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THE CENTER FOR INTERNATIONAL ENVIRONMENT & RESOURCE POLICY

ENERGY, CLIMATE, AND INNOVATION PROGRAM
THE FLETCHER SCHOOL
TUFTS UNIVERSITY

National Innovation Systems in the United States and China

A Brief Review of the Literature

Aaron Melaas and Fang Zhang

Abstract

This paper looks at three system-level factors that help define the national innovation systems of the United States and China: public and private sector activity, basic and applied research activity, and innovation objectives and outcomes. Through a review of the literature on national innovation systems in the two countries, it identifies how both governments play an active role in supporting innovation by privately-owned firms and face similar domestic policy coordination challenges. It highlights the contrasts between the two countries when evaluating the balance between their respective efforts in basic and applied research and in assessing innovation objectives and outcomes. In conclusion, despite challenges, government, industry, and university actors may yet identify valuable opportunities for international cooperation and promote a robust approach to innovation through globalization and economic integration.

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The Fletcher School at Tufts University was established in 1933 as the first graduate school of international affairs in the United States. The primary aim of The Fletcher School is to offer a broad program of professional education in international relations to a select group of graduate students committed to maintaining the stability and prosperity of a complex, challenging, and increasingly global society.

The Center for International Environment and Resource Policy (CIERP) was established in 1992 to support the growing demand for international environmental leaders. The Center provides an interdisciplinary approach to educate graduate students at The Fletcher School. The program integrates emerging science, engineering, and business concepts with more traditional subjects such as economics, international law and policy, negotiation, diplomacy, resource management, and governance systems.

The Energy, Climate, and Innovation Program (ECI) advances policy-relevant knowledge to address energy-related challenges and opportunities, especially pertaining to climate change. ECI focuses particularly on how energy-technology innovation can be better harnessed to improve human-well being, and the role of policy in the innovation process. Although ECI's outlook is global, we concentrate mainly on energy and climate policy within, and between, the United States and China. We also focus on how these countries influence the international negotiations on climate change, and the role of technology in the negotiations.

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I. Introduction

Beginning in the early 1990s, the initial research on national innovation systems tended to focus on firm activities at the core of the technological innovation process. The research model sought to measure firms' innovation performance through the development of new products, focusing on the linkages between firms and other actors in the innovation system, including their ability to absorb innovative technologies (Nelson 1993; Freeman 1995; Lundvall 2010). More recent scholarship has concentrated on the specific roles played by these other actors, such as governments' role in creating policy incentives and universities' role in conducting research. As the level of interaction among the three spheres of industry, university, and government has intensified, and as their activities began to overlap, Etzkowitz and Leydesdorff (2000) started to model the relationships among these actors as a so-called "triple helix". This helped open a new phase in the study of innovation systems, which looked at universities' role in commercializing knowledge though licensing or as the source of spinoff companies (Cai and Liu 2013).

This paper provides a brief review of the literature on national innovation systems in the United States of America and the People's Republic of China. It is strongly influenced by previous studies of national innovation systems that use the triple helix model to depict relationships among private firms, public officials, and university researchers. In that respect, this review also builds on Liu and White's (2001) effort to go beyond evaluating roles played by individual actors in order to evaluate the key system-level factors that shape innovation. This literature review considers three such system-level factors: public and private sector activity, basic and applied research activity, and innovation objectives and outcomes.

Dodgson (2009) claims that cultural legacies can profoundly influence the shape of national innovation systems, and indeed, historical events and social norms in each country have had a major impact on the shape of institutions, the articulation of priorities, and innovation outcomes. Because the United States and China both have complex political systems as well as large and diverse markets, their respective national innovation systems are each characterized by a number of important nuances and contradictions. The United States produces a significant number of technological innovations but has struggled to articulate and execute a clear national innovation strategy. And while China has established clearer priorities, its status as a transition economy means ongoing policy reforms are the source of significant changes in its innovation system. Yet, for all of the differences that distinguish the U.S. and Chinese national innovation systems, there are still a number of important similarities between the two countries, including their need to confront major policy coordination challenges.

II. Actors: Public & Private

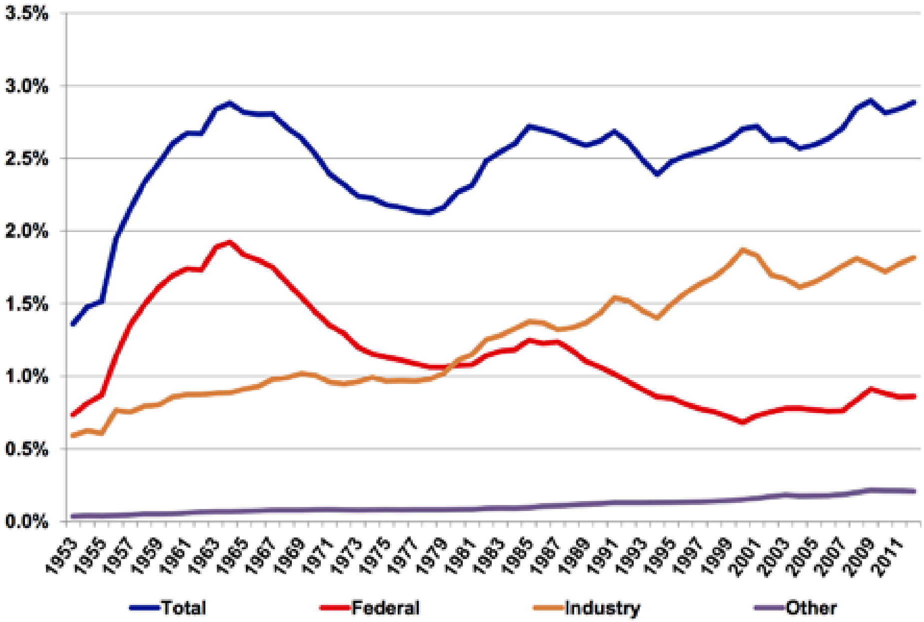
Literature on national innovation systems frequently draws a distinction between the United States and China based on the relative balance of public and private sector activity supporting innovation in each country. The level of activity in the public sector is deeply influenced by the distribution of political power between the national government and state and provincial governments and private sector activity is largely determined by the weight of R&D activity in different sectors of the economy and by the availability of financing from mature capital markets. Perhaps most importantly, however, the relative activity of each sector is determined by the opportunities and constraints that government regulations establish for private actors.

United States

The United States is governed by a federal political system, which tends to favor a more limited level of direct public sector support for innovation because of a traditional assumption that the private sector will make the best choices for allocating R&D investments. Political consensus is required for appropriation of research dollars, and under the Obama Administration, Congress has not been willing to fully support the Administration's budget requests, resulting in essentially flat R&D investments for the last decade—an achievement during the Congressional policy of "sequestration".

Meanwhile, it is unclear to what extent the private sector finances and performs R&D in the current era of economic recovery, with data showing considerable volatility (see Fig. 1). Nonetheless, the federal government still plays an important role without duplicating or "crowding out" private sector investment because it tends to focus on funding and performing basic research, whereas the private sector does so with increasingly less frequency (Gallagher et al. 2012).

Figure 1: R&D as a Share of GDP by Funder



Source: National Science Foundation National Patterns of R&D Resources Series. © 2015 AAAS

1. PUBLIC SECTOR

Overall, the federal political system tends to favor a more limited level of direct public sector support for innovation because political capabilities and responsibilities are distributed across a number of actors. Despite the articulation of a national innovation strategy by the White House, this wide distribution of power and influence and the need for extensive coordination across government agencies prevents any one agency from taking a leading role in the execution of innovation policy. In those areas where the government is most active (financing basic research and regulating firm behavior), its activities may also be constrained by changing political priorities among elected officials.

A. INDIRECT SUPPORT

As innovation scholar David Mowery has pointed out, the U.S. federal government has accounted for a tremendous share of national R&D spending over the past half-century. And despite fluctuations in the federal R&D budget over the past 30 years, the total ratio of government R&D spending to GDP in the United States is still relatively high, despite its tendency to concentrate in the defense and health sectors. A substantial amount of federal government support takes the form of funding for public universities and government labs, with some federal subsidies specifically directed to research in high-impact areas. The federal government also utilizes the Small Business Innovation

Research (SBIR) and Small Business Technology Transfer (STTR) programs to expand public/private sector partnership opportunities and strengthen the role of small firms in federally funded innovation activities.

However, technological innovation has generally been considered a second-tier item on the national policy agenda behind other economic and political issues (Mowery 1992; Shapira and Youtie 2010). Besides funding and incentivizing R&D, the principal de facto domains of federal policy are to provide the conditions for innovative activity in the private sector by establishing a strong educational system, creating incentives for greater competition, and helping solve market failures, such as the tendency of small- and medium-sized businesses to under-invest in research (Link and Scott 2010).

Consequently, U.S. policymakers tend to favor market-based tools, such as corporate tax credits that allow private firms to reduce marginal costs by permitting deductions for R&D expenditures. The U.S. patent and copyright systems also help provide important incentives for innovation by increasing potential returns to R&D activity and by protecting inventors. And in those areas where federal government procurement policies create a strong demand for innovative technologies, the absence of major state-owned enterprises means that the government must instead contract with a variety of producers in the private sector (Mowery 1998; Simons and Walls 2008).

B. DECENTRALIZATION

The federal government structure of the United States also allows regional- and state-level innovation systems to take on distinct identities and characteristics. These systems generally share common objectives, such as supporting investment in R&D and helping to solve market failures. For example, state-level R&D tax credits can double the savings available to firms that have already taken advantage of federal tax incentives (Simons and Walls 2008). Political decentralization also allows for a greater degree of local control over the selection of policies to pursue these objectives, thereby prioritizing pragmatic concerns over ideological positions when shaping policy (Wessner 2013).

While the United States does have a number of federal research labs, it has neither a federal innovation agency nor a federal university system. State governments are therefore able to make strategic policy decisions that affect large research institutions, giving them a greater degree of flexibility in matching direct support to specific research objectives. Nonetheless, it is important to acknowledge that state and local government efforts to support innovation activities do face tighter resource constraints.

2. PRIVATE SECTOR

Highly developed private capital markets play a crucial role in shaping the U.S. national innovation system, providing support to small-scale entrepreneurs as well as large established firms. Over the past half-century, private industry traditionally performed between two-thirds and three-quarters of U.S. R&D by value, and though a significant portion of that activity was funded by the federal government, private partnerships and investment banks represented the largest individual proportions of new capital commitments overall, in the number of firms funded and in total capital provided (Simons and Walls 2008).

Although the level of active support for innovation from venture capital has fluctuated over the past two decades, much of this fluctuation can be attributed to the cyclical nature of capital availability as a result of broader economic trends. During the late 1990s, the overfunding of the high-tech sector and the subsequent bursting of the tech bubble appeared to demonstrate that venture capital had become far less effective at supporting innovation. But while the economic downturn did see funds dry up temporarily, venture capital restored its large role in funding new ventures during the first decade of the 2000s, and the private sector remains a key component of the U.S. innovation economy (Gompers 2003; Simons and Walls 2008).

3. CHALLENGES

Although the U.S. national innovation system is broadly characterized by a high degree of decentralization, there is a significant degree of dissonance among scholarly views on the success of this system over the past half-century. Some scholars have pointed to decentralization as a key to success, including the degree to which it facilitates the supply of R&D funding for small firms (Mowery 1992). Other scholars, however, take a more pessimistic view, claiming that the absence of a clearly articulated innovation policy at the federal level produces a "race to the bottom" that matches national policy objectives to the most limited state-level efforts (Atkinson 1991).

Certain strategically important sectors such as national defense and public health are able to benefit from direct federal government support for technological innovation, but a number of other key areas have suffered from a lack of coordination on federal-level policy. In 2009, the Obama Administration sought to address this problem by issuing the first-ever national innovation strategy, and in October 2015, an updated Strategy for American Innovation was published.[1] The updated strategy identifies nine areas of opportunity: precision medicine, advanced manufacturing, BRAIN initiative, advanced vehicles, smart cities, clean energy, educational technology, space, and computing. But without Congressional support for the strategy, its long-run impact may be limited.

Since the 2008 financial crisis, many small firms have experienced difficulty in obtaining access to capital, whether to fund R&D or to bring their products to market.

1 https://www.whitehouse.gov/the-press-office/2015/10/21/fact-sheet-white-house-releases-new-strategy-american-innovation

Despite the existence of federal-level programs that can directly address this market failure by providing government financing, there is still space for more comprehensive efforts to coordinate with sources of private capital. Moreover, because state and local governments are often subject to greater fluctuations in the amount of resources available to them, budget constraints at lower levels of government may pose a greater threat to government commitments to support technological innovation in the United States (Carey et al. 2012).

China

In China, the public sector is directly involved in all aspects of innovation, from government agencies that define research objectives to government labs that conduct research and development, and its role in innovation is enhanced by the presence of state-run banks and state-owned enterprises. The private sector continues to play an increasingly larger role in the innovation system thanks to a series of political reforms, but immature capital markets limit its role as a financier.

4. PUBLIC SECTOR

In contrast to the political federalism and party competition that shapes public policy in the United States, Chinese public policy is defined by a highly centralized political system under single-party control. Due to political instability in China throughout the first half of the 20th century, the country was unable to develop a strategic approach to public policy that supported scientific research and technological development (Song 2008). After the establishment of the People's Republic, the country followed a Soviet model of central planning during the 1950s, which hampered the development of science and technology skills. During the 1960s and 1970s, it struggled through the Cultural Revolution, which eliminated nearly an entire generation of intellectuals.

The centralization of political power in China began to change notably under Deng Xiaopeng's "open door policies" and subsequent market-oriented reforms (Xue and Forbes 2006). Over the following three decades, decentralization has given local authorities—including those governing China's Special Economic Zones, or SEZs—a significantly higher degree of autonomy, while incremental regulatory reforms have enabled community-owned township and village enterprises to accumulate private capital and privately owned firms to expand their role in R&D and the production of new technologies (Gu and Lundvall 2006).

A. DIRECT SUPPORT

The political dominance of the Chinese Communist Party gives it the ability to shape policy to fit its political goals, such as improving domestic technological capabilities in strategic sectors of the economy. Chinese efforts to reduce the cost of importing technology have traditionally been relatively more successful than those aimed at developing indigenous R&D capabilities, and as a result, privately sourced R&D spending only began to keep pace with government spending on research during the past decade. Recent increases in domestic R&D spending were a response to public policies focused on building a knowledge-based economy over previous decades of state-led development (Zhou and Leydesdorff 2006). However, more recent analysis of China's national innovation system demonstrates that there has been a significant degree of structural transformation in two areas.

First, the funding structure has gone from one centered on government activity to a model that is enterprise-centered. Second, the performance of technological innovation itself has moved from a two-actor model—divided between firms and government research institutions—to one led principally by firms (Sun and Liu 2010). Industry surveys in China have demonstrated increasing competitive pressures akin to those of market economies, local institutional support for the independent advancement of technological know-how, and widespread development of greater learning and innovation capabilities by a number of firms, including privately owned small and medium enterprises (Dobson and Safarian 2008). A recent investigation into the effects of Chinese government financial incentives during the 1990s also showed that special loans and tax credits were far more effective than direct incentives at improving firms' innovation performance (Guan and Yam 2015).

B. CENTRAL PLANNING

China continues to use five-year plans to promote structural transformation and shift its development model from factor-oriented growth to industrial growth, and subsequently to innovation growth. Public policy is still characterized by a high degree of central planning, a wide range of policy inconsistencies, and the persistence of perverse incentives, but an important series of reforms have started to alter these dynamics (Xue 1997; Liu and White 2001; Xiwei and Xiandong 2007; Sabir and Sabir 2010).

In 1995, the National Conference on Science and Technology established a new State Leading Group for Science, Technology & Education that would coordinate national strategies for education policy and identify priority sectors areas for direct government support over the following decade (Xue and Forbes 2006). In 2006, the government revised policy and made technological innovation a more central objective of its Medium- to Long-Term Plan for the Development of Science and Technology (MLP). The MLP aimed to reduce Chinese dependence on imported technologies by supporting indigenous innovation, as well as to enhance Chinese abilities to "leapfrog" existing technologies by concentrating on areas that offer opportunities for breakthrough. It also addressed China's weak innovation record in commercial technologies, sophisticated technologies to confront national defense and social challenges—particularly the environment and health care—and weaknesses in Chinese science education (Cao et al. 2006; Liu and Liang 2013). Viewed within the broader context of the past three decades of reform, these policy initiatives demonstrate how China has prioritized improving the coordination among various national government ministries as well as provincial and city governments, reflecting an important learning process among policymakers with respect to their understanding of how innovation works in practice (Liu et al. 2011).

Although many characteristics of the macro structure of China's national innovation system also translate to the regional level, there are in fact a wide variety of changing models in different parts of the country (Sun and Liu 2010). Between 1980 and 1994, the government established 14 Special Economic Zones, deliberately located far from political power in Beijing in southeastern coastal regions, which were used as laboratories for increasingly open trade and investment policies. SEZs have experienced varied levels of success, depending on their linkages to existing nearby commercial centers and the levels of competence and corruption within their administration (Yeung et al. 2009). A massive science and technology reform process has been underway since 2013, and the result is an increased centralization of budget authority and resources. While the increased centralization and top-down approach may address the well-understood problems with fragmentation and duplication of research programs and investments (Zhou 2015), it may also reduce the diversity of the innovation enterprise.

5. PRIVATE SECTOR

An integrated network of private firms performs the majority of China's R&D. In 2015, private firms accounted for three-quarters of R&D investments totaling $211 billion (Cheng 2015). However, a majority of this activity is focused on applied research and imitation or reproduction of foreign innovations, as discussed in Sections II and III. Moreover, the industrial networks underpinning China's national innovation system are characterized by uneven standards and a lack of transparency, while the state continues to play a principal role in supplying research capital as well as managing research institutions (Xue and Forbes 2006; OECD 2008). The prevalence of state-owned enterprises also reflects the crucial role of the government in linking technology producers and users in the presence of underdeveloped private capital markets, and because many of the major Chinese financial institutions are also state-owned, it is significantly easier for state-owned firms to obtain access to investment capital (Choi et al. 2011).

6. CHALLENGES

The transformation of the Chinese research system reveals a shift from a centrally-planned system to a mixed model and offers significant evidence of increased functional performance—although some of these improvements appear inadvertent in an environment of "structured uncertainty" that forces domestic firms to innovate as a method of coping with an unpredictable policy framework (Breznitz and Murphree 2011; Jonkers 2011). Entrepreneurs in China are often discouraged by legal limitations on their activities, and as a consequence they remain in short supply when compared to the number of entrepreneurial opportunities that exist in the country (Chang and Shih 2004).

In order to accelerate the transformation to an innovation-driven growth model, China needs confront a series of challenges, including its reliance on top-down decision-making processes, educational shortcomings that hold back the development of indigenous basic research capabilities and entrepreneurial culture, and its historically weak intellectual property rights regime (Gu et al. 2009; Sabir and Sabir 2010; Gu 2013). A recent survey of small and medium enterprises also identified several institutional barriers to their development: poor enforcement of the country's competition policy regime, ambiguous bankruptcy laws, and complicated laws and regulations that increase the time and financial costs of starting new businesses (Zhu et al. 2012).

III. Research: Basic & Applied

When discussing the consequences of policy centralization for the shape of the innovation process, much of the literature refers to the degree to which actors respond to market incentives. Decentralized systems are seen to favor market pull mechanisms, wherein R&D activity responds to identified market needs, and expectations of future demand increase the incentives for investments in innovation. Centralized systems, on the other hand, tend to favor technology push, where innovation R&D is designed independent of user considerations (Martin 1994; Nemet 2009a). The choice between 'push' and 'pull' is also reflected in the commitment to supporting basic or applied research, since the former is generally guided by the motives of scientific inquiry and often fails to yield immediate prospects for commercialization, whereas the latter is often motivated by profit and therefore responds to shorter-term industry demands.

United States

In the United States, public universities and government labs play a prominent role in the generation of knowledge by providing research infrastructure and training future generations of researchers (Kim et al. 2012). Because the payoffs of fundamental research are difficult to appropriate and generally available only in the long run, basic research is most frequently carried out by universities and government labs that are funded by the public sector. Industry actors focused on the commercialization of new products tend to focus on applied research that incorporates short-term design and development considerations (Rosenberg and Nelson 1994).

7. PRIORITIES

At various levels of government, a number of recent programs demonstrate the degree to which the U.S. innovation system blends basic and applied research objectives. The America COMPETES Acts of 2007 and 2010 established a clear federal commitment to increase—or at least stabilize—federal funding for scientific education and research initiatives, by funding basic research at universities and by helping advance applied research goals at the newly created Advanced Research Projects Agency for Energy (ARPA-E) (Furman 2013). At the state level, the National Science Foundation's Experimental Program to Stimulate Competitive Research (EPSCoR) has had a significant effect on increasing the funds made available for individual states to support higher education in science and engineering, but further efforts are needed to ensure that federal support is not too concentrated in specific sectors (Wu 2010).

8. LINKAGES

Across the United States, there is a significant degree of variation in the roles that universities, government, and industry play in advancing technological innovation. While this diversity might suggest that the most effective policies are systematic in nature, there is compelling evidence that universities play a uniquely central role in many cases, due in no small part to the ability of higher education to advance a country's capacity for knowledge generation (Kim et al. 2012). But moving successfully from invention to innovation requires that technologies go beyond the laboratory and penetrate local and international markets. In the United States, several government programs have been particularly important to this process.

A. LICENSING

In 1980, the U.S. Congress passed the University and Small Business Patent Procedure Act—also known as the Bayh-Dole Act—permitting universities to license innovations that were developed with federal funds. The Stevenson-Wydler Technology Innovation Act, passed during the same year, did the same for research conducted at or in collaboration with federal laboratories. Previous regulations had obligated the same researchers to transfer their intellectual property to the federal government, complicating the process by which innovations reach consumers. But these laws profoundly reshaped the process of commercializing university research. Collaboration with private firms has since become a key component of the innovation process, with industry supplying financial support to universities in exchange for options on developed technologies and inventions (Blaug et al. 2004; Grimaldi et al. 2011). Despite claims that these relationships lead universities to abandon basic research agendas, the evidence is that licensing has in fact enhanced basic research productivity at U.S. universities (Shapira and Youtie 2010; Thursby and Thursby 2010). And one recent survey demonstrated that university scientists funded by the National Cancer Institute (NCI) choose to license their research through their university, rather than starting new firms, by a two-to-one ratio (Aldridge and Audretsch 2010).

B. SPINOFFS

Despite some evidence of stronger preference for licensing technologies over starting new ventures in the private sector, there is also a significant amount of research on the development of spinoffs from laboratory research. Early studies of technology companies that developed out of work at the University of Texas demonstrated the importance of identifying the right market opportunities to establishing a successful firm. These initial experiences highlighted the need for spinoff companies to receive greater assistance with business concerns, such as raising capital and reaching new markets, and as a result, many universities began to create technology transfer offices (TTO) to assist with the commercialization of university research (Smilor et al. 1990).

Similar work at the University of New Mexico and three major government labs—Sandia, Los Alamos, and Phillips—has shown the importance of establishing procedures for technology transfer, protecting intellectual property rights, and providing continued access to equipment and facilities, though many entrepreneurs leading new firms still struggle due to limited business experience (Steffensen et al. 2000; Carayannis et al. 2008). Other studies have showed the importance of allocating internal resources to support technology transfer, indicating a strong positive correlation between spending on intellectual property protection and TTO business development capabilities on the one hand and successfully obtaining patents (and eventually gaining market share) on the other. There is also evidence that recruiting and training technology officers with broad commercial skills can prove even more important than the broader set of financial resources in development of successful spinoff firms (Lockett and Wright 2005; Link et al. 2011).

9. CHALLENGES

In order to facilitate the transfer of innovative technologies to private sector firms, some analysts believe that further reforms are needed to support standardization, decrease redundancy, and reduce the length of the commercialization cycle (Litan et al. 2007). New research on the role of university TTOs suggests they would be more effective if they began to cultivate a clearer and more distinctive identity within the framework of the university system (O'Kane et al. 2015). However, the limits of the university system remain quite apparent in a number of other areas, including the tendency to skew funding toward a relatively small number of fields (particularly medicine, biology, and engineering); instability in the labor market among non-tenured scholars; and the potential for significant changes to budget priorities among state governments, whose capabilities are already affected by geographic inequalities in federal funding (Atkinson and Blanpied 2008).

China

Given China's relatively late technological development, it is not surprising that policymakers perceive a need to focus on technological "catch-up" and have therefore favored policies that promote applied research. The Chinese government does remain at least nominally committed to advancing science education and improving its basic research contributions, particularly in emerging fields. But whereas U.S. universities are seen to play a moderating role between government and industry, the Chinese state-led model of development gives the government a central role coordinating between industries and universities (Cai and Liu 2013). Basic research was traditionally conducted at the Chinese Academy of Science (CAS) and several large research universities, while public research institutes have traditionally performed applied R&D tasks, alongside a number of specialized universities (Liu and Lundin 2008).

10. PRIORITIES

China's shift from labor- to capital-intensive production led the government to invest more in higher education, and most major industries have a high level of interaction with the government (particularly through state-owned financial institutions). These trends have two important implications. First, the focus on applied research tends to produce a concentration of innovative technologies in "terminal sectors" rather than serving as the foundation for subsequent innovations in other areas (Shih and Chang 2009). Second, since applied research goals tend to take precedence over basic research, Chinese capabilities in the latter remain relatively under-developed: between 1995 and 2005, spending on basic research represented just 5 percent of total R&D expenditures (Eun et al. 2006; Liu and Lundin 2008). However, closer attention to basic research priorities in recent years has produced exponential growth in the global share of Chinese scientific publications and enabled China to emerge as a major player in critical new areas such as nanotechnology, where its position is second only to that of the United States (Zhou and Leydesdorff 2006; OECD 2008; Xue 2008; Zhu and Gong 2008).

11. LINKAGES

Weak linkages among industry, research institutes, and universities have prevented knowledge from being created and efficiently diffused among sectors. For many years, the Chinese government used research institutes to supply general technological support to its nascent industrial development, but when the government cut the institutes' funding during the 1980s, many sought to establish for-profit firms. The government sought to facilitate transfer of the research institutes' functions to the private sector, resulting in research institutes' share in total R&D expenditures falling from 50 percent in 1990 to just 21 percent in 2005, with the corresponding share for private firms increasing from 27 percent to 68 percent in the same period (Liu and Lundin 2008). But a number of the institutes proved unable to compete successfully in the market after the reform, and the reconfiguration of China's innovation infrastructure remained incomplete, limiting the science and technology inputs—including basic research products—that were available to private firms (Chih and Shang 2004; Gu and Lundvall 2006; Xue and Forbes 2006; Motohashi and Yun 2007; Liu and Lundin 2008).

These experiences were illustrated clearly in two important Chinese centers of innovation activity: Beijing and Shenzhen. Near Beijing, research institutes were the main factor behind the expansion of the local high-technology sector, and, following the reforms, a number were able to operate on reduced budgets and dominate the market for innovative technologies. Meanwhile, the Shenzhen Special Economic Zone was designed to be a center of high-tech industry, so policymakers did not focus on expanding fundamental research capabilities. Although local industrial growth had long been fueled by technology inputs from research institutes, and local industry did attract scientific and engineering talent, research institutes were not able to compete successfully after the reform, thereby depriving local industry of an important source of basic research contributions (Chen and Kenney 2007). Recent assessments have pointed out the inadequacies of current regional R&D patterns for an efficient national innovation system, particularly given the separation between knowledge producers and potential users (OECD 2008). Nevertheless, CAS and other research institutes may continue to experience significant productivity growth due to technological progress as well as major improvements in efficiency (Liu and Zhi 2010; Zhang et al. 2011).

A. AFFILIATION

The "downstream tendency" of Chinese universities has led a number of them to establish university-run enterprises. Beyond the university-industry integration suggested by the triple helix model, these firms serve as a more direct form of industrializing the knowledge generated by university research. Contrary to the situation under the Bayh-Dole Act in the United States, the close relationship between universities and industry in China has not provoked public expressions of concern about maintaining the integrity of faculty research. But university-affiliated enterprises have generated controversy due to operational and ownership problems, and some contend that the overall high concentration of applied research and commercial activities within a university setting may limit the development of basic research capabilities. Others suggest that recent policy shifts—such as improvements to university funding and commitment to refocus on improving higher education—have produced a relative decline in these firms' importance, though university spending continues to have a significant positive impact on both patenting activity and GDP growth (Eun et al. 2006; Xiwei and Xiandong 2007; Atkinson and Blanpied 2008; Hu and Mathews 2008).

B. SPINOFFS

The literature on Chinese university spin-offs remains relatively limited. One study has shown that Chinese universities do generate sufficient knowledge to form spin-offs, but many of the resulting companies have suffered from defective incentive structures and poor performance. Corruption scandals have also fueled doubts about the viability of the model in the long term, but a number of recent regulatory reforms do appear to have improved firm performance (Xue and Forbes 2006; Kroll & Liefner 2008).

12. CHALLENGES

While the contribution of public research institutes to China's innovation capacity has been significant, it has also been largely indirect as reforms compelled many of these institutions to transition to private sector status. Although public R&D

spending in China may still offer a more direct impact on innovation outcomes, further streamlining the public sector could enable the remaining public research institutes to play a more important steering role (Hu and Mathews 2008). The latest OECD comprehensive review of China's national innovation system encouraged shifting the focus of government policy to the provision of public goods to address key market failures, cautioned against focusing too intently on the development of high-tech sectors, and called for the improvement of sector- and region-specific policies (OECD 2008). Other analysts have highlighted the need to improve China's national innovation system by promoting greater organizational learning as well as improving passive knowledge strategies and managerial capacity (Gu et al. 2009).

IV. Innovation: Objectives & Outcomes

As a result of the other factors shaping national innovation systems, a distinction can be made between countries based on their principal innovation objectives. Some countries are capable of creating innovative technologies so that new products can be sold on consumer markets, whereas others focus on producing existing technologies via more innovative processes. Over the past several decades, the discussion around innovation in the United States has focused to an increasing degree on the earliest stages of research and development, and there has been relatively less attention paid to manufacturing as an integral component of the innovation ecosystem. Meanwhile, some key U.S. trade partners have chosen to focus on innovation in production processes: China has been particularly successful at scaling up production volume through the integration of advanced processes that increase efficiency and cost savings.

United States

13. PRODUCTION

Some technologies need greater nurturing before they are close to commercialization, funding not only research but also constructing prototypes and conducting demonstrations. Other technologies benefit more from incentives that encourage technology transition in the market, once they have been successfully produced and tested but before they can compete with incumbent technology prices (Bonvillian and Weiss 2009). Japan and Germany face much higher wage costs than the United States but still run major trade surpluses due to their efforts to encourage innovation diffusion, while the U.S. inability to extend its focus beyond early-stage support for innovators has contributed to significant manufacturing job losses and a growing trade deficit in manufactured goods (Bonvillian 2013).

14. REGIONAL INNOVATION CLUSTERS

Recent efforts to promote regional innovation clusters in the Strategy for American Innovation may help confront critical challenges to linking industry research and occupational clusters with broader regional innovation systems and regional economic development, although the program as currently constituted does include several conceptual shortcomings (Yu and Jackson 2011). Although they ideally complement private firms' own R&D commitments, research alliances can still facilitate knowledge generation by promoting information transfer and learning. The effects are greatest when firms have a higher absorptive capacity and there is a moderate technological distance between alliance partners (Lin et al. 2012). One particularly cogent example can be found in Atlanta, where the development of a major university knowledge hub at the Georgia Institute of Technology helped the state shift to an innovation-driven economy and illustrated the importance of local leadership and network capacity (Youtie and Shapira 2008).

China

One study of China's national innovation system found that it comprises two complementary components: one based on foreign technology transfer and another on indigenous innovation (Tang and Hussler 2011). Unsurprisingly, FDI-related manufacturing continues to predominate in China, given firms' relatively easy access to foreign technology (Gu and Lundvall 2006). The literature and subsequent research both suggest that local R&D and foreign technology transfer complement one another—particularly since the former helps improve local industry's ability to absorb the latter—and that without significant advances in local R&D, technology transfer yields far more limited productivity gains (Hu et al. 2005; Sun and Du 2010).

15. IMITATION

In contrast to other East Asian countries such as Korea and Japan that attempted technology "catch-up" in earlier eras and then sought to develop extensive indigenous innovation capabilities, China has created a new model that exploits its comparative advantages in modular, low-cost manufacturing and access to foreign technology. Due to limited capital and human resources, private firms' commitment to R&D remains relatively limited. They tend to focus on obtaining and replicating foreign technologies, developing faster and more innovative forms of technology production without dedicating significant resources to developing new products (Liu 2005; OECD 2008).

A recent survey of the high-tech industry in Zhejiang province found evidence of a market-based innovation where private firms focused on process innovation as the most important form of response to customer demand and competition from other firms (Dobson and Safarian 2008). More broadly, though the prevalence of foreign technologies has limited the drive to improve indigenous innovation capabilities, the level of competition between domestic and foreign firms does appear to shape efforts by domestic firms to reproduce foreign technologies with specific variations tailored to appeal to domestic consumers (Brandt and Thun 2010).

When measuring innovation by manufacturing product sales, the most successful approach for private firms appears to be investing in foreign technology imports and the ability to absorb these new technologies, rather than by focusing specifically on one activity or the other (Liu and White 1997). More recent studies have indicated that when firms' R&D decisions take into account demand opportunities, market competition, technological capability, and external networks, a focus on technological "newness" as a measure of innovative output does not increase sales, whereas a focus on the acquisition of foreign technology is positively correlated with sales growth and negatively correlated with the level of innovative output (Wang et al. 2014).

Despite a surge in patenting activity over the past decade, questions remain about whether China has in fact improved its abilities in the area of new product innovation (Li 2012). Limited property rights make it more difficult for firms to commit significant resources to long-term product development, so they have adapted in other ways that allow them to protect and gather returns on their investments. Moreover, because Chinese financial institutions tend to be extremely risk-averse, and the country's innovation environment is broadly characterized by private under-investment in R&D, large-scale foreign enterprises are often positioned to take advantage of the limitations that confront domestic firms, such as the difficulty in accessing credit (Hu and Matthews 2008; Breznitz and Murphree 2011).

16. REGIONAL INNOVATION CLUSTERS

Since the 1990s, Chinese technology parks have grown rapidly in response to policy incentives that encouraged the convergence of labor productivity. Although there has been no evidence of external economies from the concentration of high-technology firms, there are signs that these technology parks have at least countered the trend of increasing regional inequality in China (Hu 2007). However, many linkages between innovative actors and sub-systems (e.g. regional versus national) remain weak. Some observers have identified an innovation "archipelago" in China, lacking sufficient linkages between the "islands" and subsequently limiting high-tech firms' ability to generate positive knowledge spillovers (OECD 2008).

Industrial clusters allow for the establishment of connections among firms through so-called "knowledge spanning mechanisms" with four factors determining the scope of learning opportunities inside industrial clusters: technology complexity, research path dependency, links between product and process innovation, and incremental technological development (Guo and Guo 2011). A survey of electronics firms in the Pearl River Delta in Guangdong Province revealed that interactive learning was even more important to highly modular industries, as firms achieved improved innovation outcomes by expanding the scope of both the type and the targets of their interactions, from joint venture partners and parent companies to university researchers and even new customers (Fu et al. 2013). But there is also a trade-off between "short-term advantages of closer interaction between integrated units and [the] long-term cost of isolation from broader process of interactive learning" (Lundvall 2010). Because entire industries in many cities are concentrated in industrial clusters focused on the manufacture of single product or series of products, private firms can work together to create profitable economies of scale, but often find it more challenging to contribute to the advancement of the technological frontier (Breznitz and Murphree 2011).

In order to provide a more thorough analysis of behavior in clusters, it is important to consider the ability of local firms to absorb foreign technologies (He et al. 2011). One study of high-tech firms in Beijing Zhongguancun Science Park demonstrated significant knowledge spillovers from entrepreneurs who had returned from working and studying internationally, but it also revealed the extent to which the effects of scientists and engineers returning from abroad is moderated by other firms' absorptive capacity (Filatotchev et al. 2011).

17. CHALLENGES

Analysis of China's clean power markets demonstrates that when government plays a central role in driving technological change, either directly through government procurement or indirectly through market formation, it is more difficult to shape policies that provide opportunities for non-incremental technological change. On the other hand, the Chinese government's support for the wind and solar industries show how effective the Chinese government can be at stimulating markets and providing access to capital (Gallagher 2014). A study of innovation performance shows that varying levels of national government support, distinct identities of local organizations performing R&D, and regional industry-specific innovation environments have all increased the disparity between innovation efficiency outcomes in different regions of China. As a result, efforts to move away from universities and research institutes and toward private firms as the heart of regional innovation are likely to further increase the inequality in regional innovation performance (Li 2009).

V. Conclusion: Similarities and Differences

This paper looks at three system-level factors that help define the national innovation systems of the United States and China: public and private sector activity, basic and applied research activity, and innovation objectives and outcomes. It discusses the roles played by government, industry, and university actors, as well as the ways in which their interactions shape the innovation system in each country.

Overall, one does not find a fundamentally different situation in each country when evaluating the relative balance between public and private activity to support innovation, since both governments play an active role in supporting innovation by privately owned firms. But public policy and private enterprise do play slightly different roles in each country—due in part to the absence of mature private capital markets in China, which leaves the public sector as the sole source of financing for R&D. There are sharper differences between the two countries when evaluating the balance between their efforts in basic and applied research. Specifically, the U.S. government plays a more prominent role in performing basic research activities than the government of the People's Republic, since the development of stronger capabilities in that area has only become a top priority in recent years. And with respect to innovation objectives and outcomes, there are notable differences between the Chinese focus on innovation in production processes after absorbing foreign technologies and the American focus on generating new technologies without sustaining manufacturing's place within the national innovation system.

On a deeper level, the U.S. national innovation system may broadly be characterized as more fully integrated, with stronger linkages among different actors. But the high level of decentralization does make coordination challenging, as demonstrated by the Obama Administration's challenge in acquiring Congressional support to fund its innovation priorities. In China, a series of important policy reforms over the past several decades has enabled its national innovation system to achieve significant productivity growth, but it too faces challenges of coordination among different actors due to a relatively weaker set of linkages. Despite facing similar domestic policy coordination challenges, government, industry, and university actors on both sides of the Pacific may yet identify valuable opportunities for international cooperation and establish stronger linkages with actors in one another's national innovation systems in order to promote a robust approach to innovation through globalization and economic integration. ■

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