

## 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!<sup>1</sup>

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<sup>1</sup> "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 inter-related 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.<sup>2</sup> 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

<sup>2</sup> 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 Tasse (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. Tasse 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.

Tasse observes that strenuous opposition<sup>3</sup> 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

<sup>3</sup> 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 Tasse'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<sup>4</sup> 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 semi-conductors 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

<sup>4</sup> “Global ranking of China in terms of broadband speed: 91st”; see [www.chinadaily.com.cn/china/2016even/](http://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

personnel (专业技术人员 *zhuanyè jìshù rényuán*) rose from 28.6 to 30.9 million, raising the share of such workers from 29 to 62 percent of the total.<sup>5</sup>

Steep increases pushed research and development outlays beyond 2 percent of GDP, exceeding comparable totals for all low-income nations and a handful of advanced economies. R&D activity has shifted toward industry, whose share of R&D financing (74.7 percent in 2015) and spending (76.8 percent in 2015) exceeds comparable figures for all OECD nations other than Japan and South Korea (OECD 2016, p. 14). Chinese R&D focuses on development, which accounts for 84.2 percent of recent R&D outlays, rather than basic (5 percent) or applied (10.8 percent) research (Kennedy 2017, p. 20).

The reform era wrought sweeping changes in the organization of economic activity, of which the transitions from plan to market and from isolation to economic openness are particularly relevant for this study. The shift from plan to market, while gradual and incomplete, has put enterprise leaders in charge of a growing array of decisions about business strategy, product mix, price-setting, sales effort, hiring, input purchases, investment, and many other matters. Reform has spawned a succession of institutional innovations to meet the needs of an economy that now displays extensive decentralization of authority. These include commercial legislation and courts tasked with adjudicating commercial disputes, markets for the exchange of commodities and the issuance and exchange of corporate shares and bonds, a patent system, venture capital agencies, industrial parks, incubators for nurturing start-up firms, and many other novel arrangements.

Gradual transfer of authority from state organs to firms compels the state to develop regulatory systems in place of the command structures that formerly moved enterprises and resources in directions desired by policy-makers. As Irene Wu, in Chapter 2, demonstrates, building regulatory mechanisms that address multiple objectives – efficiency, wide access, and providing a “level playing field” for an increasingly heterogeneous population of actors – is no easy task, particularly in a society renowned for the ability of individuals and groups to “game the system” using networks of informal relationships. Regulation is particularly important in network industries like telecommunication and electricity, where the presence of large incumbents and the expectation that unit costs decline with rising firm size creates opportunities for abusive behavior.<sup>6</sup>

<sup>5</sup> S&T Yearbook 2016, p. 16. The data for 2015 include collective as well as SOEs and institutions.

<sup>6</sup> Chen (2012) blames telecom monopolies for “expensive and slow” internet service. In 2015, “at least forty-eight cities in fourteen provinces and regions have enacted . . . rules” specifying that “only transmission company-hired crews can install power lines and

Openness to the movement of commodities, people, information, ideas, technology, and investment across both national and domestic borders is another central feature of China's post-1978 reforms. What began as hesitant experimentation mushroomed into a sea change that has vaulted China into global prominence as the world's largest trading nation, its second largest recipient of incoming direct investment, a leading destination for international travel, and, most recently, a major source of international travelers, overseas students and outbound foreign investment.

Discussion of China's "open door" policy focuses on flows of trade, investment, and technology, most to and from a handful of coastal provinces. Equally important, however, are exchanges of people and information. Explosive growth of Chinese translations and adaptations of materials ranging from scientific papers to popular entertainment, overseas study and work experience, and participation in supply chains leading to production facilities of Toyota, Siemens, General Electric, Doosan, and other global leaders have extended the knowledge and understanding available to thousands of Chinese enterprises and millions of Chinese citizens.

Shaanxi province illustrates the profound impact of globalization on economic activity even in China's interior. Notwithstanding its limited involvement in global trade – 2009 data place the province's trade ratio (combined exports and imports as a percentage of GDP) at 7 percent – one-sixth of the national average for the same year (Yearbook 2010, pp. 38, 51, 230, 247) – fallout from the autumn 2008 global financial crisis hit Shaanxi immediately. Electricity consumption by large industrial users began to fall in October; incremental growth resumed only in June 2009 (Shaanxi Electricity 2009). Early 2009 brought the first reduction in Shaanxi's industrial output since 1949 (Shaanxi Output 2009).

### **Interventionist Policies and Programs**

The measures described above are consistent with a private initiative strategy that leaves the direction and intensity of innovative effort to the discretion of decentralized operators. China's government, however, combines this approach with interventionist policies that assign special priority and channel substantial resources to expedite the development of selected industries, the acquisition, absorption, and mastery of specific technologies, and the expansion and market share of favored companies or enterprise groups.

related equipment," a measure that in some instances doubled connection costs and prompted some property developers to cancel building plans (Huang 2015).

Interventionist policies date back to Japanese-led efforts to develop a heavy industry complex in China's northeast (Manchurian) region at the time of World War I. The Guomindang administration established an array of SOEs during the 1930s to promote defense-related manufacturing. Beginning in the mid-1950s, the newly established People's Republic initiated a sequence of Five Year Plans, a tradition that has continued despite the post-1978 expansion of the market. At this writing, China is in the midst of its 13th Five-Year Plan (FYP) covering the years 2016–20.

FYPs provide a point of departure for additional programs that target specific industries, activities, or segments of the economy. The list includes Spark, which promotes rural innovation; Torch and 863, both aimed at high technology industries; 973, which boosts basic science capabilities in certain strategic areas; the National Medium- and Long-Term Plan for the Development of Science and Technology 2006–20; the 2007 Medium–Long Term Plan for nuclear development; the 2007 Medium–Long Term Plan for renewable energy development; and the 2014 National Integrated Circuit Industry Guidelines.

Government agencies deploy a long-standing and extensive menu of interventions to assist entities tasked with pursuing strategic priorities. Beneficiaries often receive direct financial transfers in the form of cash grants or tax reductions. “Access to assets and resources” – including land, bank loans, essential commodities, and technical expertise or intellectual property housed in government research agencies – “at below-market prices” represents another class of benefits (Zeng and Williamson 2007, p. 19). Interest-rate subsidies to state firms, which Gatley (2018) places at a minimum of RMB 250–330 billion per year, illustrate the scale of such measures. The state's long reach, enhanced by ubiquitous Party influence, extends the impact of official preferences beyond state budgets and official actions.

Sub-national governments achieve unusual prominence in Chinese economic policy implementation: Bardhan and Mookherjee (2006) point to China as the lone example among low-income nations in which local government contributes substantially to economic growth. Innovation efforts are no exception: during the decade ending in 2016, the share of provincial and local governments in China's steeply rising overall fiscal outlays on science and technology rose from 47–9 percent during 2007–11 to 58–9 percent in 2015–16<sup>7</sup>. Local governments actively promote

<sup>7</sup> [www.stats.gov.cn](http://www.stats.gov.cn) (accessed July 23, 2018).

advanced products, including majority investments in four of five plants established by BOE Technology Group, “the only Chinese display company that supplies Apple, which is notoriously finicky in its demands for top-quality components” (Kubota 2018). In Chapter 3, Margaret Pearson focuses on the efforts of sub-national governments to promote the manufacture of solar cells and electric vehicles; Dinh et al. (2013) provide further illustrations.

Along with policy tools routinely deployed in many nations, China’s large and rapidly growing domestic market has enabled officials to demand that global multinationals share proprietary technology in return for (often limited) market access. In addition, there is credible evidence that China’s government condones, organizes and in some instances conducts what specialists describe as an unprecedented campaign of cyber-espionage aimed at “compromising organizations across a broad range of industries” (Mandiant 2013, p. 4), with targets extending far beyond defense-linked producers (Brenner 2014). Cybersecurity specialist James Lewis states that “Chinese companies used to be able to direct the PLA or MSS [referring to Chinese military and security agencies] to hack into Western competitors.” More recently, presumably following a 2013 US-China agreement to curtail economic espionage, “companies can still put in a request for a target to be hacked but no longer can assign tasks to the teams directly” (Wilkes 2017).

Official support routinely encompasses segments of the innovation process that Tassej, discussed above, views as involving high “public good” content and thus likely to lack commercial viability. Government-funded researchers “completely dominate” China’s push into third-generation technology for solar power generation while “private sector actors are still waiting to see if there is a realistic chance of commercializing” novel methods that are “not considered as market-ready yet” (Sun 2016, p. 31). The origin of China’s Time Division Synchronous Code Division Multiple Access (TD-SCDMA) standard for 3G telecom discussed in Chapter 5 by Thun and Sturgeon, in a “research institute under the Ministry of Information” (Zeng and Williamson 2007, p. 157), illustrates public sector involvement in “proof of concept” research. Another example comes from Davidson’s description of the National Energy Agency’s lead role in the “700°C Coalition,” a group that considers prospects for advanced supercritical thermal power generation. Speeches by representatives of three major government agencies at an event hailing the emergence of COSINE, “China’s first set of nuclear power design and safety analysis software” following a five-year effort that included official approval for building a “key laboratory of national energy nuclear power software”

highlight state involvement in creating tools and standards – part of Tasse's infratechnology category.

### Three Decades of Innovation: Good but Not Good Enough

Several decades of market-leaning reform gradually built an environment powerfully supportive of innovation and upgrading, with domestic sectors mastering technologies and processes unknown in China's pre-reform economy, and in many cases supplying the resulting products to overseas as well as domestic markets. The remarkable expansion and modernization of China's electric power and telecommunications networks illustrates this process. Chinese utility customers, formerly faced with primitive and often unreliable service, now benefit from systems that often approach and sometimes surpass comparable arrangements in advanced nations. The operations of China's utility networks rest squarely on domestic equipment, much of which finds ready overseas markets, including substantial sales of telecom equipment to advanced nations like the United Kingdom and Australia.

The extension of economic openness, which created substantial domestic opportunities for foreign firms and their products, also permitted well-endowed coastal regions to pursue somewhat independent economic strategies and multiple upgrading paths (e.g. Vogel 1989; Segal 2003; Thun 2006; Breznitz and Murphree 2011). Manufacturers of power generating equipment thrived on joint ventures – more than fifty for Shanghai Electric alone ([https://en.wikipedia.org/wiki/Shanghai\\_Electric](https://en.wikipedia.org/wiki/Shanghai_Electric)). Huawei honed its now-formidable capabilities first by selling in third and fourth tier Chinese cities and then by marketing its telecom equipment in Africa. China's emergence as a major force in the global market for nuclear electricity rests on a complex combination of domestic development (China National Nuclear), deep ties with French partners (China General Nuclear), and licensing agreements that include a complete transfer of Westinghouse Electric's Generation III AP1000 technology (State Power Investment).

Building on the successes of this market-oriented, globalist approach, the World Bank and the Development Research Center (发展研究中心), a prominent government think tank operating under China's State Council, issued a joint report, *China 2030*, that enunciates a development strategy for pushing China's economy toward new levels of productivity, prosperity, and innovative achievement. The report, completed in 2012 and formally released in 2013, proposes major policy adjustments to facilitate China's emergence as global leader increasingly focused on advanced

technology and frontier innovation rather than the past emphasis on “catching up” with advanced nations. The authors repeatedly emphasize the centrality of openness and competition for successful completion of this transition.

The report advocates “increased competition in all sectors, including in strategic and pillar industries” (WB and DRC 2013, p. xxii). The authors insist that “A competitive market environment is a necessary condition for steady improvement in productivity” (p. 173). Emphasizing that “the role of the private sector is critical because innovation at the technology frontier is quite different in nature from simply catching up” (p. 17), the report advises immediate removal of formal and informal entry barriers that “convey the clear policy message – competition from private firms is not welcome” (p. 26). Looking ahead, the authors advise that success “will require further integration with the global economy and increased specialization” and that “The benefits of openness will be central to increasing efficiency, stimulating innovation, and promoting international competitiveness” (pp. 19, 22).

The joint report also specifies policies that, in the view of the World Bank-DRC team, are unlikely to deliver strong results. Continuation of entry restrictions and regulatory approaches tilted toward state-linked enterprises threatens to “dampen innovation and creativity, and slow productivity growth” because state-owned firms “are indifferently managed . . . less receptive to strategies that give primacy to growth through innovation . . . [and their investment in R&D] tends to be unproductive and poorly integrated with the rest of their operations” (pp. 36, 170). “Direct government intervention may actually retard growth, not help it . . . [because] Innovation is not something that can be achieved through government planning” (p. 17). Therefore, “the government needs to withdraw from direct involvement in production, distribution, and resource allocation” because “the government’s continued dominance in key sectors of the economy, while earlier an advantage, is in the future likely to act as a constraint on productivity improvements, innovation, and creativity” (pp. 18, 25).

Shortly thereafter, the November 2013 Decision of the Communist Party’s Central Committee on “Major Issues Concerning Comprehensively Deepening the Reform” appeared to set the stage for implementing the policy agenda recommended in the joint Bank-DRC report. The Decision announces the Party’s determination “to deepen economic system reform by centering on the decisive role of the market in allocating resources” (Decision 2014, Item 3). The Party will “promote market-oriented reform in width and in depth [by] greatly reducing the government’s role in the



direct allocation of resources” (Item 3). Openness – both domestic and international – is another prominent theme: “. . . we must . . . overcome the barriers of solidified interests” (Item 4), “continue to break up all forms of administrative monopoly” (Item 7), and, aside from a “negative list” of specific areas that are off-limits to some would-be investors, welcome “all kinds of market players . . . on an equal basis . . . [and] strictly ban and punish all unlawful acts extending preferential policies” (Item 9). The Decision envisions a growing role for private business, pledging to “persist in equality of rights, opportunities and rules, abolish all forms of irrational regulations for the non-public economy, remove all hidden barriers . . . encourage non-public enterprises to participate in SOE reform, foster mixed enterprises with non-public capital as the controlling shareholder, and encourage qualified private enterprises to establish the modern corporate system” (Item 8).

This seeming victory for proponents of openness, competition, and market dominance, however, soon revealed itself as a short-lived episode in an ongoing tug-of-war with a rival economic strategy emphasizing a different route toward the common goal of promoting innovation and raising productivity and living standards toward advanced-country levels.

The alternative strategy emphasizes central leadership in prioritizing innovations, concentrates innovation resources in large SOEs and promotes self-reliant paths to innovation and technical development. Heilmann and Shih (2013) identify its proponents as “a ‘centrist’ or ‘statist’ advocacy coalition” – in opposition to *China 2030* supporters, who promote “market liberalization.”<sup>8</sup> “Statist” thinking, which dominated Chinese policy prior to the onset of economic reform, maintained a strong presence throughout the reform era. Its influence is readily apparent, for example, in the 2006 “National Medium- to Long-Term Plan for the Development of Science and Technology” (Cao, Suttmeier, and Simon 2006) and the 2010 “Decision of the State Council on Accelerating the Fostering and Development of Strategic Emerging Industries” (Strategic 2010). The same thinking motivates “Made in China 2025,” a program announced in 2015 that forms the centerpiece of China’s present industrial policy.

Before investigating the nature and consequences of Made in China 2015, we speculate on the cause of the sudden about-face from the 2013

<sup>8</sup> At a deeper level, this debate reflects an intense internal ideological struggle in the Chinese leadership over Western influence in economic policy-making and the push for a self-reliant China under a “home-grown” system of socialism with Chinese characteristics. On this point, see Gewirtz, 2017, p. 13.

“market dominance” strategy and its emphasis on domestic and international openness. The 2008 global financial crisis and ensuing recession necessitated forceful government action to limit the short-term damage, a circumstance that inevitably strengthened the leverage of interventionist ideas. And, like the Great Depression of the 1930s, the global recession weakened advocates of openness and internationalism and strengthened economic nationalists everywhere.

In addition, completely distinct domestic circumstances contributed to the rapid unraveling of the apparent 2013 convergence of expert policy advice and Communist Party economic strategy supporting market liberalization.<sup>9</sup>

Several decades of enviable progress may have left incoming President Xi and other Chinese leaders far from satisfied. Frustration with limited innovative capacity has become a common theme. A 2016 review of machinery manufacture, China’s largest industry, is typical: while “some segments have reached the international level of advanced technology . . . autonomous innovative capacity is weak” (自主创新能力不强 *zizhu chuangxin nengli buqiang*; Equipment Report 2016, p. 2). This observation echoes numerous accounts of large gaps between the capabilities of Chinese firms and leading overseas companies in technical level, product quality and many other areas (e.g. Equipment Report 2016, pp. 71, 165–6, 273).

Several features of China’s innovation landscape appear to strike Chinese leaders as particularly galling. Chinese innovations, often concealed within the anonymous mechanisms of global supply chains, lack visibility. Additionally, governance of these supply chains, especially for advanced products with the brightest future prospects, remains concentrated among overseas multinationals. Distinctively Chinese innovations are rare. Where are the instantly recognizable Chinese brands? Why are there no Chinese contributions to rival the Ford assembly line or the Toyota production system? Peter Nolan captures this mood:

The areas in which indigenous Chinese firms do have significant market share in the high-income countries are few, most notably telecommunications equipment (Huawei) and PCs (Lenovo). After three decades of evolutionary industrial policy based mainly around state-owned enterprises, China still faces an immense challenge if it is to achieve its long-stated goal of nurturing a substantial group of indigenous firms that can compete in international markets.

<sup>9</sup> Cox notes that “Liu He, an influential economic adviser to Xi Jinping, was one of the driving forces behind” the joint Bank-DRC report (Cox 2017, p. 8).

At the same time that China's SOEs have failed to build globally competitive businesses, global high-technology and branded-goods producers have rapidly expanded their investment and market share within China in the many sectors that are relatively open to international competition. Large swathes of the domestic market are dominated by global oligopolies. (2014, pp. 133–4)

No longer content with innovation outcomes resulting from a structure that, despite significant state intervention, rested heavily on a market economy substantially influenced by foreign firms and foreign-led supply chains, China's leaders have opted for a major expansion of state intervention. The objective is not simply to accelerate the pace of innovation, but to steer the “commanding heights” of China's economy toward a carefully crafted array of specific sectors, technologies, and outcomes.

“Made in China 2025” [中国制造2025], announced in 2015, is the centerpiece of this new innovation strategy. This program offers a detailed, ten-year agenda for innovation and upgrading in ten industries, including power plant equipment, telecommunications and semiconductors, complete with timetables for achieving precise technical benchmarks. Thus, China aims to produce complete sets of equipment for Generation III+ nuclear plants of 1000 and 1500 MW capacity by 2020 and of 2000 MW capacity by 2025, all capable of operating at ninety-three percent of capacity for sixty years (Roadmap 2015, p. 123). Documents surrounding this program (many listed in Wübbecke et al. 2016, p. 66 and US Chamber of Commerce 2017, p. 42ff) advance a multitude of quantitative targets for 2020 and 2025 covering a wide array of indicators. For example:

- *output value* for railway, power transmission and farm equipment (Roadmap 2015, pp. 85, 132, 134)
- *output quantity* for power generation equipment (ibid., p. 117)
- *unit production costs* for electric batteries (ibid., p. 95)
- *export proportion* for railway and power generating equipment (ibid., pp. 85, 117)
- *export composition* for power transmission equipment (ibid., p. 132)
- *market share* “hundreds of market share targets for 2020 and 2025, both domestic and international” (EU Chamber 2017, p. 11)
- *domestic market composition* sales share of new energy vehicles (Roadmap 2015, pp. 82, 103)
- *global market share* for Chinese-made high-end computers, mobile phone chips and equipment (ibid., p. 8)

Echoing officially sponsored consolidation efforts in coal, steel, railway equipment, and shipbuilding, the new policy aims to establish

concentrated industry structures. Planned outcomes include two of the top ten global producers of new energy vehicles as well as three globally competitive enterprise groups capable of providing complete sets of large scale, technologically advanced equipment for thermal, hydro, nuclear, and renewable power generation and storage, all backed by independent intellectual property rights (Roadmap 2015, pp. 101, 117).

In addition to budgetary appropriations and policy support, resources for implementing this agenda come from government guidance funds (政府引导基金 *zhengfu yindao jijin*), hybrid entities that have mushroomed in recent years and now exist at multiple administrative levels. Provinces direct the largest funds, with smaller operations housed at “over 300 city-level governments.” Initial funding from official budgets attracts private capital, which is “fighting to get a piece of the action” because “partnering with state funds can lower the cost of capital and obtain support from the government” (Xiang 2017).

The combined scale of these funds, RMB 1.5–2 trillion at year-end 2015 (Xiang 2017; Blair 2017) and RMB 5.3 trillion in early 2017 (*Economist* 2017, p. 65), towers above 2015 government appropriations for science and technology (RMB 700 billion) and nationwide expenditure on R&D projects (RMB 1.22 trillion; see S&T Yearbook 2016, pp. 14–15). Guidance funds invest some of their assets in joint or private venture capital funds, further extending the reach of official preferences (Millward 2016). Both guidance and venture funds enjoy wide latitude in choosing avenues to support target industries, which may include equity investments, loans, reimbursing firms for qualified expenditures, and participation in funding for domestic or overseas mergers.

While encouraging favored technologies and firms, Chinese governments appear to have stepped up efforts to undermine the competitive position of “outsider” firms. Official efforts to promote import replacement increasingly target foreign firms and foreign-linked joint ventures. Policy-makers may steer official agencies, state-controlled enterprises, and even non-state firms toward domestic products rather than imported alternatives.

Numerous examples illustrate the application of regulatory tools – product specifications, tender qualifications, product catalogs, or requirements to share technology or disclose software codes – to obstruct entry or restrict sales of unwelcome products or vendors even as low tariffs maintain a façade of market openness. A 2016 list of thirty-one officially approved suppliers for electric vehicle batteries excluded two prominent Korean firms on the grounds “that their Chinese factories had been in operation for less than a year, a requirement” not previously announced

(EU Chamber 2017, p. 40). Entry into the cloud computing market requires a license from the Internet Data Center, which refuses licenses to foreign firms (US Chamber 2017, p. 28). U.S. researchers report that China has “issued licenses for value-added [telecom] services to 29,000 domestic suppliers” but only forty-one to foreign suppliers (US Chamber 2017, p. 28).

What are the characteristics of this new policy and regulatory environment? How will this initiative shape the evolution of innovative effort within and beyond China’s power, telecom and semiconductor industries beyond?

### China’s New Industrial Policy and Regulatory Environment – Characteristics

The new policy agenda partially reverses major elements of China’s reform-era economic landscape.

Made in China 2025 and related programs greatly expand the scope and the resources devoted to top-down pursuit of big innovations. This approach is the polar opposite of the decentralized, increasingly market-driven processes that have powered four decades of spectacular growth. Most Chinese firms “pursue incremental rather than radical innovation . . . [they] seldom go for ‘moonshot’ innovations – not for them ‘iPhone envy’”. They prefer pragmatic and predictable innovations” (Yip and McKern 2016, pp. 82–3). But “moonshots” are exactly what MIC 2025 proposes.

In sharp contrast to the Bank-DRC report and the 2013 Party Decision, Made in China 2025, developed by the Chinese Academy of Engineering (中国工程院; Interview, June 2018, and MIC 2025), relegates market forces to the background as officially imposed targets and quotas preempt commercial competition in an enlarged universe of strategic priorities. The new agenda rarely mentions cost and ignores returns on investment. Instead of openness, the new approach revives the Maoist vision of self-reliance. Emphasis on “autonomous” (自主 *zizhu* i.e. without foreign involvement) innovation adds a further non-market dimension. The new agenda seems to overlook, or perhaps devalue, what economic researchers see as the immense, and immensely valuable, knowledge transfer arising from the Chinese operations of foreign firms and the rich harvest of often invisible, but commercially significant innovations by Chinese participants in global supply chains (Zeng and Williamson 2007; Breznitz and Murphree 2011).

Growing prominence of mercantilist views that equate foreign profit with Chinese loss and implicitly deny the possibility of mutually beneficial commercial trade underpins strident demands to replace imports with domestic goods, especially in technology-intensive sectors like semiconductors, IT, and nuclear power. Royalty payments to foreign vendors of technology and other intellectual property, which amount to an economically trivial 1 percent of annual exports, draw particular ire.<sup>10</sup>

To implement a big push for breakthrough innovations beyond the reach of market pressures and foreign involvement, strategic plans inevitably concentrate expectations and resources in the hands of state enterprises, especially the giant firms operating under the aegis of State-owned Assets Supervision and Administration Commission (SASAC) – a group that includes major operators in the sectors examined in this book. Recent steps elevate the position of Party structures within these firms, for example by mandating that the Board of China Railway Group “shall first listen to the opinions of the party committee of the company” before it “decides on material issues” (Hughes 2017).

### China’s New Industrial Policy and Regulatory Environment – Consequences

Following in the footsteps of China’s initial Five Year Plans and the early post-war programs of Japan’s fabled Ministry of Trade and Industry (MITI), China’s leaders have crafted a massively funded, top-down, non-market, SOE-centered strategy intended to accelerate the development of highly visible innovations resting on a foundation of Chinese intellectual property. How will this affect the prospects for innovation within and beyond electricity, telecommunications, and semiconductors? What is the likely impact on the wider economy?

China’s new approach to innovation bifurcates the economy along lines reminiscent of the 1980s policy of “Planned economy as the mainstay, market allocation as supplementary” (计划经济为主, 市场调节为辅 *jihua jingji weizhu, shichang tiaojie weifu*) as well as the “big push” industrialization strategy intended to graft a self-contained network of advanced

<sup>10</sup> China’s 2016 international payments for the use of intellectual property amounted to US\$24 billion or just above 1% of China’s 2016 exports, which totaled US\$2,120 billion in the same year. Ireland (\$76 billion), the Netherlands (\$48 billion) and the United States (\$43 billion) surpassed China’s total in 2016; Japan (\$20 billion) and Singapore (\$19 billion) followed close behind. Data from World Bank’s World Development Indicators.

producers atop an economy populated by firms with lesser capabilities (Rosenstein-Rodan 1943; Murphy, Schleifer, and Vishny 1989).

The difficulty is that, as both Chinese and external commentators (e.g. Chen 2012; Tse 2015, p. 47) observe and as recent Chinese experience copiously demonstrates, expansion of market forces promotes innovation and productivity growth, while concentration of resources in the state sector has the opposite effect. Market regimes sharpen incentives. Success brings extraordinary rewards, while laggards experience Joseph Berliner's "invisible foot," which market systems apply "vigorously to the backsides of enterprises that would otherwise have been quite content to go on producing the same products in the same ways, and at a reasonable profit, if they could only be protected from the intrusion of competition" (1976, p. 529).

Opening China's economy to international trade and investment attracted a torrent of new technologies and advanced products into the domestic market, creating both risk and opportunity:

Chinese companies have gained a great deal of knowledge from multinationals in China through acting as their suppliers and customers, and as staff trained by foreign investors have hopped across to jobs with Chinese organizations . . . The scale of inward foreign investment and trade has meant that Chinese companies have been forced to learn how to compete with multinationals from day one in order to survive in their home market. Compared to their Japanese and Korean cousins, Chinese companies have had to face the cold winds of international competition almost from infancy (Zeng and Williamson 2007, p. 17).

Case studies show how Chinese producers of telecom and construction equipment used the accumulation of technical knowledge and market experience as a springboard to claw their way into fiercely competitive global markets, eventually wresting market share from long-entrenched multinational rivals (Brandt and Thun 2010, 2016). Mandel (2013) finds rapid quality improvement of Chinese exports (measured by rising unit values and growing penetration of high-income markets), demonstrating the breadth and strength of links between openness and upgrading. Brandt, Van Biesebroeck, Wang, and Zhang (2017) find a causal relation between reduced tariffs on both outputs and inputs, signals of growing economic openness, and sector-level productivity growth.<sup>11</sup> These effects extend into the state sector, with the likelihood of dismissal for leaders of poorly performing SOEs rising in sectors experiencing lower tariffs.

<sup>11</sup> In addition, falling tariffs push firms to lower markups (the ratio of sales price to marginal cost), indicating reduced market power.

Extending domestic openness to include “all kinds of market players” (Decision 2014, Item 9) seems equally beneficial. While SOE dominance coincides with strong productivity outcomes in some instances, enterprise-level data for 1998–2007 reveal a strong association between state sector influence and poor results. Total factor productivity (TFP, discussed below) *rose* by an average of 20.8 percent in sectors where the output share of SOEs was below 50 percent and *declined* by 11.7 percent in sectors where SOEs provided the majority of output value. Perhaps more important than this yawning gap is the observation that, in SOE-dominated sectors, new entrants on average *reduced* TFP outcomes regardless of ownership, “suggesting an entry process that is highly politicized and distorted,” with connections, rather than competence, in the driver’s seat (Brandt 2016, p. 289).

Bifurcation signals a partial reversal of the gradual and uneven, but cumulatively massive shift in the direction of greater market discipline that has accompanied four decades of reform. Official assignment of innovation targets rolls back past efforts to commercialize state enterprises, for example under the rubric of “separating government from enterprises” (政企分开 *zhengqi fenkai* see Decision 2014, Item 7). It is the antithesis of Chen Qingtai’s (2012) vision of a renewed state sector in which “the government no longer controls and manages, firms become independent market entities oriented to financial outcomes, led by boards of directors, that gain strength and expand through market competition.”

Partial retreat from the spread of market forces follows a period of rapid expansion and consolidation among giant state-sector firms in coal, steel, railway equipment, and shipbuilding, among others. Between 2004 and 2015, the number of subsidiaries under centrally led enterprise groups that existed in both years jumped from 6,830 to 14,227; in 2014, these groups also held minority stakes in over 5,000 non-subsidiary firms (Brandt, Dai, and Zhang 2017).

The sheer size of the now-enlarged priority sector, the continuing inflow of innovation-linked resources, and the prospect of expanded official protection for firms that already enjoy a regime of “limited competition . . . and . . . virtually insurmountable barriers to new firm entry” (Naughton 2015, p. 52) means that the rollback of market discipline accompanying the shift toward plan fulfillment is likely to spill beyond the boundaries of the priority sector.

Relaxation of competitive pressures arising from priority status and from the growing market power of SOE giants imposes unwelcome costs. State Grid Corporation’s 2009 acquisition of Pinggao (平高电气) and Xuji (许继电气), two prominent manufacturers of electrical



machinery, illustrates the problem. An industry source reports that these mergers triggered abrupt declines in (formerly excellent) quality and service (Interview, June 2013), apparently because the two firms viewed their new association with State Grid, the world's largest public utility, as guaranteeing ample sales.<sup>12</sup>

Bifurcation means exclusion. Priority status for some firms relegates multiple enterprise categories to the periphery of China's new innovation efforts. Official preference for scale excludes small firms, which the joint Bank-DRC report lauds as "the big firms of the future" (WB & DRC 2013, p. 36), including all but the largest private operators. Strategic planners tilt toward vertical integration, as Brandt and Wang note for wind turbines. They favor multi-purpose manufacturers, insisting, for example, that applicants seeking recognition as manufacturers of new energy vehicles (NEV) "demonstrate that they have mastered the . . . technology for the complete NEV, not just for one of three core technologies" (EU Chamber 2017, p. 39). Such measures exclude specialist firms that contribute substantially to innovative structures both within and outside China.<sup>13</sup> Nationalist objection to imports of technology-related commodities and services erects barriers to the involvement of imported goods or foreign-linked domestic firms in priority innovation projects.<sup>14</sup>

Innovation outcomes are highly uncertain. New ideas appear in unexpected places. Unheralded firms or even individuals – think of Microsoft's Bill Gates, Apple's Steve Jobs, Alibaba's Jack Ma, Huawei's Ren Zhengfei, Baidu's Li Yanhong, TenCent's Pony Ma, State Grid's Liu Zhenya, or Haier's Zhang Ruimin – can build hugely influential operations from scratch. Experts can easily misjudge the potential of would-be innovators, as when Japan's legendary Ministry of Trade and Industry "attempted to

<sup>12</sup> Xu 2017 notes that these particular acquisitions prompted "strong criticism" that "accused SGCC of using its economic muscle to . . . squeeze out competitors, and make it difficult for other manufacturers to get fair deals from the giant consumer" (2017, p. 258). More generally, "Many small and medium companies complain that . . . large SOEs . . . are abusing their market power by favoring their own connected companies and excluding" others (WB & DRC 2013, p. 170).

<sup>13</sup> Excluded firms seeking to sell into priority sectors may find themselves forced into costly and unwanted alliances with insider firms. As Breznitz and Murphree note, "virtually all high-technology enterprises seek what Adam Segal (2003) terms 'a bureaucratic mother-in-law' by becoming an affiliate of a state agent" (2011, p. 44). Private wind farm operators complain that even with official approval of their projects, they cannot avoid selling out to state-sector rivals (Zhang 2016).

<sup>14</sup> The term 自主 (*zizhu*) meaning "autonomous" or "acting for oneself," as in autonomous research, intellectual property, brands, innovation, design, etc. appears 123 times in Roadmap 2015.

deny a fledgling Sony the \$25,000 . . . to license transistor technology from Western Electric” (Johnstone 1999, p. xv).

Channeling large-scale innovation support to administratively selected insider firms is unwise in any context. China’s strategy of concentrating resources and responsibilities in the hands of state enterprises, a problematic group with a collective history of “weak cost, profit and productivity performance” seems particularly dangerous (Brandt, Ma, and Rawski 2017, p. 223). Unpleasant surprises await, as “companies with innovative ideas find themselves out of the loop” (Breznitz and Murphree 2011, p. 32), while state-run champions equipped with “the capacity for innovation” but saddled with “defective incentive systems” (Fu 2013, p. 54) expend valuable resources on poorly chosen projects.

While four decades of reform have wrought remarkable changes in China’s economy, it is easy to overlook the distinctive legacies of Soviet-inspired institutional structures, especially in SOE-dominated segments of the economy. Consider the following observations by Peter Wiles, all written long before the start of China’s economic reform:

- There is something ‘socialist’ and ‘progressive’ about mere size, even if unaccompanied by lower costs (1962, pp. 304–5).
- Perpetual loss-makers are either subsidized . . . forcibly amalgamated with profit-makers, or kept alive by bank loans (1968, p. 48).

And, particularly relevant to innovation, what Wiles dubs:

- Technological snobbery . . . the notion that the most modern way of producing the most fashionable product is the best way to employ our resources (1968, p. 178).

Announcement of competition-stifling mega-mergers, complaints that soft budget constraints prolong the existence of uneconomic “zombie” enterprises (僵尸企业 *jiangshi qiye*), and a report that “By mid-2016, 28 provinces and provincial-level cities had designated robotics as a priority sector” (EU Chamber 2017, p. 35), confirm the uncanny relevance of Wiles’ half-century-old observations about the former Soviet Union.

An official innovation strategy that promises a partial revival of Soviet-style planning can only increase the already considerable costs that Soviet-era legacies impose on China’s economy.<sup>15</sup> Several areas seem particularly relevant.

<sup>15</sup> To cite a single example: during the recent financial crisis, the worst in living memory, quarter-to-quarter fluctuations in US nominal investment spending fell short of 10%. In

### *Innovation without Economic Benefit*

Accounts of Chinese innovation often focus on inputs – rising numbers of research personnel, growing R&D outlays, or expanding ranks of engineering graduates – factors that elevate innovative potential rather than results. Common measures of innovation output – numbers of publications, share of output designated as “new” or “high tech” products<sup>16</sup> – are easy to manipulate and may therefore have little connection with innovation outcomes.

Studying patents, which researchers view as “a leading indicator of emerging technological prowess” offers a more promising link to innovation, one that is particularly relevant for this volume because electrical engineering accounts for 57 percent of Chinese applications under the Patent Cooperation Treaty (PCT; see Boeing and Mueller 2016, p. 145; 2018, p. 17). A steep rise in patent submissions has vaulted China past the United States as the leading source of worldwide patent applications beginning in 2011 (Boeing and Mueller 2016, p. 145). China climbed into second place for PCT submissions during 2017, trailing only the United States (WIPO 2018).

Focusing on international search reports associated with PCT applications to avoid biases arising from the nationalistic inclinations of individual patent offices, Boeing and Mueller analyze trends in the quality of Chinese patent submissions and compare them with similar results for the United States, Germany, Japan, and Korea. To measure quality, they calculate the frequency with which specific patents receive citations in subsequent submissions originating in other countries, in the patent-holder’s home country and/or in self-citations by the initial patent-holder.

Basing their quality measure solely on overseas citations leads Boeing and Mueller to conclude that, relative to submissions from other leading sources of patent submissions, the quality of Chinese patents is low and declining. Including domestic and self-citations produces results that approach or surpass outcomes for the international comparison group (2018, p. 16).

Boeing and Mueller attribute the latter outcomes to measurement bias. Noting economists’ long-standing concern that “indicators fail as reliable measures if they become the target of policy,” they find that China “has incentivized increases in the quantity of applications to the detriment of

China, the legacy of giant plan-inspired seasonal fluctuations persists: periodic reports issued by the National Bureau of Statistics show first-quarter investment spending routinely dropping more than 40% from the figure for the previous year’s fourth quarter.

<sup>16</sup> The authors have visited “high tech” production facilities that resemble garment factories, except that workers use screwdrivers and other manual tools rather than sewing machines and assemble electrical components rather than pieces of fabric.

quality.” Their conclusion: current policy “rewards low quality patents with no economic benefit,” transforming “Chinese patent applications and citations thereof” into “questionable measures of innovation levels” (2018, p. 29).

Episodes of innovation with little benefit and prioritizing quantity or scale over quality reverberate across the landscape surveyed in the chapters that follow.

Michael Davidson in Chapter 4 finds that low utilization saps the expected benefits of advanced thermal power units.

A Chinese specialist offered the view that developing ultra-supercritical thermal power equipment would require massive expenditure to obtain “marginal” performance improvements (Interview, June 7, 2013).

Beijing plans a massive expansion of China’s electric vehicle fleet even though researchers at Tsinghua University find that the “life cycle energy consumption and greenhouse gas emissions of . . . battery electric . . . vehicles in Chinese context . . . are about 50% higher than those of an internal combustion engine vehicle” (Qiao et al. 2017).

Developing advanced technology for its own sake – Wiles’ “technological snobbery” – creates benefits that may fall short of the “opportunity cost” of deploying resources elsewhere.

In 2017, following eight years of experimentation, Dongfang Electric completed factory testing of a prototype 5 KW offshore wind turbine designed for service in typhoon-prone waters off Fujian province (Dongfang 2017). The prototype builds on autonomous (自主 *zizhu*) intellectual property, electronic controls and core technology and achieves a “high degree of localization.” Data compiled by Brandt and Wang show that, as of 2012, Chinese firms put far greater effort into large wind turbines than foreign manufacturers: their Table 9.10 shows five international firms offering two models rated at 5KW or more, whereas ten Chinese firms offer ten models in the same category, with an additional five prototypes in preparation. With equipment rated at or below 2KW consistently accounting for more than 80 percent of new Chinese installations, concentrating R&D efforts on improving the (currently low) quality of their main products would in all likelihood have generated far greater economic benefits than developing prototypes of prestigious (and far more complex) but little-used large-scale devices.<sup>17</sup>

While Xu shows in Chapter 6 how State Grid has become a world leader in ultra-high voltage long distance power transmission, Thomas G. Rawski

<sup>17</sup> Yang (2015) gives annual market shares for turbines of various sizes for 2012–14. For 2015, see [www.researchandmarkets.com/research/p4pwbh/global\\_and\\_china](http://www.researchandmarkets.com/research/p4pwbh/global_and_china) (accessed August 15, 2018).

in Chapter 8 notes that domestic critics assail the costs associated with this undoubted technical advance: they complain that transmission lines incorporating the new technology suffer from higher costs and lower utilization rates than conventional alternatives. Widespread comment on the costs associated with China's inadequate facilities for cross-regional power transmission<sup>18</sup> encourages the view that State Grid's successful pursuit of global technology leadership has come at the expense of much-needed expansion of conventional power transmission facilities.

Observing that the slogan *zizhu chuangxin* 自主创新, officially translated as “indigenous innovation,” could also be fairly translated as “autonomous innovation,” Arthur Kroeber notes that the objectives of Made in China 2025 “and other Chinese innovation policies often seem less about creativity per se, and more about reducing reliance on imported products, services and ideas” (2016, p. 65).

As the world's largest producer and consumer of many commodities, domestic production often makes good economic sense. But since exchange of similar commodities – for example machine tools, automotive components, and patent licenses – occupies a huge share of international trade among advanced nations, the *economic* benefit of pursuing wide-ranging replacement of imported products, components, software and technology is far from clear.

### *Market Segmentation and Market Power*

Chinese governments at all levels routinely place a premium on building large-scale enterprises. They also promote industrial concentration – i.e. raising the market share of the largest producers. Market segmentation, which creates barriers that exclude outsiders to benefit favored participants, magnifies the consequences of policies that promote scale and concentration.

Chen Qingtai (2012) eloquently explains the caste system that governs Chinese business. State enterprises are “insiders” (体制内 *tizhinei*) with privileged access to natural resources, finance, administrative approvals, and entry conditions that are often “made to measure” (量身定制 *liang-shen dingzhi*) for large firms. Centrally directed firms like State Grid, China Telecom and the big power generation and nuclear firms, “have the highest social status and the right to speak up.” Locally supervised state enterprises

<sup>18</sup> For example, the provincial NDRC head in Gansu, a leading producer of wind and solar power, attributes the province's massive spillage of renewable power to weak demand and to “limited capacity for outbound transmission” (Zhang Zirui 2017a).

occupy the second rank. Then come foreign invested firms with “considerable strength and voice.” Finally, private firms, which are “blocked by glass barriers,” seen as uncreditworthy by banks, and “often forced to merge with money-losing state firms,” occupy “the least favorable status.” Chen concludes that segmentation of firms according to ownership status, along with unresolved issues of local protectionism, which imposes its own entry barriers, creates “two powerful anti-competitive forces that reduce efficiency and limit our development potential.”

With growing emphasis on autonomy, import replacement and self-reliance, China’s current innovation strategy raises the prospect of new entry barriers aimed at imported products, foreign-invested enterprises and foreign-owned intellectual property. Wübbeke et al. (2016, p. 7) summarize potential difficulties facing foreign businesses and high priority sectors:

While Chinese high-tech companies enjoy massive state backing, their foreign competitors in China face a whole set of barriers to market access and obstacles to their business activities: the closing of the market for information technology, the exclusion from local subsidy schemes, the low level of data security and the intensive collection of digital data by the Chinese state.

Access depends on fine-grained official actions that often allow extensive local discretion:<sup>19</sup>

As more industries implement Internet-enabled products and services, standards have the potential to create trade barriers in industries nominally open to foreign investment (US Chamber 2017, p. 30).

Implementation at the local level is often a major barrier . . . obtaining [High- and New-Technology Enterprise status] . . . depends on local authorities’ interpretation of the requirements, as well as their political and industrial strategies. This discretionary approach creates uncertainty . . . (EU Chamber 2017, p. 60).

Reference to the “political and industrial strategies” of sub-national governments serves as a reminder of their tendency to replicate the center’s effort to nurture “champion” firms in “strategic” industries and to protect these clients from unwelcome rivals. Although the proliferation of trucks and expressways has eroded historic barriers to domestic trade, we now find provinces and localities blocking electricity “imports” from elsewhere. As Beijing moves to limit firms with partial or full foreign ownership from

<sup>19</sup> Official discretion is commonplace. A manager in the electrical equipment sector notes “high ranking officials of grade 6 or 7” make purchasing decisions; in doing so, “they may award contracts to familiar firms without even looking at the bid documents” (Interview, October 2012).

participating in priority industries, we can expect local officials to apply their own brand of mercantilism to domestic as well as foreign outsiders. Requiring wind farms to install locally manufactured turbines (Zhang Zirui 2017b) or ordering taxi companies to replace conventional cars with electric vehicles whose manufacturer promises local production (Taiyuan 2016) illustrates a wider protectionist agenda:

Local protectionism creates regional entry barriers . . . for example by forbidding or restricting sales of outside products, implementing special approval procedures . . . or tax and fee standards for outside enterprises and products, or implementing different standards for quality and technical inspections or different price restrictions for local and outside firms (Fu 2013, p. 54).

### *Poor Investment Decisions*

Kornai (1980) noted that universal shortages of goods stoked an unlimited appetite for investment in the former Soviet Union and its European socialist allies because new production could always find buyers. In China, this “investment hunger” persists even in the absence of excess demand. Prominent Marxian economist Liu Guoguang is among many authors who deplore China’s “long history of deep-rooted investment hunger and impulse for blind expansion” (根深蒂固的投资饥饿 和盲目扩张冲动 *genshen digu de touzi ji'e he mangmu kuozhang chongdong*; 2000, p. 6).

The incentives underlying widespread investment excesses include the benefit that building new facilities confers on leaders’ career prospects, widespread preference for local self-sufficiency, and the informal income opportunities surrounding every stage of project planning, approval, and implementation. Weak financial controls surrounding innovation outlays – Xiang (2017) notes that government guidance funds “often operate in utmost secrecy,” that “most . . . do not conduct performance assessment” and that “no one is named to be accountable for performance” – encourage the worst features of past investment behavior.

Despite four decades of market-leaning reform, demand prospects, price-cost comparisons and other standard market metrics often have little place in the calculus underlying investment decisions, especially within the state sector. In January 2018, for example, a news report announced that a newly completed hydropower plant along Sichuan’s Yalong River faced immediate closure because protracted wrangling over a proposed transmission line left the new facility without links to potential markets (Su 2018). Continued pursuit of new power generation projects in the face of declining utilization rates highlights the non-commercial nature of many investment decisions. Generating companies view these investment

excesses as “staking a claim” (跑马圈地 *paoma quandi*) to future delivery quotas, which are typically distributed among all available producers (He 2015; see also Excess Capacity 2016).

In a 2017 interview, power specialist Yuan Jiahai (袁家海) offers the prospect that yet another tranche of reforms may inject (previously absent) economic calculation into electricity investors’ decision-making:

Reformed arrangements in which newly approved power plants no longer receive delivery quotas and government no longer sets prices will lead investors to make rational decisions [合理决策 *heli juece*], so that the market mechanism will curb the enthusiasm for investing in new thermal power plants (Yu 2017).

While Yuan’s observations focus on thermal power, planned economy thinking pervades every segment of the power sector, with producers first building new facilities and then looking to government to arrange outlets for enlarged power production.

Electricity is not unique. Enhanced entry and diminished exit, both documented in Margaret Pearson’s exploration of local government behavior, breed overinvestment and excess capacity. Announcements of strategic priorities spark widespread investment excesses, as companies, localities, universities, and research institutes scramble to share in the bonanza of cash and recognition lavished on robotics, new energy and other “hot” sectors. The result: repeated criticism of “blind expansion” and “Great Leap-style” overinvestment not just in thermal power, but also in renewable energy, electric vehicles, semiconductors, and elsewhere.<sup>20</sup>

Electric power illustrates the scale of excess investment. Power systems maintain a cushion of reserve generating capacity that enables them to respond effectively to unforeseen equipment failure or demand spikes. US industry specialists recommend a back-up capacity amounting to 15 percent of a power system’s peak load (Lin, Liu, and Kahrl 2016, p. 10). In 2015, the average and median back-up capacity among China’s provinces exceeded 90 percent of peak load. No less than twenty-four province-level jurisdictions reported 2015 back-up capacity exceeding 50 percent of peak load, with Inner Mongolia, which houses the largest generating capacity, maintaining reserve capacity amounting to 278 percent of its peak load. Yet investment rolls on. Provinces with capacity cushions exceeding 50 percent

<sup>20</sup> For recent criticism of “blind expansion,” see Jia 2017 (thermal power), He 2017 (batteries), Zhang Zirui 2016 (wind power), Bie 2017 (clean coal); for “Great Leap,” see Thermal Leap 2015 (thermal power). Critiques referring to both include Blind Leap 2012 (new energy vehicles) and Green Energy Leap 2015 (wind and solar power).



accounted for 83 percent of nationwide growth in generating capacity during 2015/16 (Power Compendium 2016).

Excess capacity erodes the payoff to new technologies. Brandt and Wang show how low utilization rates and grid connection issues – another consequence of excess capacity – drive up the cost of wind and solar electricity (see also Lam, Branstetter and Azevedo 2016). Utilization rates for thermal power plants have declined sharply amid a recent burst of expansion: the 2016 average of 4,165 hours, the lowest since 1964, is far short of the 5,000–5,500 hours needed to cover costs. Madhavan, Rawski, and Tian report that average 2016 operating hours for nuclear plants may have fallen below 7,000 (sources disagree on the exact figure), the benchmark allowing timely repayment of loans. With analysts predicting further declines in operating hours, generation companies will face escalating financial pressures.

Overcapacity limits environmental as well as financial benefits from technical upgrades. Michael Davidson shows how China's long-standing system of equally distributing operating hours among incumbent generating plants translates into low utilization rates for the newest and most efficient facilities. This arrangement limits production from cleaner plants to preserve market share for lesser facilities, a common outcome of Chinese industrial and regulatory policy. The result: higher costs and excess burdens on China's already overloaded air resources.

### *Quality Lapses*

Neglect of quality is a long-standing weakness among Chinese manufacturers that dates from the initial years of socialist planning. A 1957 commentary advocated “creating an atmosphere in which importance is attached to quality.” Two decades later, Deng Xiaoping demanded that products falling “below the quality standard should not be allowed to leave the plant” (quoted in Rawski 1980, pp. 119, 125). A 1982 account castigated “the existing erroneous tendency to . . . neglect product quality” (FBIS 1982).

Despite vast reform-era improvements and occasional pockets of excellence, the legacy of socialism, along with pressure from cost-conscious customers, has left quality issues to fester in many segments of manufacturing. The machinery industry, China's largest and also the centerpiece among the ambitious targets written into Made in China 2025, has not overcome its history of limited attention to quality. In 2015, an American energy company's personnel discovered that their Chinese licensee had skipped some segments of a quality control protocol; when confronted with this lapse, the Chinese supplier responded that it had to meet its production schedule (Interview, September 2017). Neglect of quality is

widespread. In 2016, former Deputy Machinery Minister Shen Liechu (沈烈初) summarized the reputation of Chinese-made equipment among both domestic and foreign buyers as “usable but not too reliable” (能用, 不太可靠 *nengyong butai kekao*) – particularly because “small defects continue” (小毛病不断 *xiaomaobing buduan*; Hu 2016). Echoing earlier discussions of quality issues in the manufacture of nuclear equipment, an enterprise-based author writes that “procedural violations (违章现象) are very common” and that “reversing the habit of violating procedures is difficult” (Shao Yong 2016, p. 55; see also Li Xiushan 2012 and Tan Gan 2012).

Quality problems extend beyond machine building. A brief September 2017 document issued by China’s highest authorities – the Communist Party’s Central Committee and the State Council – lamented the “inadequate effective supply of mid-level and high end products and services.” Summoning language that echoes pleas of earlier decades, China’s leaders urge “across the board effort to push economic development into an era of quality” (Central Committee 2017).

With its emphasis on large firms and “big innovation,” China’s latest innovation push may overlook the humdrum bits and pieces that underpin the precision and durability of advanced systems. A 2016 survey noted that “production technology for parts and components lags behind the advances of major equipment” manufacture, illustrating the problem with reference to the limited reliability and durability of hydraulic pneumatic seals (Equipment report 2016, p. 261).

Current stress on import replacement threatens to undermine product quality in the technically advanced sectors that dominate official innovation plans by encouraging premature adoption of inadequate domestic components. After presenting a litany of shortcomings, noting, for example, that “the reliability of domestic sensors lags 1–2 orders of magnitude behind comparable foreign products,” a review of instrument manufacture proposes that trade policy should “adjust procurement of meters and instruments to give a certain policy preference to domestic products” (Equipment Report 2016, pp. 249, 254).

#### USING PRODUCTIVITY TO RECONCILE CONFLICTING EVIDENCE

Faced with substantial reason to anticipate both acceleration and slow-down of innovation and upgrading we turn to productivity trends, which combine a multitude of factors into a single measure of an economy’s

trajectory. While no one can foretell the future, we know that continued rapid growth depends on what Gordon Redding calls “the crucial test of productivity” expansion (2016, p. 58).

Brandt, Van Biesebroeck, and Zhang (2012) and Brandt, Van Biesebroeck, Wang, and Zhang (2017) document impressive productivity growth in Chinese manufacturing through 2007 that matches or exceeds achievements in other Asian economies during similar periods in their development. The metric is total factor productivity (TFP), the economist’s yardstick for measuring the pace of innovation and upgrading in any economy.<sup>21</sup> Underlying these gains are highly complementary domestic market reforms, including initiatives that lowered entry barriers for new firms, and trade liberalization.

Table 1.1<sup>22</sup> provides related information for 1998–2013 at the three-digit level<sup>23</sup> for industry as a whole (manufacturing, mining, and utilities) and for several sectors analyzed in the following chapters.<sup>24</sup> Annual TFP growth for the entire industrial sector averages 1.44 percent – a substantial figure – over the entire period, but well below the result for 1998–2003 and especially 2003–8. Beginning in 2008, the figures show a sharp downturn in overall productivity advance, which averages only 0.38 percent for the period between 2008 and 2013.

Among the specific sectors highlighted in Table 1.1, telecom equipment – sector 405 in the Chinese industrial classification (CIC) – displays the best performance, with substantial growth of TFP in all sub-periods, including exceptional annual growth in excess of 5 percent during 2003–8.

Subdivisions linked to the production and transmission of electricity deliver mixed results. Generation and transmission equipment (CIC 381

<sup>21</sup> TFP is the ratio of deflated gross output (roughly equivalent to sales revenue in constant prices) to an index of combined inputs (labor, capital and intermediates like the coal used to generate electricity). TFP rises if average output per combined unit of labor, capital and materials is increasing; its rise reflects both cost reductions and improvement in product quality.

<sup>22</sup> Quantitative results presented in the tables and figures below are the product of joint work involving Brandt, Luhang Wang, Johannes Van Biesebroek, and Yifan Zhang.

<sup>23</sup> A one-digit breakdown of manufacturing separates firms into broad categories such as textiles, chemicals, and machinery. A two-digit breakdown distinguishes segments within each broad category, e.g. electrical equipment and transport equipment within the machinery category. Table 1.1 employs a three-digit classification that provides a further breakdown, e.g. showing separate figures for power generation (category 381) and power transmission equipment (382) within the broader electrical machinery category.

<sup>24</sup> We restrict the comparison to 1998–2013 to avoid issues of comparability arising from periodic revisions to China’s industrial classification system. We are unable to isolate data for semiconductor firms.

Table 1.1 *Total Factor Productivity Growth for Manufacturing and Electricity-Related Subsectors, 1998–2013*

CIC Code	Average Annual Percent Change				
	1998–2013	1998–2003	2003–8	2008–13	
	All Industry	1.44%	1.64%	2.25%	0.38%
	Subtotal for Electricity and Telecom-Related Sectors	1.66%	1.36%	3.27%	0.42%
381	Generation Equipment	1.51%	2.10%	3.83%	<b>-1.37%</b>
382	Transmission Equipment	0.82%	1.31%	2.84%	<b>-1.67%</b>
383	Wires and Cables	0.54%	1.41%	0.14%	0.08%
392	Telecom Equipment	2.88%	1.21%	5.05%	2.32%
	Solar Materials and Equipment	1.35%	0.84%	2.79%	<b>-1.65%</b>
	Wind Turbines	n.a.	n.a.	0.38%	<b>-4.54%</b>

*Note:* For wind turbines, sufficient data to develop sector-wide TFP data become available only from 2003.

China Industrial Classification (CIC) codes are those implemented in 2013. We classified firms as producers of wind turbines or solar (silicon, panels, and modules) based on descriptions of their main products.

*Source:* Analysis of firm-level data compiled by China's National Bureau of Statistics.

and 382) show positive and increasing levels of TFP growth up to 2008, but suffer declining TFP (shown in boldface) thereafter. TFP for producers of solar panels and materials such silicon, wafers and cells rises to 2008, but declines thereafter. Wind turbines experience negligible growth between 2003 and 2008, followed by sharply negative TFP change during 2008–13.

The sources of these changes deserve close attention. Table 1.2 presents decompositions of TFP growth in each of three sub-periods – 1998–2003, 2003–8, 2008–13 – into four components, which jointly account for overall TFP growth. The components include “Incumbents,” which measures the contribution to TFP change from improvements in *incumbent* firms that operated throughout the period of analysis. “Entrants” captures TFP changes attributable to the activities of *new firms*. “Exit” measures changes in TFP due to the disappearance of firms – presumably poor performers – that leave the industry. “Reallocation” measures TFP change arising from the redistribution of resources *between* firms; the contribution is positive if high-productivity firms enlarge their share of available resources, and thus market share. The four components’ share in overall TFP change add to 100 percent when TFP rises, and to –100 percent when TFP declines.

Table 1.2 *Decomposition of Total Factor Productivity Change in Six Subsectors during Each of Three Periods, 1998–2013*

Panel A: TFP Changes during 1998–2003					
	Average Annual TFP Growth	Percent Share of TFP Change in This Sub-period Due to			
		Incumbent	Reallocation	Entrant	Exit
Generation Equipment	2.10%	54%	–5%	48%	3%
Transmission Equipment	1.31%	39%	–7%	54%	13%
Wires and Cables	1.41%	36%	18%	39%	7%
Telecom Equipment	1.21%	29%	–28%	97%	2%
Solar Materials and Equipment	0.84%	–101%	–82%	145%	138%
Panel B: TFP Changes during 2003–2008					
	Average Annual TFP Growth	Percent Share of TFP Change in This Sub-period Due to			
		Incumbent	Reallocation	Entrant	Exit
Generation Equipment	3.83%	66%	–22%	56%	1%
Transmission Equipment	2.84%	61%	–20%	57%	1%
Wires and Cables	0.14%	238%	–168%	184%	–154%
Telecom Equipment	5.05%	79%	–16%	29%	7%
Solar Materials and Equipment	2.79%	–11%	–12%	90%	33%
Wind Turbines	0.39%	375%	–340%	–136%	0%
Panel C: TFP Changes during 2008–13					
	Average Annual TFP Growth	Percent Share of TFP Change in This Sub-period Due to			
		Incumbent	Reallocation	Entrant	Exit
Generation Equipment	–1.38%	30%	–46%	–75%	–9%
Transmission Equipment	–1.67%	–3%	–20%	–79%	2%
Wires and Cables	0.08%	3%	126%	82%	–110%
Telecom Equipment	2.32%	30%	10%	38%	22%
Solar Materials and Equipment	–1.65%	–54%	–8%	–66%	28%
Wind Turbines	–4.54%	6%	–20%	–84%	–2%

Note: For wind turbines, sufficient data to develop sector-wide TFP data become available only from 2003.

Source: Analysis of firm-level data compiled by China's National Bureau of Statistics

Prior to 2008, the leading sources of productivity growth are entry of new firms with above-average productivity, followed by improvements among incumbents. Solar is the exception, with incumbents exerting consistently negative effects on TFP outcomes – meaning that TFP among incumbent producers of solar panels and materials and declined during each sub-period.

During 2008–13, however, only telecom equipment maintains TFP momentum amid a general collapse of productivity improvement. The matrix of components bristles with negative components (shown in bold-face), previously confined mainly to the column headed “Reallocation.”

Two features stand out. In a dramatic change highlighted in Figure 1.1, the impact of new firms on TFP turns negative: generation equipment, transmission equipment, solar, and wind turbines all show entry exerting a negative impact on sector-wide TFP.<sup>25</sup> This means that, on average, new firms have lower productivity than incumbents – stunning evidence of poor investment choices.

Equally striking is the consistently negative TFP impact of “Reallocation” throughout the entire period covered in Table 1.2. These negative entries indicate that shifts of labor, capital, and other resources among incumbent firms have, on average, elevated the market share of poor performers at the expense of firms achieving higher levels of TFP – again signaling substantial inefficiency.

Recent productivity outcomes for the electricity and telecom-related sectors included in Table 1.1 and in Figures 1.1 and 1.2 seem representative of industry-wide trends. The top row of figures in Table 1.1 shows that the TFP trajectory described above – substantial advance during 1998–2008 followed by a steep drop-off in TFP growth thereafter – characterizes the recent evolution of China’s entire industrial sector.

Further similarities emerge from Figure 1.2, which displays the contribution (rather than percentage shares) of the previously discussed components to industry-wide TFP change during the periods shown in Table 1.1. Two observations stand out. The positive impetus to TFP arising from the appearance of new enterprises virtually disappears after 2008. And for the entire industrial sector, as for the electricity and telecom-related segments described in Table 1.2, the TFP impact of Reallocation is generally negative – meaning that market share gravitates from higher to lower productivity firms, an inherently wasteful and debilitating outcome.

<sup>25</sup> Figures 1.1 and 1.2 draw on the same data used to compile Tables 1.1 and 1.2.

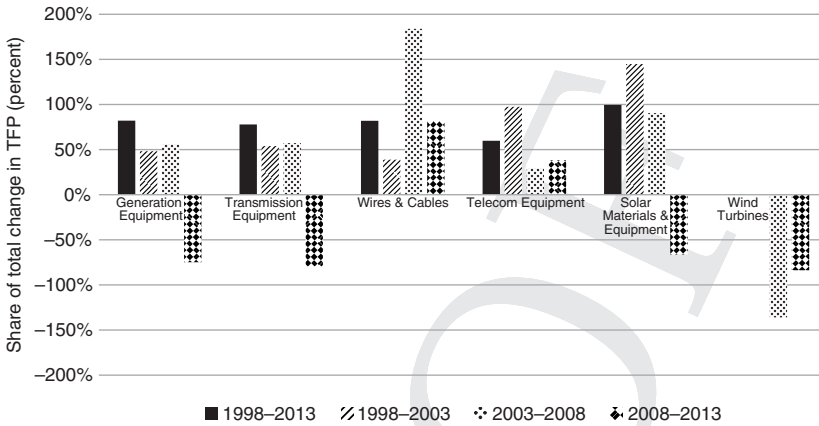


Figure 1.1 Contribution from Entry of New Firms to Total Factor Productivity Change by Period in Six Subsectors, 1998-2013

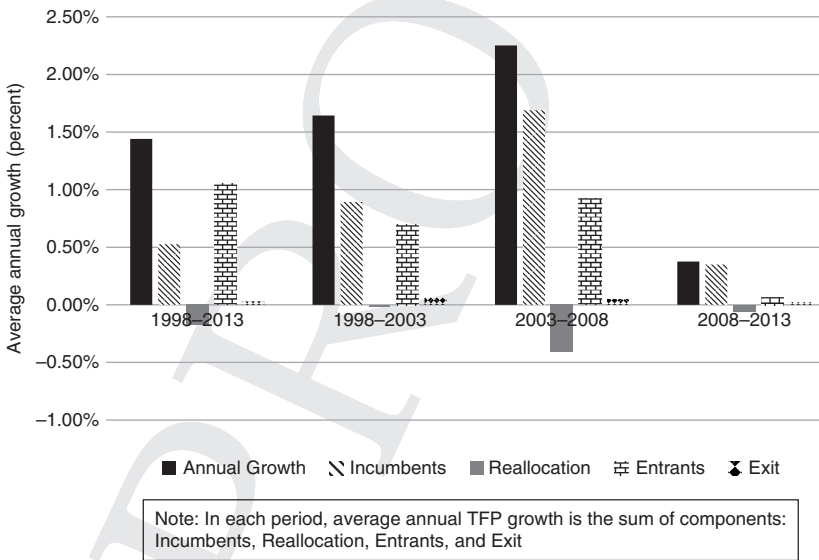


Figure 1.2 Average Annual Total Factor Productivity Growth and Components for China Industry, 1998-2013

These productivity outcomes encourage a skeptical appraisal of the likely impact of recent policy trends on future prospects for innovation and upgrading. One puzzling aspect: how can productivity decline in industries like power generation and transmission equipment when, as

the chapters by Michael Davidson, Xu Yi-chong, and Thomas Rawski amply demonstrate, these very sectors have demonstrated the capacity to master new product varieties that embody advanced, and in some cases, world-class technologies?

One possibility is a slowdown in demand growth for electricity that reduces sales prospects, and thus productivity growth, for electrical equipment. However, the recent decline in electricity demand growth cannot explain the weak productivity outcomes for 2008–13 shown in Table 1.1.

More plausible explanations cluster on the supply side. Decision-makers who are partially or entirely divorced from market discipline may pursue innovations that, while technically feasible, fail to generate enough revenue to drive productivity growth. Consistently negative “reallocation effects” in Table 1.2 and Figure 1.2, indicate flows of resources *toward low-productivity firms*, and signal the presence of incentives and/or institutional arrangements that systematically promote productivity *decline*. Finally, high system costs of the sort observed in electricity generation and distribution (Chapter 8) may undercut potential productivity advances.

Looking beyond the sectors covered in Table 1.1, trends in the generation and distribution of electricity illustrate the potential for simultaneous appearance of technical advance and weak productivity outcomes. Electricity consumption per unit of generating capacity (1,000KWh per KW of installed capacity) rose from 3.54 in 1957 and 4.11 in 1976 to a peak of 4.97 in 2004, and then languished below the 1986 level throughout 2008–17. The average for 2008–17, 4.09, is 10.2 percent below the comparable figure for 1998–2007.<sup>26</sup> Such a decline surely erodes, and perhaps overwhelms simultaneous improvements in combustion efficiency and output per worker, pointing toward an unlikely coincidence of widespread upgrading and weak productivity results.

The total factor productivity metric employed in the foregoing discussion is best suited to gauging an economy’s long-term success in absorbing and diffusing new and improved technologies. The influence of cyclical factors can push short-term results, such as those discussed here, above or below longer-term trends. In addition, productivity calculations are complex; uncertainties surrounding the underlying Chinese data, which include enterprise-level figures for output value, employment, and capital stock as well as sectoral and economy-wide measures of price change, necessitate substantial error margins.

<sup>26</sup> See authors’ file Electric Power Use & Generating Capacity Data Summary.072518, available upon request.



Because of their short time span and lack of precision, the productivity results in Figure 1.1 and Table 1.1 cannot support definitive projections of future productivity trends. Evidence of the recent productivity slowdown, however, continues to accumulate. Unpublished materials that classify China's exports to Germany during 2000–15 according to varying levels of technological sophistication show the share of exports in the topmost category declining since 2010, with the 2015 level falling below the 2005 figure. Furthermore, the share of products in the lowest category has risen steadily; beginning in 2011, it exceeds the share from the top category. These data show China's exports to Europe's leading economy evolving in a direction that differs widely from what Chinese upgrading plans envision.

Many sources observe weak productivity outcomes. Ross Garnaut (2016) finds a “bleak story” with no “sign of a lift in the low rates of productivity growth that emerged in the aftermath of the fiscal and monetary expansions of 2008 and 2009.” Economy-wide studies by Dollar (2016), by Wei, Xie, and Zhang (2017), and by Bai and Zhang (2017), all employing different data, find little evidence of productivity growth since the global financial crisis.

Convergence of results pointing to a steep decline in the most comprehensive measure of economically relevant innovation makes it difficult to avoid the conclusion that the economic impact of innovation and upgrading appears to have slowed or even stalled in major segments of Chinese manufacturing, in the entire industrial sector, and in the whole economy.

#### CHINA'S INNOVATION PROSPECTS BEYOND ELECTRICITY AND TELECOM

China represents the most recent and largest proving ground for competing visions of innovation dynamics. Building on extensive field study as well as detailed documentary research, this volume offers a series of case studies focused on the development and operation of three sectors: electricity, telecom, and semiconductors. Our findings include observations that will encourage proponents of both decentralized and interventionist approaches to promoting innovation and upgrading.

China's success in building modern and widely accessible infrastructure systems, including high-speed rail, expressways, civil aviation, and ports as well as the electricity and telecom networks analyzed in the chapters that follow, demonstrates the potential of interventionist policies to deliver stunning success. Despite the inevitable costs associated with features that critics of interventionism fiercely denounce – top-down planning,

state enterprises and heavily restricted market access – China’s semi-market environment has nurtured a dynamic process of innovation and upgrading that has produced innovative and entrepreneurial firms, improved “soft skills” as well as technical capabilities, and produced instances of world class achievement.

Douglas Fuller’s study in Chapter 7 documenting the failure of protracted and expensive official efforts to establish a competitive beachhead in semiconductors leads a parade of difficulties, many self-inflicted, that bedevil innovation efforts in the industries studied in this volume. Excess costs, idle facilities, wasted investments, local protectionism, and ill-advised nativism, all conducted against a backdrop of large-scale diversion of public resources into private pockets, cumulate into a powerful indictment of Chinese-style interventionism.

But innovation, like economic growth, is an inherently wasteful process. While cataloging large and persistent inefficiencies and tabulating the likely magnitude of avoidable costs, we must recall the wisdom of Joseph Schumpeter, who famously wrote that a system:

that at *every* given point in time fully utilizes its possibilities to the best advantage may yet in the long run be inferior to a system that does so at *no* given point in time, because the latter’s failure to do so may be a condition for the level or speed of long-run performance” (1942, p. 83, with emphasis in the original).

The Schumpeterian disconnect between efficiency and growth summarizes the post-World War II experience of East Asian economic dynamism, which combines unprecedented growth with massive inefficiency, a pairing much in evidence in the recent history of Japan, South Korea, and, above all, of China itself. In the same vein, Thun and Sturgeon highlight the possibility of “successful failure,” meaning that failed attempts to master specific technologies or products may create capabilities that allow the economy to navigate formerly unattainable innovative paths.

Mounting evidence of weakening productivity performance warns that continuing along the trajectory of the recent past may produce outcomes weighted toward inefficiency rather than innovation. Episodic efforts to enlarge the orbit of market forces, most notably in segments of the energy sector, cannot conceal the absence of major reform initiatives of the sort that removed major barriers to entry, competition and through them, innovation during the 1980s and again in the 1990s.

Reflecting the protracted struggle between supporters and opponents of greater market opening, reduced top-down economic control, and

expanded opportunity for private enterprise – prominent features of reform efforts during both the 1980s and 1990s, recent policy initiatives, with Made in China 2025 in the forefront, move in the opposite direction, emphasizing top-down technological choice, relying on state-run firms, and insulating priority sectors from potential rivals. Current policy trends magnify plan-era weaknesses that four decades of reform have never squarely confronted. Worse yet, China's leaders seem intent on reviving Mao Zedong's economically counterproductive veneration of self-reliance and suppression of criticism. Beijing's mercantilism, amplified by exclusionary echoes among China's provinces and localities, threatens to undermine product quality, a central component of success in the advanced industries that dominate China's ambitious innovation agenda.

China's new ten-year plan aims to inject Chinese technology and Chinese producers into the forefront of multiple high-end industries. The scale and breadth of this initiative has no parallel; it extends far beyond historical predecessors in Stalin's Soviet Union, Mao's China, and Kennedy's America. China's unique combination of momentum, confidence, scale, determined leadership, and vast financial and human resources creates massive potential for innovation – a frightening prospect for would-be competitors.

Yet the mechanics of China's new innovation drive – substituting official directives for market logic, elevating bureaucratic entities over commercial businesses, spurning established products and technologies in favor of untested Chinese alternatives – add new dangers into the unavoidably risky pursuit of cutting-edge innovation.

Looking forward, we expect China's innovation drive to deliver a mixture of headline-making successes and failures. The scale of Chinese demand, the size of individual Chinese industries and the magnitude of official support leads us to anticipate that, whatever the degree of success, Chinese efforts to target specific technologies and products will exert deep and protracted influence over a wide swathe of global markets during the coming decades.

While Chinese leaders and outside observers focus on iconic products of advanced technology, the outcome of China's innovation agenda will rest on the less visible results of myriad upgrading efforts affecting the millions of bits and bytes that collectively fill out the architecture of modern industry. For these operations, implementation of policy and regulation is far more important than plan announcements. If China's leaders allow regional governments and entrepreneurial managers to bend policies to

suit ground-level economic realities, if private business dynamism can survive growing Party oversight, if official paeans to self-reliance can coexist with extensive Chinese participation in global supply networks, innovation may thrive both within the industries we have studied and throughout China's economy. Doctrinaire enforcement of policies that extend recent limitations on competition and openness, the key drivers of China's post-1978 economic gains, has the potential to hobble or even stall China's remarkable economic trajectory.

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