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Policy, Regulation, and Innovation in China's Electricity and Telecom Industries

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Britain's industrial revolution spawned efforts by "followers" to match and surpass the achievements of leading firms and industries in advanced nations.[*] Two centuries later, the drive for industrial upgrading, which Nelson and Rosenberg (1993) define as "the processes by which firms master and get into practice product designs and manufacturing processes that are new to them, if not to the universe or even the nation," continues. There is a parallel history of governmental efforts to accelerate the progress of national firms and industries toward global best practice and, upon approaching the frontier, to enter the realm of original innovation.

China's unprecedented economic surge, now entering its fifth decade, adds a new dimension to the history of industrial upgrading and to ongoing debate over the effectiveness of supportive official actions. Growing evidence of Chinese technical prowess has inspired a jumble of observations, ranging from fears that shifting corporate research and development (R&D) activity to China "could destabilize the interaction of all the other parts of the [US] innovation ecosystem" (Segal 2011) or "destroy . . . entire business models" (Kennedy 2017) to skeptics who "don't believe that China will lead in innovation anytime soon" (Sass 2014) and explain "why China can't innovate" (Abrami, Kirby, and McFarlan 2014). Comment on this vital dimension of China's economy bristles with stereotypes and unwarranted generalizations. China's industrial policy is routinely viewed as both ineffectual and threatening, sometimes on the same page![1]

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1 "Soviet planning cannot replicate the Silicon Valley. Ming Dynasty mindsets can't create microchips. Megaprojects . . . are likely to end in a trail of tears. As more details of indigenous innovation plans emerge, American and European politicians are seeing an assault on their core national economic strengths" (McGregor 2010, p. 37).

Such wide disagreement reflects a knowledge gap that surrounds the fulcrum of official efforts to lever China's economy onto a new innovation-based growth trajectory. It signals that outside observers lack a nuanced understanding of China's regulatory structures and industrial policies, which range from general measures that encourage startup firms and raise university enrollment to sharply focused efforts that channel resources to help priority sectors and favored firms master specific technologies.

The chapters that follow are the outcome of a group effort to remedy this disturbing and, from a foreign policy perspective, dangerous lacuna. To pursue this subject, we convened a multidisciplinary group of researchers to investigate Chinese efforts to energize upgrading and innovation. Inclusion of multiple specialties facilitates work that follows policy initiatives from start to finish, avoiding the incompleteness of studies that focus on policy and neglect outcomes (common among political scientists) or examine outcomes without links to policies (widespread among economists).

To achieve depth in a field beset by facile generalizations, our work combines documentary research with extensive field study, and focuses on electricity and telecommunications, along with semiconductors – a core component in telecommunications systems. With recent developments, notably the cessation of labor force growth and the declining growth rate of investment, enhancing the centrality of innovation and upgrading as determinants of future growth, the following chapters address four interrelated sets of questions arising from recent Chinese experience:

- How does the Chinese state promote industrial upgrading and innovation? To what extent can we identify direct links, positive or negative, between policy objectives and innovative outcomes?
- How do Chinese regulatory and institutional structures influence business behavior? Do regulations encourage firms to make cost-effective investment choices – for example in building new facilities or purchasing production equipment? Or do official actions distort enterprise-level incentives in directions that incline enterprise managers toward unproductive or wasteful decisions?
- What is the trajectory of Chinese improvements in quality, cost, and productivity? When and, if so, how do Chinese producers approach global best practice? When and where can we observe evidence of cutting-edge advances that extend global production possibilities?
- How can the development of specific industries illuminate future prospects for China's national innovation system?

We preface our review of these issues with a brief description of the sectors under review here and a summary of ongoing controversy over the practicality of state intervention to accelerate industrial upgrading and innovation.

CHARACTERISTICS OF ELECTRICITY AND TELECOMMUNICATIONS

Electricity and telecommunications fall into the category of "network industries." These sectors display somewhat unusual features (Shy 2001). Network industries have high fixed costs – expenses that arise regardless of the level of output. High fixed costs open the door to scale economies – meaning that unit costs decline as output rises. Scale economies undermine market competition – because small entrants cannot match the low costs attained by well-established incumbents. Consumers of network products purchase systems (e.g. smart phones with operating systems that provide access to multiple software options) rather than individual products (e.g. a haircut or a shirt). The benefit available to individual purchasers of such systems increases with their popularity. Unlike buyers of haircuts or shirts, buyers of network products may find that switching from one system to another (e.g. from IOS to Android) imposes considerable financial and start-up costs. The resulting "lock-in" effect adds to the market power of incumbent firms. Extensive market power, especially for items seen as necessities, invites government intervention, which may take the form of regulation, public ownership, or, as in China, both.

The difficulty of melding the peculiarities of network industries, the benefits of business competition, and the need to limit the power of entrenched suppliers has defeated efforts to delineate preferred market structures. Global reform efforts intended to inject competition into industries formerly treated as "natural monopolies" have delivered mixed results. There is no clear model of success. Reform remains a work in progress. Efforts to deregulate US electricity markets, for example, have stumbled over episodic price spikes, opportunistic supplier behavior and shortages.

These industries deploy a mix of old and new technologies. Semiconductor technology has evolved through the commercialization and upgrading of mid-twentieth century innovations. Telecoms combine the popularization of old (fax, landline) and the rapid development of new (3G, 4G, 5G, mobile phone miniaturization) technologies. The combined impact of hardware and software innovations has revolutionized the conduct of daily affairs for individuals in China and across the world. Advances in electric power depend on the refinement of well-known, widely disseminated technologies. Larger plants (reflecting scale economies), fine-tuning of controls, and combustion at higher temperatures and pressures have raised the efficiency of coal-fired thermal plants. Solar technology is not new – massive cost reduction is the chief innovation. Wind turbines also employ familiar technology – a wide array of engineering firms can easily enter this market. Nuclear technology, like semiconductors, emerged from mid-twentieth century innovations. Potentially significant innovations, including smart meters, automated grid systems, distributed power generation and new techniques for large-scale storage of electricity, hold great promise, but lack sufficient traction to influence the analysis offered in this volume.

HISTORIC DEBATE OVER INTERVENTIONIST POLICY

Controversies over the efficacy of interventionist policy in accelerating technological change date from nineteenth-century clashes between free traders, among them David Ricardo and Frederic Bastiat, and early advocates of state developmentalism, including Alexander Hamilton and Friedrich List. Recent debate has swirled around the dynamic East Asian region, with the share of opinion highlighting or disparaging the contribution of interventionist policies fluctuating with the economic fortunes of the region's high-growth economies.[2] China's explosive growth provides fresh ammunition for controversy, with some analysts portraying Chinese industry as a frightening colossus marching to the dictates of a central plan, while others insist that institutional shortcomings and epidemic levels of fraud and corruption must hobble efforts to progress from imitation and cost reduction to cutting-edge innovation.

Proponents of activist policies justify their stance with appeals to market failure and externalities. Without forceful governmental intervention, capital market imperfections may limit funding to start-up firms. Protection for "infant industries" shelters nascent sectors from ruinous competition while they traverse learning curves and build competitive

[2] Johnson (1982), Kim (1987), Wade (2004), and World Bank (1993), among others, emphasize the benefits of state intervention; recent setbacks in Japan and Korea have stimulated critical approaches, for example by Miwa (2004) and Miwa and Ramseyer (2010).

strength. Without subsidies or protection, individual firms may limit spending on research or labor training because they cannot capture benefits that diffuse across the economy. Coordinated expansion of manufacturing and infrastructure "can help foster a mutually profitable big push even when . . . investment in any one sector appears unprofitable" (Murphy, Schleifer, and Vishny 1989, p. 1024). In China (and elsewhere), such thinking is often reinforced by the perception that foreign-dominated global value chains may choke domestic upgrading opportunities – for example by refusing to transfer or license proprietary technologies.

The perennial issue concerns the state's *most effective* levers for accelerating an economy's progress toward global technological frontiers. There are two competing policy designs. The *private initiative approach* sees government's key function as "setting the table" for private endeavor by creating a business environment conducive to entrepreneurship. Relevant policies include promoting universal education, expanding universities, creating courts and other regulatory mechanisms, establishing export zones or industrial parks, and financing basic research. Supporters oppose prioritizing specific industries, firms or technologies, fearing that ill-advised official efforts to "pick winners" among potentially dynamic sectors or firms stand little chance of success and, worse yet, may open the door to "crony capitalism," with corrupt officials ladling out subsidies, protection and monopoly rights to well-connected insiders.

Interventionists believe that, in addition to creating attractive conditions for commercial ventures, states can beneficially deploy a range of policy tools such as grants, tax concessions, risk-sharing arrangements, officially inspired consortia, and trade protection to accelerate advances in carefully selected segments of manufacturing. Japan's post-war development of steel and autos (Johnson 1982; Okimoto 1989) and Taiwan's push into electronics and chips (Hsueh, Hsu, and Perkins 2001; Amsden and Chu 2003, Wade 2004) demonstrate the potential gains from policy activism.

China's strongly interventionist stance is congruent with recent research highlighting the contribution of activist governments to accelerating innovation and technological catchup in both advanced (Block and Keller 2011; Mazzucato 2013) and developing (Rodrik 2004; Cimoli, Dosi, and Stiglitz 2009) nations. China's approach reflects Beijing's reading of international best practice as well as its skepticism toward Anglo-American "invisible hand" perspectives that extol the innovative capacity of private firms and free markets.

New work that re-evaluates the links among basic science, applied research, and commercial development of new or improved products casts further doubt on the independent innovative capacity of private business. Conventional thinking partitions R&D space into "basic" science, which produces new concepts, theories, and materials that provide the foundation for commercial innovation, and "applied" research, which moves such discoveries toward commercial fruition. The "public good" nature of basic research (meaning that, unlike products that confer benefits only upon individual buyers, scientific advances – for example calculus or plastics – benefit entire societies), and the consequent benefit of direct public support, is not in dispute. Applied research, by contrast, promises immediate financial returns that obviate the need for public support, as when developers of techniques that extend battery life for mobile phones can obtain patents and collect royalties.

Gregory Tassey (2014) presents a more complex picture of the path from basic discovery to commercial sale. He divides applied research into three stages, namely:

- Proof-of-concept technology research, for example "Bell Labs' demonstration . . . that semiconductor materials can be organized to perform the functions of an electronic switch or amplifier" (2014, p. 37);
- Infratechnologies – essential technical tools "often embodied in the standards that are ubiquitous in high-tech industries" (2014, p. 38); and
- Commercial product development.

Only the last of these stages involves activity that is mainly "private" in the sense that operators can expect to capture most of the financial payoff arising from their effort. Tassey doubts that private businesses can justify paying the full cost of efforts associated with proof-of-technology or infratechnology development. Survey evidence shows major American corporations increasingly focusing R&D activity on projects that promise short-term payoffs. Globalization-inspired competitive pressures deter firms from supporting the "luxury" of basic and mid-stream research that generates more prestige than profit.

Tassey observes that strenuous opposition[3] to modifying the traditional reliance on private sector initiative to conduct the entire gamut of "applied" research places the US national innovation system at a disadvantage in competing with rival systems, including China's, where

[3] Thus the "Heritage Foundation . . . argues that the federal government should fund only very basic scientific research and get out of the business of helping companies commercialize new energy technologies" (Plumer and Davenport 2017).

government-business-university partnerships routinely support activities that occupy Tassey's proof-of-concept and infratechnology categories.

TASK OF THIS BOOK

Electricity and telecoms, like many other segments of China's economy, represent epic success stories. During the early days of reform, we toured factories by flashlight and watched Chinese colleagues send cyclists across Beijing to deliver lunch invitations rather than attempt to communicate by telephone. All this has changed. Chinese systems now provide nationwide access to electricity, phone and internet services. Leading Chinese firms sell telecom equipment in the United Kingdom and Australia and operate grid systems on several continents. China is a major exporter of power plant equipment and a nascent supplier in the global market for nuclear power plants.

The following chapters investigate the contribution of official policies and regulatory actions to these impressive advances. The issue is complex. If innovation and upgrading occur – as in telecom and nuclear power – are these advances a product of official initiatives? Of unrelated accumulation of technical and managerial capabilities? Of some combination of the two? Can we see specific instances in which government initiatives accelerate (or obstruct) innovation? What of high priority sectors – semiconductors offer an obvious example – that fail to gain competitiveness despite determined (and expensive) official support?

We adopt a broad definition of innovation, which extends beyond completely new developments to encompass upgrading of products and services that falls short of the global frontier. Once commercialized, innovations of both types – world-leading Chinese voice recognition software or improvements that reduce unit coal consumption in thermal power plants – raise product value, reduce input requirements, or both. The result is higher productivity (or lower cost, its mirror image).

Innovation of either variety increases demand. Rising demand encourages higher output, which promotes scale economies and experience-based learning, both likely to reduce costs and thus refresh the cycle of fruitful interaction between productivity and growth. Rising productivity is the central feature of long-term economic expansion in every society. Looking ahead, China's shrinking labor force, diminishing returns to investment, and the declining growth rate for capital formation arising from economic rebalancing toward consumption all ensure the continued dominance of productivity increase as the key determinant of future growth.

Focusing on electricity, telecommunications, and semiconductors, we find a wide dispersion of innovative outcomes that includes instances of impressive achievement, numerous areas of solid advance, and occasional failure. We can summarize our findings regarding innovation outcomes by looking successively at technology, services, and market penetration.

INNOVATION OUTCOMES

Technology

Our studies find a mix of success and failure. We observe many instances of successful absorption and operation of advanced technologies developed outside China. Examples include supercritical and ultra-supercritical thermal power generation technology as well as Westinghouse's Generation III nuclear reactor design.

Examples from telecom and power sectors illustrate an intermediate outcome in which Chinese firms absorb overseas technology but also contribute to technical advance. Eric Thun and Timothy Sturgeon in Chapter 5, for example, document Chinese participation in joint efforts to develop standards for 4G and 5G networking. Telecom equipment specialist ZTE's 2016 agreement "to sell a patent portfolio – including, significantly, a number of China-only patent families" to a US firm provides clear evidence of growing Chinese presence at the global knowledge frontier (Ellis 2017). The decision by Huawei, another leading producer of telecom equipment, to launch patent infringement lawsuits against T-Mobile and Samsung in US courts points in the same direction (Pressman 2016). Xu Yi-chong in Chapter 6, examines State Grid Corporation's success in extending global distance and voltage standards for long-distance transmission of electricity. Her findings illustrate China's emergent capacity to achieve frontier innovation.

Douglas Fuller in Chapter 7 shows that sustained and costly effort has done little to reduce the distance between Chinese semiconductor producers and global leaders. Fuller finds that leading Chinese firms have attained "intermediate" levels of technological capability in two major industry segments, foundry and complementary metal oxide semiconductor (CMOS) image sensors; elsewhere, available information indicates that Chinese firms achieve no more than "relatively low technology capability."

Services

Chinese telecom customers enjoy inexpensive, high-quality voice service. Operators like Alibaba and TenCent provide convenient and highly innovative online services that enjoy huge popularity. Electrical service, although expensive – except for subsidized residential and agricultural users – is reliable, especially in urban centers. Both power and telecom networks provide nationwide coverage – an impressive achievement for a continental nation. Broadband service, although widely available, is slow[4] and relatively expensive. Despite the ubiquity of online consumer activity, the poor quality of broadband service contributes to the hesitancy of many Chinese businesses to explore internet-related opportunities (Woetzel et al. 2014, pp. 18, 28, 41).

Market Penetration

Trends in market shares captured by various producers provide a valuable metric for the progress or absence of innovation and upgrading, especially in the presence of open competition that obliges enterprises to meet customer requirements without official support. The success of unheralded producers of telecom and construction equipment in capturing domestic market share, scaling industry quality ladders, and breaking into global markets formerly dominated by powerful multinationals illustrates the link between openness and innovative success (Brandt and Thun 2010, 2016).

International competition generates particularly valuable information about the extent of innovative advance. The news may be unwelcome, as when a German auto club labeled a Chinese-made SUV as “the worst performer in its 20-year testing history,” or when the Massachusetts Department of Transportation rejected a bid from a major Chinese rail-car manufacturer “in three categories: technology, manufacturing and quality assurances” (Spinelli 2005; Mouawad 2015). Brandt and Wang find that quality issues have prevented Chinese wind turbines, unlike other types of power generating equipment, from attaining substantial overseas sales. Fuller’s study of semiconductors provides another instance in which substantial growth of domestic output has brought little overseas market penetration.

Successful outcomes, however, convey an equally clear message. China’s substantial exports of solar panels, telecom equipment, and rail cars to

[4] “Global ranking of China in terms of broadband speed: 91st”; see www.chinadaily.com.cn/china/2016even/ (accessed August 19, 2018).

advanced nations demonstrate international competitiveness, as does the growing capacity of Chinese firms to wrest domestic market share from leading multinational vendors of construction equipment. In hydropower equipment, China has become "the dominant global force in manufacturing and exporting." (Chellaney 2011, p. 65). Exports of thermal power generation equipment, telephone handsets and, looking forward, nuclear power equipment, most directed toward low- and middle-income economies, indicate competitive strength that suffices for some markets but cannot satisfy the demands of high-end customers.

CHINA'S PROMOTION OF UPGRADING AND INNOVATION

China's efforts to accelerate industrial upgrading and innovation fall into two categories. One is the accumulation of resources and development of institutions that can support innovation. The second is the implementation of policies that channel resources in directions that reflect the state's strategic ambitions. We discuss each in turn.

Accumulating Resources and Building Institutions

Systematic development of innovation-related resource pools and institutional arrangements dates from the 1950s, when China pushed to expand mass education, initially emphasizing universal primary attendance, dispatched students to study technical subjects in the Soviet Union and Eastern Europe, and created a thick web of science and technology related schools, research establishments and professional associations. Despite politically inspired disruptions arising from the Hundred Flowers campaign, the Great Leap Forward, China's split with the Soviet Union, and the Cultural Revolution, these efforts increased literacy and school attendance. Of particular relevance to our sectoral focus, the 1950s witnessed the emergence of at least ten universities focused on electricity or telecommunications.

Following the start of reform in the late 1970s, the push to expand innovation-linked resources became more intense and more consistent. Further expansion of the education system multiplied middle school, high school, college, and university enrollments. Changing employment patterns in state-owned enterprises (SOEs) and institutions reflect a shift of official priorities toward technology-intensive industries. While SOE employment dropped by nearly half between 1997 and 2015, falling from 97.2 to 49.6 million, the number of employees classified as technical