technological innovation is profitable only if the state does not reward other kinds of unproductive behaviour, such as rent-seeking. If the rules of the game are biased against reaping the profits of innovation, fewer innovations will be disseminated, retarding economic growth.[22] Entrepreneurs must be rewarded more for innovation than for other activities. Entrepreneurs need access to capital markets, strong intellectual property rights, and the regulatory freedom to alter their organizational structure to the innovation. Overall, the state must refrain from

[17] Rafael Reuveny and William Thompson, 'Leading Sectors, Lead Economies, and their Impact on Economic Growth'. Paper presented at the 1999 International Studies Association annual meeting, Washington, DC.

[18] Jacob Schmookler, 'Economic Sources of Inventive Activity', *Journal of Economic History*, 22 (1962), pp. 1–20; S. Myers and J. Marquis, *Successful Industrial Innovation* (Washington, DC: National Science Foundation, 1969); J. Langrish et al., *Wealth from Knowledge* (New York: Wiley, 1972); Christopher Freeman, *The Economics of Industrial Innovation* (Cambridge, MA: MIT Press, 1982); Romer, 'Endogenous Technological Change'.

[19] Freeman, *The Economics of Industrial Innovation*.

[20] Paul Milgrom and John Roberts, 'The Economics of Modern Manufacturing: Products, Technology, and Organization', *American Economic Review*, 80 (1990), pp. 511–28.

[21] Reich, *The Work of Nations*, p. 259; David Blank and George Stigler, *The Demand and Supply of Scientific Personnel* (New York: National Bureau of Economic Research, 1957).

[22] William Baumol, 'Entrepreneurship: Productive, Unproductive, and Destructive', *Journal of Political Economy*, 98 (1990), p. 909.

interfering too much in the private sphere of innovative activities, so as to prevent a distortion of incentives.

Given the state's delicate role in fostering innovation, why would a decentralized, weak state be preferable to a strong centralized state? Assume for the moment that there existed a Platonic guardian, concerned only with advancing the national interest, in charge of allocating the state's resources for innovative activities. What challenges would this guardian face? By definition, any state close to the technological frontier cannot know which sector will generate the most strategic and/or lucrative trajectory of innovation. Leading sectors rise and fall with scientific, technological and organizational advancements. In the past three hundred years there have been several redefinitions of the 'high-technology' sector of the economy. Agricultural innovation was a crucial determinant of economic growth and political power during the Renaissance. One hundred years ago the production of steel and chemicals were considered critical sectors. Aerospace and information technologies now represent a state's high-tech capacity.

With finite resources, the Platonic guardian would opt to invest in the most generic forms of education and science, restricting sectoral investments to those areas most clearly related to defence. Beyond the defence sector, investments into research projects would be diversified, in an effort to acquire information about which technologies are promising.[23] The rules of the innovation game would ensure that innovators would be rewarded for successful experiments but not for sustained failures. More important, perhaps, is what the guardian would *not* do. It would not commit too many resources to one project or mission, because of its uncertainty about the exact nature of future innovations. Unpromising avenues of inquiry would be dropped, since there are no political costs to admitting failure. Indeed, failure would be expected, since at the technological frontier no one can predict which innovations will be profitable and which ones will be blind alleys.

Now, instead of a purely Platonic ideal, assume a unitary state actor that requires some political support to stay in power. Regimes with an incentive to remain in power will make three significant deviations from the Platonic ideal. First, the state will prefer allocating innovation resources towards specific sectors rather than education and basic science. It is an iron law of interest group politics that leaders will prefer transferring large rewards to targeted groups over small rewards diffused throughout society. Mission-oriented innovation policies that reward specific actors with subsidies yield a larger political dividend to policymakers.

Second, the state will be more reluctant to discard an unprofitable research program or strategy. All government programs inculcate interest groups with a vested incentive in maintaining that program. Government failures persist for longer than business failures, because governments are more sensitive to political pressures to keep ineffective programs alive.[24] States also have the power of taxation to sustain inefficient policies. Government organizations will develop institutional path dependencies that increase the cost of changing policy. If a prior policy was even marginally successful, bureaucracies will be predisposed against any change, particularly if

[23] Nathan Rosenberg, 'Economic Experiments', *Industrial and Corporate Change*, 1 (1992), pp. 187–8.

[24] A classic US example would be the Strategic Defense Initiative. See Frances Fitzgerald, *Way Out There in the Blue: Reagan and Star Wars and the End of the Cold War* (New York: Simon and Schuster, 2000).

admitting failure would affect the advancement prospects of individual bureaucrats associated with the existing policy.[25] In addition to political pressures and institutional path dependencies, central decision-makers have little psychological incentive to admit error. Nathan Rosenberg observes:

> Any central authority will have a strong motivation for withholding financial support from those who are bent on proving that the central authority made a mistake, or on imposing on the central authority the cost of scrapping splendid-looking facilities whose only fault is that some interloper has devised more productive facilities or discovered that the work done in the facilities can be accomplished more cheaply in some other country—or perhaps not be done at all.[26]

Third, states will have less of an incentive to invest in truly pathbreaking technologies. Mancur Olson argues that if nations experience a long period of stability, pressure groups can form that focus on increasing their relative share of existing benefits rather than increasing overall economic growth. Olson points out that the increasing strength of these groups retards innovation: 'Since a major technological advance will normally change the optimal policy for a cartelistic organization and the relative strength of its members, it will normally require difficult new rounds of bargaining which the special-interest organization may not survive. This in turn makes cartelistic groups cautious about innovation and change'.[27]

Technological leaders are particularly ripe for this problem, since there must be a lengthy period of internal stability to develop the public goods necessary for technological leadership. Governments, democratic or autocratic, are concerned with maintaining their power. This does not bode well for innovators. Glibly put, the industrial revolution would not have occurred if it had been put to a vote. New technologies create winners, but they also cause losers. The prospective winners are entrepreneurs at the forefront of technology, traditionally unorganized and lacking in political clout. The prospective losers are established interests that are more politically organized. The potential losers can prevent the state from fulfilling its necessary functions to promote innovation. Governments maximize their chances of maintaining power by placating those who represent the *status quo*. Even if the social returns to investing in the necessary public goods for technological change may be high, the private returns to the ruling coalition may be small. Although general economic growth clearly benefits the government in power, it fails to do so if the growth comes at the expense of entrenched interest groups.

This is how any governing administration with an incentive to remain in office will deviate from the ideal set of innovation policies. Why would a decentralized state structure lead to a superior outcome? First, and most important, the creation of multiple centres of authority to allocate innovation resources reduces the chances of the entire country pursuing the wrong policies. Decentralization permits policy diversification, increasing the likelihood that at least a few areas of the nation-state will hit on the correct formula for fostering lead technologies. If the central government errs in its policies any correction must also take place at the national level. Nation-states are less likely and less able to learn from other countries than from

[25] Douglass North, *Institutions, Institutional Change, and Economic Performance* (Cambridge: Cambridge University Press, 1990).
[26] Rosenberg, 'Economic Experiments', pp. 192–3.
[27] Mancur Olson, *The Rise and Decline of Nations* (New Haven, CT: Yale University Press, 1982), p. 62.

regions within the same country, because the transaction costs of learning are greater at the international level.

Regional autonomy permits a portfolio diversification of innovation policies. Consider a crude numerical example. A country has a central government and ten regional governments. The central government is more competent than the regional governments. If the central government is in charge of allocating resources for innovation, there is a 75 per cent chance of staying at the technological frontier. Each regional government has only a 50 per cent chance of doing the same thing. If the central government controls all policy, the chances of failure are 25 per cent. On the other hand, if the regional authorities are in control, the chance of all ten regions failing are 0.0923 per cent.[28]

The discussion to this point assumes that regional governments will be less competent than national authorities to make decisions about promoting technological innovation. There are two reasons why the opposite should be the case. First, regional governments enjoy the benefits of local knowledge in crafting the public goods necessary to spur private investment in innovation activities. The more removed the government entity, the less knowledgeable its investment decisions, increasing the chance for error.[29] Second, even though regional governments are just as prone to interest group capture as central governments, the incentives of the relevant interest groups might be different. Regional autonomy can blunt Olsonian biases against innovation. Established interest groups at the regional level are larger relative to the rest of society. They face a reduced incentive to pursue distributional gains at the expense of the rest of the regional economy, and are more likely to push the state for investments in public goods that increase the overall size of the regional economic pie. Frontier technologies and industries can have a much bigger impact on the local area, thus increasing the incentives of the state to invest in the necessary public goods. These reasons undercut the Olsonian move towards rent-seeking.

Decentralized state structures prevent states from inalterably selecting an inferior evolutionary path in their technological development. The existence of multiple governments within the same country also allows entrepreneurs and innovators to relocate if one government is unsympathetic to the needs of local industry. Competition among regions within a country forces a closer alignment between the preferences of private industry and governments. Decentralized institutions permit other governing organizations to exploit learning effects. If one region falters in innovative activities while another region's policies are conducive to innovation, other sections of the nation-state will mimic the successful region and learn from less successful regional experiments.[30] This learning mechanism also works at the international level, but there are fewer barriers to learning within a single sovereign entity.

To be sure, regional autonomy is not a magic tonic for spurring innovation, and centralized state structures are not incapable of contributing to technological inno-

[28] The odds of all the regions failing independently is equal to taking 0.5 to the tenth power, or 1/1028. For a more sophisticated simulation, see Joel Mokyr, 'Cardwell's Law and the Political Economy of Technological Progress', *Research Policy*, 23 (1994), pp. 561–74.

[29] Friedrich A. Von Hayek, 'The Use of Knowledge in Society', *American Economic Review*, 35 (September 1945), pp. 519–30.

[30] Furthermore, central governments can also learn from regional initiatives and adapt their own innovation policies in turn.

vation. The hypotheses developed in this section are probabilistic. As Section 4 will demonstrate, centralized state structures in Japan helped accelerate the process of technological catch-up. However, for technological leaders, the odds of continued dynamism are better with a decentralized innovation system.[31]

Comparative case studies will be used to test the plausibility of this argument. The next two sections examine the technological competition between Great Britain and Germany at the turn of the previous century, and the more recent rivalry between the United States and Japan. These cases were chosen to separate the effects of state structure as a variable from the effects of other factors on innovation. In both time periods, trade barriers were relatively low, so the size of each country's national market (often correlated with the pace of innovation) is less important because of access to global markets. The compatibility of state structure to the industrial organization of the leading sectors can also be discounted.[32] The optimal industrial organization of the leading sectors in the nineteenth century (large, vertically integrated corporations) differs from the optimal organization of the leading sectors in the present day (network-based firms of differing size). Thus, market structure is not correlated with the state structure of the technological hegemon. Finally, these cases also distinguish the effect of state structure from the broader economic ideology of the ruling elites, as Table 1 shows. The argument presented here is distinct from economic debates about the extent of government intervention in the marketplace, and by choosing the relevant countries, this variable can be controlled.

Table 1. Research design

	Centralized state structure	Decentralized state structure
Laissez-faire economic ideology	Great Britain	United States
Corporatist economic ideology	Japan	Germany

Technological supremacy at the dawn of the twentieth century

This section examines the chemicals sector in Europe during the late nineteenth century to see if the previous section makes a compelling argument about the factors

[31] Before the modern era, there are historical examples of centralized states maintaining their technological lead for significant lengths of time. China prior to 1500 was certainly centralized and had a rather impressive run of technological innovations. However, there were no really decentralized states during this time period. It is also worth noting that once Europe emerged with a set of stable nation-states, the decentralized governance structure of that continent helped it to quickly outpace China and India. See Kennedy, *Rise and Fall of the Great Powers*, ch. 1, and E.L. Jones, *The European Miracle* (Cambridge: Cambridge University Press, 1981). More recently, possible exceptions to the arguments made here have been wartime innovations. During wars, however, the disincentives of innovation in centralized states discussed here are considerably lessened.

[32] For this argument, see Kitschelt, 'Industrial Governance Structures, Innovation Strategies, and the Case of Japan'.

behind national technological dynamism.[33] It is generally accepted that chemicals qualifies as a leading sector. It was an engine for research and development activities during the time period in question. David Mowery and Nathan Rosenberg estimate that between 1899 and 1946, the chemicals sector created 25 per cent of *all* research laboratories. If one includes chemical-related industries such as petroleum, rubber, and glass, the figure rises to 40 per cent.[34]

While the British dominated the chemicals sector for much of the nineteenth century, by 1914 they were a spent force. Between 1851 and 1867, in repeated industrial exhibitions, the British displayed its superiority over all other countries. Ralph Landau and Nathan Rosenberg observe, 'In the 1860s and 1870s Britain had almost every comparative advantage in the new chemical industry. It had the largest supplies of high quality coal in Europe, and the largest and most successful textile industry. It knew how to make dyes. It was rich. But it let its advantages slip away'.[35] Between 1886 and 1900, the six largest German chemical firms took out 948 patents; during the same period, the figure for the entire British chemical industry was 86.[36] The Germans established a stranglehold over most of the new products created due to the economies of scope of organic chemical production, such as paints, plastics, fertilizers, and artificial nitrates. By 1913 the British accounted for only 11 per cent of world chemical production; the Germans accounted for 24 per cent. In dyestuffs, the key organic chemicals sector, the Germans produced 140,000 tons in 1913; the British manufactured only 4,400 tons.[37]

Why was Great Britain the technological leader from 1850 to 1870? The origins of British domination came from *laissez-faire* market forces. The first industrial revolution meant that Great Britain was where the demand for chemicals originated. The chemicals sector did not really start to grow until the introduction of organic chemicals, in particular the synthesis of artificial aniline dyes. The demand for the artificial dyes was generated by textile manufacturers as the cost of naturally-produced dyes increased, and the British dominated the textile sector in the mid-1800's.[38] England was also well-endowed with coal-tar, the primary input for manufacturing artificial dye.

[33] The United States also overtook Great Britain during this time period. I have chosen to focus on German policies for two reasons. First, German science and technology at this time were still superior to the United States. All American graduate students in chemistry were required to learn German, and most US professors in chemistry and chemical engineering were educated in German universities. Second, Germany is a better test of the hypothesis, because unlike the United States, the German government was investing substantial resources into its military. In fact, German military spending as a percentage of GNP was greater than Great Britain's. The claim that Britain's relative productivity declined due to military commitments can thus be discounted.

[34] David Mowery and Nathan Rosenberg, *Technology and the Pursuit of Economic Growth* (Cambridge: Cambridge University Press, 1989). See also Modelski and Thompson, *Leading Sectors and World Powers*.

[35] Ralph Landau and Nathan Rosenberg, 'Successful Commercialization in the Chemical Process Industries', in Rosenberg, Landau, and Mowery, *Technology and the Wealth of Nations*, p. 79; See also J.J. Beer, *The Emergence of the German Dye Industry* (Urbana, IL: University of Illinois Press, 1959).

[36] L.F. Haber, *The Chemical Industry During the Nineteenth Century* (Oxford: Clarendon Press, 1958); see also David Landes, *The Unbound Prometheus* (Cambridge: Cambridge University Press, 1969), pp. 352–3.

[37] Ralph Landau, 'Economic Growth and the Chemical Industry', *Research Policy*, 23 (1994), p. 592.

[38] Landes, *The Unbound Prometheus*.

Despite its early lead, the British government failed to invest in the public goods necessary for innovation, satiating the need for educated chemists and engineers by importing them from Germany. German chemists were ubiquitous in British industry in the later part of the nineteenth century.[39] The creator of the Royal College of Chemistry was a German, August Hoffmann. He in turn brought in many of his pupils to England to try and jump-start the British chemical community. With the aid of imported German scientists, the British jumped to the technological lead in the chemical sector.

If the state played no role in fostering innovation, and law of comparative advantage was the only factor determining the location of industrial innovation, then the British should have maintained their dominance in this sector. This was not the case. Despite its advantages, British control of the chemicals industry lasted a brief twenty years. After growing by 9.7 per cent in the 1860's, the UK chemicals sector stalled out, growing a lowly 0.1 per cent for the 1880's.

There is a small cottage industry to explain why Great Britain lost its technological dynamism in the late nineteenth century. The explanations range from a culture predisposed against entrepreneurship to the rising burden of Britain's imperial obligations.[40] However, a contributing factor was certainly the failure of the British government to make the necessary investments in education and basic research, reducing the incentive for firms to invest in scientific research. Overall British investment in advanced scientific or technical education was appalling. A survey in 1900 of employed chemists in Germany found that 69 per cent had doctorates, 10 per cent held degrees from the *technische hochschulen*, and 5 per cent held degrees from both. By contrast, only 10 per cent of British chemists held doctorates, and only 21 per cent graduated from secondary school. Germany was not only producing a higher quality of chemists, it was producing far more of them. In 1890, the ratio of German chemists to British was 101:51. By 1900, the university in Munich produced more chemistry doctorates than all of England combined. There were 7,130 engineering students in the German *technische hochschulen*; for Britain, the number was only 1,433.[41]

Very little money flowed from the British Treasury to the universities. Only in 1889 did the State Treasury begin to contribute to university education, and even then it was only £15,000 for all English universities. The German government, by contrast, contributed between £40,000 and £80,000 on average to *each* university. In 1900, public funds underwrote 80 per cent of German university budgets; in the UK, the figure was 20 per cent.[42] By the 1920's, the noted economist Alfred Marshall, surveying European education, declared that the British education system was at least a generation behind Germany's. Marshall was hardly a proponent of state intervention, but in this case he blamed the British government for relying too heavily upon the private sector to promote a public good.[43]

[39] Michael Sanderson, *The Universities and British Industry, 1850–1970* (London: Routledge and Kegan Paul, 1972), p. 18. See also Beer, *The Emergence of the German Dye Industry*.
[40] See Landes, *The Unbound Prometheus*, for a review of these explanations.
[41] Walter M. Gardner, *The British Coal-Tar Industry* (London: Williams and Norgate, 1915); Sanderson, *The Universities and British Industry,* ch. 1.
[42] Ibid, pp. 46–7.
[43] Alfred Marshall, *Industry and Trade* (London: Clarendon Press, 1927), pp. 97–9.

The lack of state support retarded the incentive for the British chemicals sector to invest in private innovation goods, whereas in Germany, the generous public investments spurred private research and development. The number of trained chemists gave the Germans great economies of scale. Looking back in 1902, one British observer of the industry noted, 'We had the capital, and we had the brains, for we originated the whole thing. But we did not possess the diffused education without which men of ideas cannot fructify beyond the limited scope of the individual'. Another noted that, 'While, in every branch of science we have men of original capacity equal to Germans, or to anyone else, we have not, even now … anything corresponding to the rank and file they have in Germany'.[44]

The British were aware of the problem. As early as 1851, Lyon Playfair stated in a public lecture: 'as surely as darkness follows the setting of the sun, so surely will England recede as a manufacturing nation, unless her industrial population becomes much more conversant with science than they are now'.[45] Two Royal Commissions, in 1872 and 1884, reiterated the need for state investment in education and basic research. One witness testified in 1872: 'It is acknowledged that Science is neither recognized, nor paid nor rewarded, by the State as it ought to be, that mainly owing to this, there is no career for science and that parents and masters are justified in avoiding it'. Another witness was even blunter: 'The State does not at present by any of its acts, acknowledge pure science as an element of national greatness and usefulness and progress'.[46] The 1884 commission noted that the situation had not changed: 'The Englishman is accustomed to seek for an immediate return and has yet to learn that an extended and systematic education up to and including the methods of original research is now a necessary preliminary to the fullest development of industry'.[47] The British were also aware that their inability to innovate was affecting their international position, yet the government failed to rectify the situation. Why?

The answer is consistent with the hypotheses presented in the previous section; centralized states proved susceptible to political pressure from *status quo* interest groups. Joel Mokyr concludes: 'The gradual decline of technological leadership in Britain was closely associated with the rise in resistance by vested interests … in the period after 1850'.[48] At the national level, proponents of new technologies were unable to persuade more powerful and established interests of the need for further technical education. British manufacturing interests were unsympathetic. The chemicals sector differed from the sectors created by the first industrial revolution because it involved the delicate handling of several compounds. Most of the established industrial processes in Britain involved the metamorphosis of only one substance. The other industrialists could not comprehend the importance of process innova-

[44] Beer, *The Emergence of the German Dye Industry*, p. 71; Gardner, *The British Coal-Tar Industry*, pp. 224–5; D.S.L. Cardwell, *The Organization of Science in England* (London: Heinemann Educational Books, 1972), p. 136. See, more generally, Haber, *The Chemical Industry During the Nineteenth Century*. The perfect symbol of this problem was the British inventor of the first artificial dye, William Perkin, who went into business soon afterward. According to his son, he eventually sold out because he recognized that there were not enough chemists around to be able to improve on existing processes or to innovate new products.

[45] Quoted in Cardwell, *The Organization of Science in England*, pp. 87–8.

[46] Quoted in Gordon Roderick and Michael D. Stephens, *Scientific and Technical Education in Nineteenth-Century England* (Plymouth, UK: David and Charles, 1972), p. 40.

[47] Quoted in Cardwell, *The Organization of Science in England*, p. 135.

[48] Mokyr, 'Cardwell's Law and the Political Economy of Technological Progress', p. 565.

tions or the need for scientifically trained personnel.[49] David Landes summarizes the attitudes of the traditional manufacturing bosses: 'they were convinced that the whole thing was a fraud, that effective technical education was impossible, scientific instruction unnecessary. Their own careers were the best proof of that: most manufacturers had either begun with a minimum of formal education and come up through the ranks or had followed the traditional liberal curriculum in secondary and sometimes higher schools'.[50]

The educational establishment was also opposed to the introduction of scientific and technical classes, since this would have implied a wholesale change in their own practices. This feeling was strongest at the university level. In 1880, only nine out of 165 endowed fellowships at Oxford were for the natural sciences; at Cambridge, three out of 105. The establishment attitude was typified by John Stuart Mill in his 1867 inaugural address as the rector of St. Andrews College: 'There is a tolerably general agreement about what a university is not. It is not a place of professional education. Universities are not intended to teach the knowledge required to fit men for some special mode of gaining a livelihood. Their object is not to make skillful lawyers or physicians or engineers, but capable and cultivated human beings'.[51] The resistance of these established interest groups made it difficult for the chemicals sector to get the government's attention. Without backing from other industrialists or the education sector, the chemicals industry was handicapped in its ability to influence the British government.

Second, the British government was reluctant to tamper with previously successful policies. The *laissez-faire* approach of the previous century had paid off in a series of inventions that led to British technological hegemony. There was a strong faith that inventions and innovations came through tinkering on the shop floor as opposed to a massed scientific assault.[52] The British government was concerned about their loss of technological hegemony, but were not convinced that it had a role to play. In 1869 the Chancellor of the Exchequer refused to make any scientific grants, stating, 'I am in principle opposed to all the grants and it is my intention not to entertain any applications of this nature. … I hold it as our duty not to spend public money to do that which people can do for themselves'. Matthew Arnold, one of the most vigorous nineteenth-century proponents of copying from the German education system, concluded, 'There are two chief obstacles which oppose themselves to our consulting foreign experience with profit. One is the notion of the State as an alien, intrusive power in the community, not summing up and representing the action of individuals but thwarting it … The other is our high opinion of our own energy and prosperity'.[53] The central government did not want to alienate established interests, nor was it convinced of the need for action due to the previous success of its *status quo* policies.

49 Jean-Claude Guedon, 'Conceptual and Institutional Obstacles to the Emergence of Unit Operations in Europe', in William Furter (ed.), *History of Chemical Engineering* (Washington, DC: American Chemical Society, 1980).

50 Landes, *The Unbound Prometheus*, p. 345.

51 Quoted in Sanderson, *The Universities and British Industry*, p. 5. See also Landau, 'Economic Growth and the Chemical Industry', p. 592.

52 Cardwell, *The Organization of Science in England*, and W.E. Wickenden, *A Comparative Study of Engineering Education in the United States and Europe* (New York: The Society for the Promotion of Engineering Education, 1929), pp. 23–41.

53 Exchequer quote from Cardwell, *The Organization of Science in England*, p. 126; Arnold's quote from Roderick and Stephens, *Scientific and Technical Education in Nineteenth Century England*, p. 47.

State structure was not solely responsible for the British decline, but it compounded the effect of other errors. Because the British government was so centralized, the regional and local authorities could not recover from the central government's error. Some localities managed a half-hearted response to the needs of the chemicals sector. There were efforts to create new universities that would produce qualified professionals. Liverpool University received generous donations from chemical industrialists like E.K. Muspratt, John Brunner, and William Gossage. New engineering schools were set up in Leeds, Manchester, and Birmingham as well. The best success was Imperial College in London, which focused on chemical engineering. Yet there was still an under-provision of education; even in those sciences covered, the output was too low for much of the period.[54] Even these efforts by the municipal governments were retarded with the further centralization of education in the 1902 School Reform Act. This act placed these newly created technical schools in the hands of the central government. Robert Morant, the Permanent Secretary of the Department of Education at the time, thought technical education was worse than no education at all.[55] Local governments, though more sensitive to the needs of local industries, did not have the power or resources to act contrary to the central government. Without public investments in scientific and technical education, these firms lacked the incentive to invest in significant research and development. As a result most of the British chemical firms withered away after 1890.[56]

The German chemical industry, in contrast to the British, flourished. The Prussian state helped spark the initial growth in the chemicals sector through its demand for textiles, a complement of the dyestuffs sector. The firms in the chemicals sector also prospered because chemists were given sufficient resources to establish research laboratories and develop new products and processes, and they had a pool of trained chemists to draw on. This led to a cluster of product innovations centered in Germany, including pharmaceuticals, photographic film, and artificial dyes. Not only did these firms develop new products, but by constantly improving the processes, the unit costs were continually lowered. Germany won its ascendancy in the chemical field by wrenching thousands of facts from nature through a massed assault.[57]

The German state invested heavily in advanced education in both the universities and the *technische hochschule*, or polytechnics. Between 1872 and 1914, outlays on education were roughly equal to the expenditures made for defence. One German observer at the time stated, 'Basically we had technical schools in Germany before there was a truly developed industry, while in other countries the reverse was the case'.[58] Later observers concur with the role that investment in education played. David Landes observes, 'Where Britain left technical training, like primary education, to private enterprise, which led in the event to a most uneven and inadequate

[54] Sanderson, *The Universities and British Industry*, p. 115.

[55] Meriel Vlaeminke, 'The Subordination of Technical Schooling in Secondary Schooling, 1870–1914', in Penny Summerfield and Eric Evans (eds.), *Technical Education and the State since 1850* (New York: Manchester University Press, 1990); Cardwell, *The Organization of Science in England*.

[56] There were some noticeable exceptions such as Brunner & Mond or Levinstein & Co. These firms later became the backbone behind Imperial Chemical Industries.

[57] Beer, *The Emergence of the German Dye Industry*, p. 90.

[58] Kees Gispen, *New Profession, Old Order: Engineers and German Society, 1815–1914* (Cambridge: Cambridge University Press, 1990), p. 44.

provision of facilities, the German states generously financed a whole gamut of institutions, erecting buildings, installing laboratories, and above all maintaining competent and, at the highest level, distinguished faculties'.[59] The large supply of technical expertise and scientific infrastructure lowered the risks to German capital of investing in an industry that relied upon technological innovation as the source of profits.[60]

The decentralized structure of the German government contributed to the provision of the necessary public goods for innovation. The plethora of German principalities led to a decentralized German state structure during this time period. Even after the creation of a single German state, the regional governments collected taxes, drew up their own budgets, and allocated resources to education. The southern states of Bavaria and Baden enjoyed relative autonomy from the central German state.[61] Some of the German regions mimicked the British attitude towards technical education, but others were more positive. Officials in Karlsruhe led the way in developing the *technische hochschulen* as a way to increase technical education and bypass the resistance of tradition-bound educators.[62] After unification the central German government played only a limited role, consisting of further support for education, a strong patent system, and a favourable tariff structure for raw materials inputs.[63]

The owners and managers of the chemical industry were well aware of the debt they owed to the regional governments. Furthermore, they were able to use their success with some regions to boost support from more recalcitrant regions. Consider the following letter from the German Chemical Industry Association to the Prussian Minister of Education:

> The real reason for the flowering of German chemical production is no secret to the other industrial nations. … It is precisely in these countries that great efforts are being made as of late to catch up with us through the construction of laboratories which are equipped with the latest, most modern research tools. If, therefore, Germany wishes to maintain its present lead, it must be ready to turn its attention to the rapid multiplication of its chemical teaching and research facilities.
>
> Convinced that large sums of money spent for this purpose would bear ample fruit, the South German governments and legislatures have led the way in making generous appropriations. All the Bavarian, Badensian, and Hessian institutions, as well as the Universities of Strasbourg and Jena, have during the last twenty years obtained magnificent laboratories, generously staffed and financed.[64]

59 Landes, *The Unbound Prometheus*, p. 344; see also Clive Trebilcock, *The Industrialization of the Continental Powers, 1780–1914* (New York: Longman, 1981), p. 64.

60 Paul Hohenberg, *Chemicals in Western Europe: 1850–1914* (Chicago, IL: Rand McNally, 1967), p. 47.

61 This characterization of Germany's state structure is somewhat at odds with the popular notion of Germany as a centralized state under Bismarck. This confusion can be repaired by understanding that in matters of defence and foreign policy, the German state was centralized. In other policy areas, Germany slowly centralized over time. See S.E. Finer, *The History of Government,* vol. 3 (Oxford: Oxford University Press, 1997), pp. 1599–1604, and Mark Hallenberg, 'Tax Competition in Wilhelmine Germany and its Implications for the European Union', *World Politics*, 48 (April 1996), pp. 324–57.

62 Wickenden, *A Comparative Study of Engineering Education in the United States and Europe*, pp. 47–54.

63 Beer, *The Emergence of the German Dye Industry*, ch. 10.

64 Ibid, pp. 111–12.

The decentralized nature of the German state led to the optimal formula for state involvement in innovation. As a result, the German firms faced lower costs of innovation and reaped greater rewards from it. German firms were able to exploit economies of scope and get the jump on a host of spin-off products, permitting Germany to catch up and overtake Great Britain prior to the First World War.

The United States, Japan, and technological leadership

Japan's rapid catch-up and persistent failure to overtake the United States in leading technologies points to an intriguing paradox. The very institutions that accelerate economic and technological catch-up in developing countries also constrain innovation once they reach the technological frontier. Centralized political economies are capable of incorporating existing technologies, but are less able to adapt to the demands of technological leadership.

In 1985, Japan was the only credible challenger to US technological hegemony, and was thought to be an ideal candidate to overtake the United States. The role of the Japanese bureaucracy in fostering the postwar rise of the Japanese economy has been a source of intense debate.[65] It cannot be disputed that since 1945 the Japanese government has played an important role in supporting leading technologies, and that by the mid-eighties there were expectations that Japan would overtake the United States. In 1988, the Japanese Ministry for International Trade and Industry (MITI) published a White Paper stating that Japan was on a technological par with the United States in leading sectors, and was more likely to push ahead in the next decade. The US Council on Competitiveness came to a similar conclusion.[66] By 1989, the *Economist* gushed: 'Japanese firms now have a virtual stranglehold on the technologies for making cars, cameras, semiconductor memory chips, video equipment, fibre optics, robots, quality steels and composite materials. Japanese firms are responsible for almost half of the patents being filed around the world. All this, and they are only just getting into their stride'.[67]

The similarities between the Japanese–American competition in information technologies and the Anglo–German competition in the chemicals sector would be hard to ignore. Indeed, in their study of the chemicals sector, David Mowery and Nathan Rosenberg observed, 'This rapidly growing German domination of dyestuffs helped to propel that country into the position of the strongest continental indus-

[65] A brief survey of such works includes Hugh Patrick and Henry Rosovsky (eds.), *Asia's New Giant: How the Japanese Economy Works* (Washington: The Brookings Institution, 1976); Ezra Vogel, *Japan as Number One* (Cambridge, MA: Harvard University Press, 1979); Chalmers Johnson, *MITI and the Japanese Miracle* (Palo Alto, CA: Stanford University Press, 1982); Ryutaro Komiya et al. (eds.), *The Industrial Policy of Japan* (Tokyo: Academic Press, 1988); Daniel Okimoto, *Between MITI and the Market: Japanese Industrial Policy for High Technology* (Stanford, CA: Stanford University Press, 1989); Daniel W. Drezner, 'Running on Empty: The Birth, Life, and Death of Japanese Industrial Policy' (undergraduate thesis, Williams College: Williamstown, MA, 1990). Laura D'Andrea Tyson, *Who's Bashing Whom? Trade Conflict in High-Technology Industries* (Washington, DC: Institute for International Economics, 1992); Russell Hancock, 'A Farewell to Japanese Industrial Policy', *Stanford Journal of International Affairs*, 2 (Fall/Winter 1993), pp. 111–28.

[66] Tyson, *Who's Bashing Whom?*, pp. 46–52.

[67] *The Economist*, 'Thinking Ahead: A Survey of Japanese Technology', 2 December, 1989, p. 1.

trial power. The parallels to the Japanese strategy in electronics in recent decades are striking'.[68]

It is telling that all of the quotations in the preceding paragraphs were made prior to 1990. A decade later, there is little talk about Japan displacing the United States as the technological hegemon. In 1998, a Council on Competitiveness report concluded that the United States was far ahead technologically in the five most crucial sectors of the economy. Between 1990 and 1994, US external patent applications jumped by 113 per cent; Japanese applications increased by only 8 per cent. The American trade surplus in technology licences increased from $6.7 bn in 1986 to $20.6 bn in 1995. In semiconductors, American firms reclaimed both the technological edge and market share from Japanese companies except in low-end memory chips. In microprocessors, US firms increased their global market share from 74.3 per cent in 1990 to 90.1 per cent in 1993.[69] American firms dominate the more lucrative software markets. The latest surge in information technology, prompted by the Internet and the World Wide Web, has left the Japanese behind.

The US resurgence in this leading sector has led to spillover effects in many service industries, enhancing American productivity and profitability across the spectrum of services. From 1996 to 1999, US growth in total factor productivity tripled from the previous decade to approximately 2.4 per cent, on par with the 1960's; Japan's rate sank to a half per cent. For the entire manufacturing sector, US labor productivity remains 36 per cent higher than in Japan.[70] In 1996, one appraisal in *Foreign Affairs* concluded, 'The one country that can best lead the information revolution will be more powerful than any other. For the foreseeable future, that country is the United States … it dominates important communications and information processing technologies … and has an unparalleled ability to integrate complex information systems'.[71] It appears that claims of Japanese technological leadership were, at the very least, premature.

Why did the Japanese fail to become the technological hegemon? Japan's successful catch-up strengthened the practices it needed to change in order to become the technological leader. During the rapid growth era of the fifties and sixties, the Japanese central government played a crucial role in promoting technological catch-up. Despite the acrimonious debate among academics about the merits of Japan's industrial policy, it is agreed that MITI was uncommonly shrewd in its husbanding of foreign exchange to purchase technology licences from the United States and Europe. Until the late sixties, all requests for purchasing foreign technology had to be approved by MITI. The bureaucracy used this power to direct certain firms to specialize in particular technologies and, more importantly, prevented repeated purchases of the same technology. Between 1950 and 1980, Japan spent less

[68] Mowery and Rosenberg, *Technology and the Pursuit of Economic Growth*, p. 80.

[69] *Economist,* 'A Survey of Innovation in Industry', 20 February 1999, p. 27; *Economist*, 'Who's Producing Now?', 22 February, 1997, p. 87; Organization for Economic Cooperation and Development, *Main Science and Technology Indicators*, 1st qtr, 1996, Table 74; Paul Doremus et al., *The Myth of the Global Corporation* (Princeton, NJ: Princeton University Press, 1998), p. 102. Modelski and Thompson, *Leading Sectors and World Powers*, p. 221.

[70] *Economist*, 'Another Miracle: Productivity', 15 May 1999, p. 30; Nicholas D. Kristoff, 'Empty Isles are Signs Japan's Sun Might Dim', *New York Times*, 1 August 1999, p. A4.

[71] Joseph Nye and William Owens, 'America's Information Edge', *Foreign Affairs*, 75 (March/April 1996), p. 20.

than $10 bn on foreign technology.[72] It has proven extremely efficient at incorporating new technologies from outside Japan.[73] MITI was able to direct this effort because it held strong policy tools and a technological road-map of the future in the United States.

This success would seem to contradict the predictions made here about centralized state structures. However, Japan's confused reaction to approaching the technological frontier is consistent with the argument presented here. As a technological follower, Japan's centralized state structure was ideally suited to accelerating growth through the acquisition of foreign technologies. In the process of catching up, however, the Japanese state left institutional legacies that hampered its ability to promote innovation. Throughout the postwar era, MITI encouraged mergers in targeted industries such as automobiles, electronics, and computers, creating an extraordinarily concentrated industrial organization.[74] The Ministry was convinced that the only way for Japanese companies to maintain their competitive edge on a global scale was to exploit economies of scale and scope. Thus, Japan's innovation policies catered to existing firms, not start-ups. Capital markets in Japan remained underdeveloped. In 1988, Japan had a venture capital market of $2.1 bn compared with a US market of $30 bn.[75] This raised significant barriers to entry for high technology start-ups.

The sectors that prospered during Japan's era of rapid growth were well-entrenched and more concerned with their own prosperity. This led to a bias in Japan's innovation policies that favoured mature industries. By 1980, 67 per cent of Japan's public R&D funding went to industrial sectors with low levels of technological innovation; in contrast, 88 per cent of US funding went to high technology sectors.[76] Kenichi Ohmae observes, 'This kind of planned economy—the working basis for the much discussed "Japan, Inc."—may have made sense at an earlier stage of the country's development. But now, … continued direction from the center can mean only ever-greater subsidies to the areas and industries left behind'.[77] Prior successes reinforced the bureaucracy's belief in its own powers of foresight, making it less likely to alter its policies. Japanese regions have much less power than American states to set policy; they are generally instruments for politicians to provide hand-outs. Without regional autonomy, it will be difficult for Japan to make the necessary adjustments for technological leadership.

Rivalries between the Japanese ministries prevented any linkages between universities and industry. Although the Japanese bureaucracy has placed a great deal of emphasis on education, it has failed to invest in other public goods such as basic

[72] Akira Goto and Ryuhei Wakasugi, 'Technology Policy', in Komiya et al. (eds.), *Industrial Policy of Japan*; Merton Peck and Tamura Shuji, 'Technology', in Patrick and Rosovsky (eds.), *Asia's New Giant*; The *Economist*, 'Thinking Ahead'; Taylor, 'Dominance Through Technology'.

[73] Edwin Mansfield, 'Industrial Innovation in Japan and the United States', *Science*, 241 (September 1988), pp. 1769–74. See also Doremus et al., *The Myth of the Global Corporation*, pp. 64–5.

[74] Johnson, *MITI and the Japanese Miracle*. See also Yoshihiro Morozumi, 'A Statement Against Free Competition', in Daniel Okimoto and Thomas Rohlen (eds.), *Inside The Japanese System* (Stanford, CA: Stanford University Press, 1988).

[75] Arthur Alexander, *Comparative Innovation in Japan and the United States* (Santa Monica, CA: RAND, 1990), p. 47.

[76] See Table 2 in Henry Ergas, 'Does Technology Policy Matter?' in Bruce Guile and Harvey Brooks (eds.), *Technology and Global Industry: Companies and Nations in the World Economy* (Washington, DC: National Academy Press, 1987).

[77] Ohmae, *The End of the Nation State*, p. 124.

science. Between 1955 and 1990, university research budgets declined from ¥10 million *per capita* to ¥8 m.[78] The bureaucratic muscle of the Japanese Ministry of Education, Sport and Culture (MESC) hampered efforts to innovate. In 1980, when the Japanese Science and Technology Agency proposed disbursing funds to universities for basic research, the Education Ministry threatened professors not to accept research funds from other government departments or they would lose MESC funding. By 1992, little had changed. One professor observed, 'MESC controls from elementary school to the highest levels of the research system. This is a major problem. High research is like art—it's a mistake for it to be under the control of one bureaucratic system. We have to have maximum flexibility—but you cannot have this within a single bureaucratic structure'.[79]

Recent attempts at industrial policy highlight the differences between nineteenth-century Germany and present-day Japan. Germany was able to acquire technological leadership because its central and regional governments funded technical education and basic science, and then left businesses to innovate on their own. The Japanese state has underfunded basic scientific research, but its other mistake has been its attempts to micromanage the direction of innovation. Efforts to create a planned 'science city' in Tsukuba proved extremely problematic, and failed to boost the pace of Japanese basic research.[80] MITI's technology consortiums in the past twenty years proved frustrating. In response to approaching the technological frontier, MITI increased the time horizons of the consortia. This increased MITI's control, but was ill-suited to the fast pace of technological innovation. The technologies targeted by MITI's consortiums—fifth generation computers, semiconductors, civilian aircraft, aerospace—all failed to take off.[81] Scott Callon's conclusions about MITI are consistent with the problems centralized states face as technological leaders:

> With catch-up efforts, MITI knew where to spend its money, because it was following a technology trail that had already been blazed by US firms. It could focus all of its money on the particular targeted technology. But once MITI switched to funding future technologies, things became more complicated. It was no longer clear where and how to spend the money, since future technologies by definition did not exist yet and it was very hard at times to figure out which technologies would prove to be important and which would not.
>
> The implications for MITI R&D funding patterns were enormous. What had been the right strategy during the catch-up era now became precisely the wrong strategy. Whereas concentrated funding of a new technology area was highly effective during catch-up, since the money would be spent on existing, proven technologies, these same concentrated bets would prove to be highly dysfunctional as part of a futuristic R&D strategy entailing basic research. Diversification, not concentration, was the appropriate strategy.[82]

78 *The Economist*, 'Thinking Ahead', p. 7.
79 Quoted in Alun Anderson, 'Japanese Academics Bemoan the Cost of Years of Neglect', *Science*, 258 (October 1992), p. 567.
80 David Hamilton, 'Has Tsukuba Put Its Worst Days Behind It?' *Science*, 258 (October 1992), p. 572. James W. Dearing, *Growing a Japanese Science City* (New York: Routledge, 1993).
81 Hiroyuki Odagiri and Akira Goto, 'The Japanese System of Innovation: Past, Present, and Future', in Richard Nelson (ed.), *National Innovation Systems: A Comparative Analysis* (New York: Oxford University Press, 1993).
82 Scott Callon, *Divided Sun: MITI and the Breakdown of Japanese High-Tech Industrial Policy* (Stanford, CA: Stanford University Press, 1995), p. 170.

In recent years, MITI and other bureaucracies have responded, slowly, to being a state at the technological frontier.[83] However, centralized state structures remain an impediment to fostering innovation in leading sectors. Herbert Kitschelt concludes, 'Japanese governance structures comprising corporations, public agencies, and universities have been too centralized … and have allocated too much risk to private investors to cope with the challenges of highly uncertain, complex interactive systems'.[84]

The strength of decentralization can be observed in the surprising resilience of the United States. The power and autonomy of state governments contributed to the rise of the United States to technological pre-eminence before the Second World War, and laid out the institutions necessary for maintaining technological leadership.[85] Starting in the 1950s, the federal government began to play a bigger role in the funding of basic research. It was not an exclusive role, however. Because the state governments had considerable autonomy over education and the rules of the innovation game, it was possible for some regions to adjust to new technologies quicker, with other regions quickly patterning their polices after the successful states.

In the 1970s, the most active regions in information technology were located in the Route 128 area outside of Boston, and in Santa Clara Country surrounding Stanford University. Both initially benefited from federal government contracts to develop computer technology. In response to the Japanese challenge, Route 128 proved unable to maintain its technological edge. Silicon Valley was able to adapt, and is still the locus of innovation in this leading sector.

Why the difference? In part, it was due to the variation in the provision of public goods and the rules of the game set by the state governments. Although both areas were well-endowed in elite, private universities (Stanford, Harvard/MIT), California provided more funding for state and community colleges than Massachusetts.[86] California's tax structure favoured small business formation and rewarded capital gains more than Massachusetts.[87] Venture capital was prominent in California because the rules of the game did not discriminate against it. In fashioning these policies, the state government increased the incentives for individuals to form start-up firms and market their innovations. One 3Com executive observed: 'One of the things that Silicon Valley lets you do is minimize the costs associated with getting from idea to product'.[88] Politically, Silicon Valley had fewer interest groups that opposed its aims. Massachusetts had more entrenched interest groups that opposed policies conducive to innovation.[89]

[83] Glenn Fong, 'Follower at the Frontier: International Competition and Japanese Industrial Policy', *International Studies Quarterly*, 42 (June 1998), pp. 339–66.

[84] Kitschelt, 'Industrial Governance Structures', p. 482.

[85] David C. Mowery and Nathan Rosenberg, 'The US National Innovation System', in Nelson (ed.), *National Innovation Systems*, pp. 31–9. It should be stressed that neither Mowery and Rosenberg nor I would be foolhardy enough to claim that US economic success is solely caused by a decentralized state structure. Market size, the constant infusion of immigrant labour, and myriad other factors played a role as well. However, a contributing factor to the US ability to acquire and maintain its status as the technological hegemon was its state structure.

[86] Thomas Kane and Cecilia Rouse, 'The Community College: Educating Students at the Margin Between College and Work', *Journal of Economic Perspectives*, 13 (Winter 1999), p. 65.

[87] Another crucial difference was that California law refused to recognize post-employee covenants not to compete. This raised the incentives for entrepreneurs to leave their firms if they wanted to start up their own company. See *The Economist*, 'Silicon Valley: A Survey', 29 March, 1997, p. 12.

[88] Saxenian, *Regional Advantage*, p. 114.

[89] AnnaLee Saxenian, 'In Search of Power: the Organization of Business Interests in Silicon Valley and Route 128', *Economy and Society*, 18 (February 1989), pp. 25–70.

As the government's role in the recipe for successful innovation became clear in California, other state governments mimicked their public and private institutional forms and thus accelerated the US advantage in information technologies. In the eighties, most states began to support links between public universities and industry-based research, and provided funds to ensure the growth of those linkages. Soon, other regions in the United States followed. The adoption of these policies contributed to the growth of Austin, Boise, Boulder, Minneapolis, New York City, Seattle, and North Carolina's Research Triangle as innovation centres for information technologies. Policy adoption was a diffusion process among the states based on competitive emulation.[90] Successful policies were implemented; less fruitful policies were rejected more quickly than in Japan.

The federal government's role in promoting technological innovation was also significant, but it offers a stark contrast to Japan. The Japanese government has attempted to micromanage the innovation process while underfunding certain public goods. The United States kick-started information technologies by contributing to the initial demand for this sector, and providing public goods in the form of basic science. Both the military and space programs boosted the demand for these technologies; in the 1960's, over half of Route 128 and Silicon Valley's demand came from the government.[91] This demand benefited US power directly through the development of new military technologies, and indirectly, through the fostering of sustained technological leadership. The federal government also funded basic science research in the universities, which lead to the growth of new firms outside of Stanford and MIT. The provision of these funds was decentralized within the federal government, coming through multiple agencies and departments.[92] In contrast to Japan's education ministry, no federal bureaucracy had the power to block other agencies from funding research and development activities.

In addition to boosting demand and providing public goods, the federal government set some of the rules of the game that promote innovation, particularly the patent laws.[93] Beyond that, however, the federal government's main contribution came through its restraint. *The Economist* observes, 'If nothing else, the American government has made a powerful contribution by not doing things that would have messed it up. … In Silicon Valley, success in just about any area turns out to hinge on either some liberalizing legislation, or the absence of any legislation at all'.[94] In contrast to the Japanese government, the United States refrained from stacking the rules of the game towards any particular set of technologies or organizations. This permitted variation in regional policies and produced the set of regional policies that best promoted innovative activities. Other countries that have attempted to copy the Silicon Valley approach have often failed precisely because the government policies

[90] Virginia Gray and David Lowery, 'Corporatism Without Labor? Industrial Policymaking in the American States', *Journal of Public Policy*, 11 (July 1991), pp. 315–29.

[91] Saxenian, *Regional Advantage*, ch. 1.

[92] Doremus et al., *The Myth of the Global Corporation*, p. 63. See also Aaron Friedberg, 'Science, the Cold War, and the American State', *Diplomatic History*, 20 (Winter 1996), p. 110. It should be noted that, consistent with the hypotheses developed here, when the US federal government tried to take an active role in the promotion of specific technologies, it had much less success. See Linda Cohen and Roger Noll, *The Technology Pork Barrel* (Washington, DC: The Brookings Institution, 1991).

[93] For example, federal contractors can own any inventions developed with federal R&D funding. Ergas, 'Does Technology Policy Matter?', p. 199.

[94] *The Economist*, 'Silicon Valley', p. 12.

were too narrowly tailored to a particular technology or organizational form.[95] This prevented the growth that has been observed in Santa Clara county.

Conclusion

Technological dynamism remains an important component of state power. This article argues that technological leadership is ephemeral if national innovation systems are too centralized. Politically powerful interest groups can alter the provision of public goods or the rules of the game and reduce the incentives for further innovation. States can also make policy mistakes because they are at the technological frontier and assume that past successes will be replicated in the future. Regional autonomy within the nation-state can prevent decision-makers from being captured by domestic interests with an investment in the *status quo*, from pursuing the wrong technological paradigms, or from letting errors by the central government corrupt an entire national innovation system.

Germany's rise to technological leadership in the chemicals sector provides strong support for the hypothesis presented here. Resource endowments gave Great Britain a comparative advantage in the chemicals sector, yet between 1867 and 1900 its technological leadership evaporated. Germany was able to take the lead because of its significant investment in basic science and technical education. Local and regional governments had considerably autonomy over these policies, and had the local knowledge necessary to increase the incentives for firms to innovate. Although local governments in Great Britain recognized the value of technical education, they had insufficient resources and autonomy to make the necessary public investments. The British central government did not wish to upset entrenched interests in manufacturing and education. Most of the government decision-makers assumed that future successes would be built on prior successes, and thus saw no need to alter their policies.

A comparison of Japanese and American technological performance in the past two decades also supports the argument about state structure. The concentration of power within the Japanese bureaucracy proved to be useful for technological catch-up. Beyond the provision of public goods and establishing the rules of the game, the bureaucracy also minimized the costs of technology transfer and strongly encouraged vertical and horizontal integration among firms in leading sectors. However, by the mid-1970s these advantages had turned poisonous to Japanese innovation. The bureaucracy intervened too much in the innovation process and guessed wrong about the future innovation trajectories. The central government underfunded public goods such as basic science research, believing future successes would mirror past ones. Even as the state tried to adapt, it intervened too much in the innovation process, compounding the problems of the Japanese innovation system.

[95] AnnaLee Saxenian, 'The Cheshire Cat's Grin: Innovation, Regional Development, and the Cambridge Case', *Economy and Society*, 18 (November 1989), pp. 448–77; Dearing, *Growing a Japanese Science City*.

The centralized nature of the Japanese government meant that errors by the central government could not be offset by regional autonomy, affecting the entire nation. In the United States, however, the federal government limited its role to spurring initial demand, funding basic research, and protecting patents. The autonomy of the state governments caused some regions to falter, but allowed others to thrive, leading to the surge in technological and organizational innovation in Silicon Valley. As other states and regions mimicked the institutional aspects of this region, the United States again built up a technological lead over Japan.

The conclusions of this article have two immediate implications. First, it reaffirms the importance of domestic political structures in determining the economic power of nation-states. There is no evidence in the case studies that international systemic forces affected innovation policies. This is striking, given that the flaws in these policies led to British hegemonic decline and contributed to Japan's anaemic economic growth in the past decade. In both cases, resistance by well-entrenched interest groups and bureaucracies contributed to the lack of change. This suggests that in areas vital to the position of the nation-state in the world, the systemic effects on domestic policy are not privileged. This provides a counterpoint to recent claims about the effects of globalization on national economic policies.

For the near future, there are two further observations. First, the decentralized nature of American innovation policies suggests that the United States will maintain its technological and economic primacy, in contrast to predictions of decline by a myriad of sources. Of the potential challengers, only Germany has the same level of decentralization, and that may change with further European integration and centralization. The very weakness of the federal government, criticized by both classical and structural realists in terms of crafting foreign policy, also contributes to the sources of US power.

Second, the results suggest that technological latecomers face a paradox in attempting to compete in the global economy. The ingredients for motivating technological catch-up are ill-suited for technological leadership. While the countries of the Pacific Rim may be enjoying the fruits of rapid growth and government support, they will find it necessary to alter their policies as they converge towards the technological frontier. Some countries, such as Taiwan, appear to have been able to make the adjustment from follower to leader with a concomitant adjustment in state policies. However, the Asian economic crisis suggests that the transition may be more painful for other countries in the region. There may be an Asian path to development, but it is doubtful that sticking to that path will lead to Asian hegemony.