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China's Propensity for Innovation in the 21st Century

Identifying Indicators of Future Outcomes

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Preface

How far will China be able to go toward achieving the pathbreaking innovation it seeks broadly across many sectors? How well might standard criteria for evaluation used in other technology-leading nations apply to a system affirmatively designed to follow a development path "with Chinese characteristics"? Although there are studies of China's technological achievements, scientific standing, and innovation *potential*, most often presented as a tally of innovation assets, this report considers the question of China's *propensity* for innovation—the system-based dynamics for converting potential into achievement—in the coming decades. We offer a prospectus for examining China's system for generating innovation by determining what observable measures might be the early indicators or precursors that would allow us to more accurately gauge the trajectory of China's rise to innovation prominence and how far it may go. We consider important activities, factors, and venues for innovation in China, place them in an integrated framework, propose measures for the most important factors affecting the propensity toward innovation in China, and then from among these measures select an initial "dashboard" of candidate indicators going forward.

This report should be of interest to those interested in trade policy, military affairs, national innovation systems, China's investment policies and development as a major contributor of technological innovation and applications, and the prospects for the relative standing of China and the United States as innovation leaders and competing nations in the future.

This research was conducted within the Acquisition and Technology Policy Center of the RAND National Security Research Division, which operates the RAND National Defense Research Institute, a federally funded research and development center sponsored by the Office of the Secretary of Defense, the Joint Staff, the Unified Combatant Commands, the Navy, the Marine Corps, the defense agencies, and the defense intelligence enterprise.

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Summary

China aspires to be a major creator of new technologies and novel value-adding applications for those that already exist. How well might this aspiration for innovation be realized as it moves toward a more state-of-the-art technology base? One may imagine two worlds in some 30 years absent trend-disrupting events. In one, China will have gradually closed most gaps between its technology level and those of the leading countries across most sectors and have excelled in some. But in a different future, China could supplant the role primarily played by the United States since 1945 as the global leader in technology and innovation across many sectors.

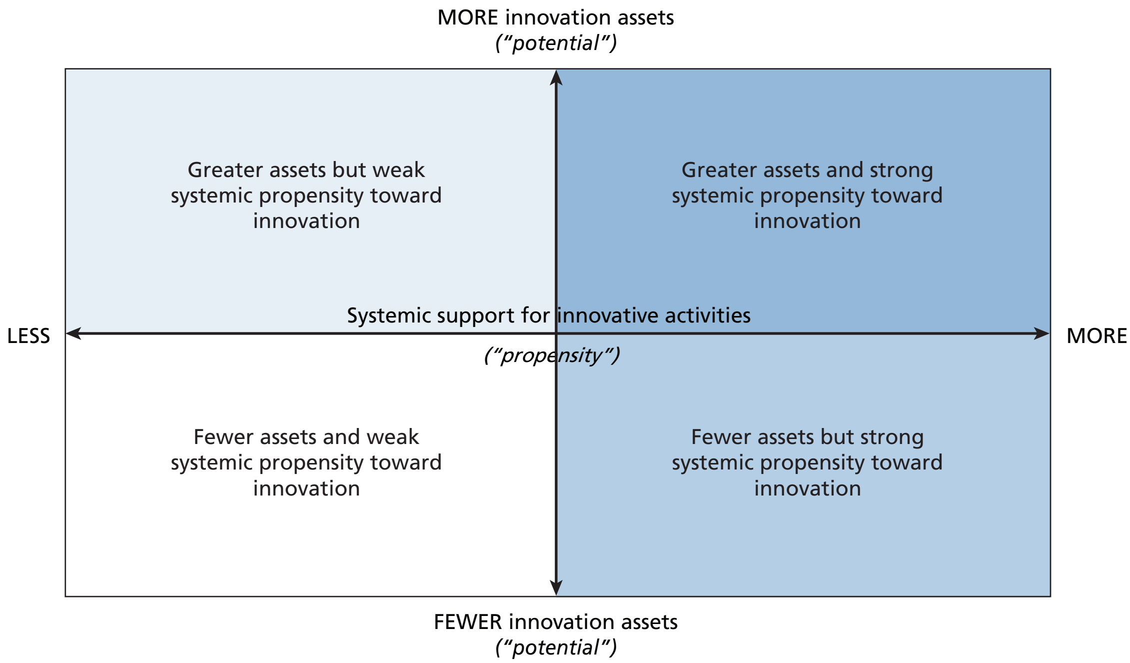
No one knows today which of these two futures is most likely. This report asks what information we would need for us to better understand China's propensity for innovation and thus assess its trajectory in the coming decades.

Innovation is the application of new or existing knowledge in new ways or to new purposes. The systemic similarities between the leading innovating countries prior to China's rise leads assays of innovative potential to focus on the innovation assets each possesses: annual gross expenditure on research and development (R&D), Ph.D.'s per thousand population, numbers of patents, etc. Such measures are amenable to relatively easy enumeration and snapshot views. In the case of China, however, the implicit assumption of (more or less) similar systems at work in comparative assessments of innovative potential among the countries of the Organisation for Economic Cooperation and Development (OECD) is no longer valid. In contrast with innovation *potential* and discussion of the scale and quality of inputs to innovation within China, innovation *propensity* inquires instead into the ability of China's system to fully elicit that inherent potential. Although innovation requires many inputs and is also affected by external forces, there are also systemic aspects at play. Two nations similarly endowed with innovation assets and so gauged to have the same innovative potential in a static sense may operate under two different internal regimes. One may perform dynamically better than the other—possess a greater systemic propensity—for achieving innovation outcomes with similar resources.

Beyond the immediate economic effects wrought by successful innovation, the dynamism of a nation's economy is itself a source of state power in the 21st century. Therefore, the consequences of innovative activity go beyond just economic considerations. It may be that the new competition well beyond the economics is who can out-innovate whom.

A major policy thrust of China's party leadership has been to inculcate adherence to a model of development "with Chinese characteristics." Therefore, it is not sufficient to presume similarity of institutional structure with prior innovation case studies. The nature of the system needs to be regarded explicitly and a presumed equivalency resisted. Yet, trying to

Figure S.1
Relation Between Innovation Potential and Innovation Propensity



describe China's political, economic, social, and financial systems—to say nothing of its technological and national innovation systems—is to glimpse a swiftly moving target. We therefore require a prospective framework of observable measures that might go beyond describing the static elements that tend to be the focus of national innovation comparisons and instead provide insights into the nature and dynamics of the changing system that will affect the trajectory of China's rise to innovation prominence. This report takes on that challenge.

Figure S.1 provides an illustration of these concepts. Although it suggests a more precise theoretical distinction than may be realizable in practice between the assets for innovation available within the system and the propensity of the system itself toward innovation, it does provide one key insight. China possesses many of the inputs required to become a major—and possibly the leading—innovating nation. Absent major disruption, future decades will likely find it located in one of the two upper quadrants. It will be the dynamics generated within the system, what we have termed the innovation propensity, that will determine which one.

Deriving Measures for China's Innovation Propensity

Constructing candidate metrics for innovation propensity is inherently difficult given the focus on dynamics and change. No one measure will be sufficient in itself to illuminate these dynamics. Further, the measures taken together will only become meaningful when they are compared with the prior- and future-year values of the same measures. Any "dashboard" of such measures would need to be understood in this light.

The report describes the information gathered in assembling a list of potential measures for China's innovation propensity over time. Sources included the academic literature on

Table S.1
Framework for Representing Factors Relevant for Innovation in China

Theme	Innovation Factors	"Firms" and "Laboratories"	Markets	Networks	Local Authorities	National Authorities
Institutions	Structure					
	Policy					
	Informal					
Process	R&D					
	Invention					
	Diffusion					
Precursors	Funding					
	Incentive					
	Skills					

China as well as the "gray" literature found in journalism in print and online, the general literature on innovation and national innovation systems, sectoral case studies developed during our research, as well as several experiments in measurement. Because of the disparate nature of these sources and the number of factors that contribute to innovation, we first developed a conceptual framework, shown in Table S.1, as an intellectual accounting system for factors affecting both innovation potential and innovation propensity. As such, it is intended to be populated with the main elements of China's system for generating innovation, both "apples and oranges." That is, innovation assets, actors in organizations, and system characteristics and dynamics at various scales and venues may cohabit within individual matrix cells.

The columns represent several different venues or levels within which actors make decisions affecting innovative activities, either their own or by others: the **firm**, the **market**, **networks** for nonmarket exchange of ideas and support, **local authorities**,[1] and **national authorities**. The rows of the matrix in Table S.1 represent the main factors that arise from analysis of innovation. We divide them into three main themes that then map across the venues. **Institutions** describe the framework of organizations and norms for innovation operating in each venue. **Processes** of innovation take place within and between these organizations. **Precursors** are inputs into innovation processes, their raw material. Taken together, the full framework maps the "operating system" for innovation. It is a convenient shorthand to first house the heterogeneous evidence providing clues to that operating system and then, later, identify those elements that might provide indicators of innovation propensity.

1 "Local" or "regional" authorities refer to those administrative levels below that of the national leadership. As a practical matter, we refer mostly (but not exclusively) to those entities at the highest of China's five levels of subnational administrative classification. These include its provinces, major municipalities, autonomous regions, or special administrative regions. However, the principal distinction being drawn is that between authorities who are responsible for applying a national perspective to policy and those who primarily have an interest in achieving distinction for their subnational area of responsibility.

The subcategories within the institutions theme include formal **structure**, **policy**, and **informal** institutions. The latter are arrangements that exist among individuals and organizations that appear in no rulebook or set of written records but are nonetheless as strongly present as are the formal linkages. Innovation occurs in three stages: **R&D** or knowledge creation, **invention** or creation of a novelty based on that knowledge, and **diffusion** of the novelty through adoption. Precursors to innovation include **funding**, personal and organizational **incentives**, and human **skills**.

The candidate short list of indicators for China's innovation propensity was derived by sifting through existing relevant literatures, both academic and journalistic, conducting case studies of sectors selected for the contrast they could provide, and investigating possible measurement techniques. The method was qualitative and reductive. We viewed individual pieces of evidence with a view toward populating the Table S.1 matrix (Chapters Two to Five). We next looked for factors residing in individual matrix cells that recurred frequently as well as for contrasts between, for example, findings from the general literature on innovation and reports on China's innovation practices and policies (Chapter Six). We then sought to identify measures or proxies for the factors appearing in the matrix and finally suggested a short list of indicators that when tracked over time might provide early signaling of the systemic propensity toward innovative activity in China (Chapter Six).

Several key concepts emerged from the sources of information sampled and are reflected both in the structure of the Table S.1 matrix and the contents developed for its cells. A nation's innovation system depends on people with the knowhow, materials, equipment, and other resources coming together in effective collaboration. The "national innovation system" concept also embraces institutional configurations and interactions, finance, and policy. Yet, the national concept may also be misleading. Regional innovation clusters dominate because early stage information and the exchanges that occur in the intensely social activity surrounding innovation are not easily codified. Initially, the type of information on materials, technique, phenomena, and possibilities that constitutes raw input to innovation is passed among individuals along networks fueled by mutual benefit and trust. The abilities to self-organize, to freely search, and to combine and recombine knowledge and teams in unanticipated ways have been regarded in the literature as crucial to the innovation process. Participation in networks is fluid, an aspect distinguishing them from hierarchies and institutions.

Systemic Elements Affecting Innovation in China

Several aspects of the Chinese system stand out as factors within the innovation framework, often in contrast to the implicit models in the innovation literature. Most obvious is the dual message of exhorting actors to pay attention to market signals while recognizing the leading role for the Chinese Communist Party (CCP) in guiding development policy. In 2015, China released an innovation-driven development strategy along with targeted initiatives supporting innovation, such as "Made in China 2025." Overall, China continues to steer more of its innovation from the top down compared with the countries of the OECD. Subnational government bodies are to act in support of national plans and strategies yet also retain interest in promoting their locales. Policies therefore often have strong "campaign" components. This may result, for example, in proliferating industrial and technology parks drawing from mixed sources of support that some suggest resemble an innovation archipelago lacking the linkages that would make the most of network spillovers. Yet, the amount of R&D expenditure funded by businesses, including foreign-owned entities, has been rising and in 2017 accounted for 75 percent of the national total.

Chinese political theory makes law courts instruments of government policy. This may reduce confidence for potential innovators in the ability to enforce contracts and so undercut trust. A propensity toward vertical integration may be the result. This may be partially compensated for by the system of *guanxi*, or personal connections, but this may have deleterious effects as well. The Chinese approach to intellectual property (IP) has been especially problematic for foreigners but may affect domestic innovation too. This goes beyond respect for ownership. Rather than view IP as a valued commodity nurtured to maximize returns, it is instead treated as an input for which the socially appropriate course is to lower costs—and China has acted to establish this approach as a new global norm.

Innovation's inherent disruption engenders changes that are unpredictable and prone to experiment and failure—a milieu that a party designated to provide leading-edge guidance may not fully embrace. Reform may take the form of administrative and organizational changes, but the continued role of state-owned enterprises (SOEs) attests to several decades of the Chinese government picking and supporting winners. The competitive forces that empowered China's surge over several decades are countered by a tendency to pump resources into ailing SOEs and slow investment by more productive firms. China's leadership has also made clear that it expects Chinese firms and teams leading innovation to be cognizant of the requirements of the People's Liberation Army and the possibilities for new inventions, even those in the commercial sphere, to have dual applications.

Candidate Indicators of Innovative Propensity in China

In Chapters Two to Five, we populate the Table S.1 matrix to create a framework of factors important for understanding innovation in China. Chapter Six identifies possible measures for those factors. We sought not to defer to expediency in data availability at this stage but rather to first determine where we might want to look and why.

With no single measure or proxy being sufficient, we sought to produce a parsimonious subset of measures focused on better understanding of systemic innovation propensity in China. We selected from among these measures a smaller set of indicators, a "dashboard," that received frequent mention in the sources, were determined by us as being especially pivotal in addressing innovation propensity, or represented points of difference between innovation processes in OECD countries and the Chinese innovation system; often all three criteria were met.

Table S.2a shows the candidate indicators placed within Table S.1. Their purpose is described in Table S.2b. These indicators are intended to add an additional veneer of systemic insight when considered along with more traditional measures of innovation performance. Our hypothesis is that they could serve as leading indicators, benchmarks not of current performance but of the propensity toward further innovative behavior. This would provide insight into movement along the horizontal axis in Figure S.1.

At a minimum, the candidate indicators would paint a fuller portrait of the innovation system evolving in China and provide a basis for considering potential implications. They may also potentially address two systemic questions. Were we to witness increasing Chinese innovation along with positive propensity indicators, we might reject the conjecture that China's system will not be able to overcome systemic barriers to path-breaking and frontier-defining innovation. Disappointing results in both would reinforce the idea that what leads to (or fails to result in) innovation elsewhere applies to China as well.

On the other hand, observing increasing innovation going forward yet accompanied by propensity indicators at odds with these results might highlight that China did, indeed,

Table S.2a
Candidate Indicators of China's Innovation Propensity: Matrix View

Theme	Innovation Factors	Firms and "Laboratories"	Markets	Networks	Local Authorities	National Authorities
Institutions	Structure			Size, nodes, density, location, heterogeneity of networks		
	Policy		Media reports of court/ noncourt recourse of legal grievances			
	Informal	Media narratives on risk, entrepreneur-ship, culture		Develop and assay various proxies for trust among potential network nodes		
Process	R&D		IPR protection	Scientific research teaming		
	Invention			Sectoral patent networks		Policies affecting incentives
	Diffusion			"Contagion" mapping of diffusion patterns		
Precursors	Funding					
	Incentive	Innovation performance of young, small, older, and larger firms		Media narratives on partnering, teaming, knowledge, and skill spillovers		Attitude, reaction by innovation workers to social control by state
	Skills			Diffusion of specialized skills		

Table S.2b
Candidate Indicators of China's Innovation Propensity with Intended Purpose

Row, Column	Candidate Indicators	Intended Purposes
1, 3	Size, nodes, density, location, heterogeneity of networks	-Measure changes in dimensions and growth of networks over time
2, 2	Media reports of court/noncourt recourse of legal grievances	-Determine the extent that contracts and other legal recourse are enforceable as a gauge of risk perception
3, 1	Media narratives on risk, entrepreneurship, culture	-Gain insight into how entrepreneurial culture is being valued, rewarded, held accountable
3, 3	Develop and assay various proxies for trust among potential network nodes	-Trust as an asset making it easier to convey and act on innovative ideas
4, 2	IPR protection	-Degree to which innovators may feel protected -De jure and de facto policy on creative rights and processes
4, 3	Scientific research teaming	-Degree to which Chinese knowledge creation gains from global knowledge networks -Gauge of government policy toward cooperation
5, 3	Sectoral patent networks	-Infer implicit networks, especially cross-fertilization among fields -Measure of priority attached to focused innovation
5, 5	Policies affecting incentives	-Examine People's Republic of China/CCP de jure and de facto policies from perspective of innovation
6, 3	"Contagion" mapping of diffusion patterns	-Understand secondary barriers to innovation at stage of adoption
8, 1	Innovation performance of young, small, older, and larger firms	-Measure of dynamic pace, transformation of industrial sectors, and tech fields -Measure of ways in which firms compete
8,3	Media narratives on partnering, teaming, knowledge, and skill spillovers	-Gain insight into how well skill and knowledge spillovers are occurring
8,5	Attitude, reaction by innovation workers to social control by state	-Assess degree that succeeding cycles of state control intrude on innovative behavior
9,3	Diffusion of specialized skills	-Proxy net effects of chance encounters, heterogeneity, and cross-disciplinarity and teaming

NOTE: The first column positions the indicator in one cell of the framework presented in Table S.1. Thus, "5, 3" indicates the fifth row, exclusive of the column and row titles ("Invention"), and the third column ("Network"). "Media" refers, as appropriate, to broadly available sources including academic research, case studies, and the gray literature on the internet from several sources.

succeed in creating a different system of innovation with Chinese characteristics. If the innovation propensity indicators in China do not resemble those in the OECD countries with which it wishes to be compared, that need not necessarily portend failure in its ambition to join their ranks. We need also to determine whether those different arrangements might be able to play a similar role of encouraging innovative activity rather than just allocating innovation inputs ultimately less effectively. This report is an initial step in building the capacity for doing so.

Acknowledgments

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Abbreviations

AI	artificial intelligence
API	active pharmaceutical ingredient
API	application programming interface
CAS	China Academy of Sciences
CCP	Chinese Communist Party
CCPCC	Central Committee of the Chinese Communist Party
CFDA	China Food and Drug Association
CPC	cooperative patent classification
CRO	contract research organization
CR Pharma	China Resources Pharmaceutical Holdings Company Limited
DLT	distributed ledger technology
FDA	Food and Drug Administration
FFM	finished form manufacturers
FPP	finished pharmaceutical product
FWCI	field weighted citation impact
FYP	Five-Year Plan
GDP	gross domestic product
GMP	good manufacturing practice
GPU	graphics processing unit
IOT	internet of things
IP	intellectual property
IPR	intellectual property rights
IT	information technology
MIIT	Ministry of Industry and Information Technology
MLP	Medium- and Long-Term Plan

MOST	Ministry of Science and Technology
NDRC	National Development and Reform Commission
NIS	national innovation system
OECD	Organisation for Economic Cooperation and Development
PBOC	People's Bank of China
PLA	People's Liberation Army
POE	privately owned enterprise
PRC	People's Republic of China
R&D	research and development
SAFE	State Administration for Foreign Exchange
SEZ	special economic zone
SMEs	small and medium enterprises
SOE	state-owned enterprise
STEM	science, technology, engineering, and mathematics
TCM	traditional Chinese medicine
VC	venture capital
WIC	World Intelligence Congress

CHAPTER ONE

Capturing Lightning in a Bottle: Innovation and State Power

Thirty years from now, trends currently at work within innovating nations could bring us to either of two different futures. Barring a major disruption in either global or local trends, in one future China will have largely closed the gap between its technology position in multiple fields with that of the leaders in these sectors. (This may be expected to occur at a decreasing rate as the remaining gap requires greater effort to bridge [Gerschenkron, 1952].) In some sectors, it may clearly have led in innovation. In the majority, the United States or another Organisation for Economic Cooperation and Development (OECD) nation would either hold or share the position of incumbency, however tenuously. Were we to project how such a world might come into being, the course would resemble, in at least some respects, the world as we currently know and understand it. As we factor China's rise into our foresight efforts across many fields of policy and interest, our imaginations would not become unduly strained. The change would appear to be one of evolution rather than fundamental disruption.

But a different future could be drawn from data we currently possess. In this one, China approaches the idealized technology frontier and then surpasses it across a large range of technology fields. Its trajectory is less asymptotic, less subject to slowing as the gap narrows, and the challenges rise. In short, China will have supplanted the role primarily played by the United States since 1945 as the global leader in technology and innovation. That is a world and set of accompanying consequences that few of us will be able to imagine easily. It would be sufficiently outside the realm of our experience that it might prove difficult to anticipate and plan for. Certainly, looking forward from our present circumstances, the consequences for much of the fabric of the world that we implicitly accept may be quite difficult to anticipate. This not only limits our ability to fully account for the future "China effect" in the realms of international relations, trade, energy, society, culture, and security, among others, but may well prove a source of uncertainty and therefore instability. The potential for misunderstanding may prove to be greater in this world of China as the dominant innovator than in one in which it more gradually takes its place as a technological peer.

This paper reports a project to peer more closely at the wellsprings of China's drive for innovation in the coming decades. It will not resolve the questions we have raised. Instead, it is an initial inquiry into what we should be looking for as potential indicators of which of the two worlds we have posited might be coming into being. The balance of this chapter will discuss the drive toward innovation in China and establish the analytical foundation on which the balance of this report is based.

China's transformation in the four decades since its reorientation of economic policy following the death of Mao Zedong has been not only of great benefit to its people, it has been one of the singularly great events in modern history. For the first time, China's people have largely been freed from the land and in the process built one of the world's most important economies. In the early decades, China benefited from its very backwardness to make great strides. It marshaled its resources and took advantage of technologies first developed elsewhere. But its leaders envisioned making a shift at some point from such an "extensive" pattern of growth to a more "intensive" pattern. That is, rather than rely solely on bringing its resource endowments to bear, most particularly its huge labor supply, they wished to reap gains stemming from the creation of greater value by using those resources more effectively and efficiently. The goal was not only for China to advance to the frontiers of science and technology across many sectors but also to become a global leader in innovation (Serger and Magnus, 2007).

This further transformation of China's economy is now underway. The transition in development patterns was one that the former Soviet Union (and perhaps the successor Russian Federation) could not completely manage despite its leadership in many fields of basic science and research. But though led by a unitary Communist Party, the differences between contemporary China and the failed Soviet state are legion—too many to use the Soviet experience as a reliable guide to the future. Indeed, China is being seen increasingly as an important creator of value-adding technologies and developer of new applications for those that already exist. The question is how far this process is likely to proceed as it pushes toward a more state-of-the-art technology base across many sectors.

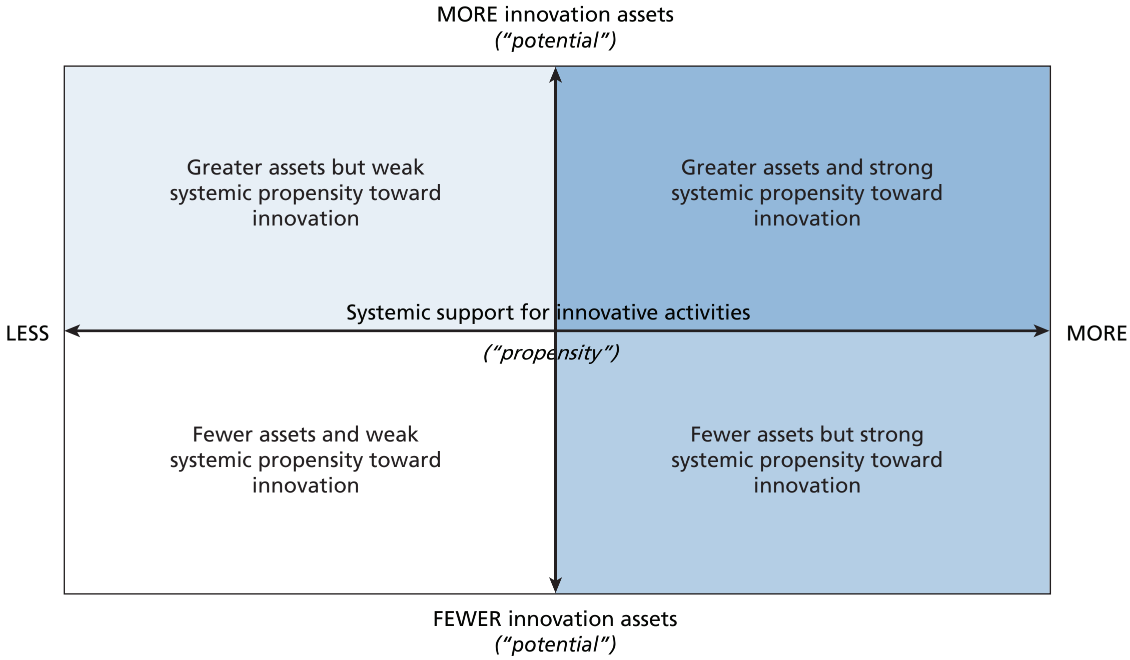
Recent years have seen several studies on the state of science, technology, and innovation in China with ever more in the offing. Some suggest that Chinese research has been (and continues to be) more applied than basic and derivative of foreign innovation (Melass and Zhang, 2016)—a perspective that could invite complacency among its competitors. Others suggest that having achieved the status to qualify as a middle-income country, China's policy has begun to evolve toward more flexible and less heavy-handed approaches to innovation in support of transformation to a high-income country (Liu et al., 2017). The dynamic and uncertain nature of the situation demands caution in interpreting available research that cites data from sources spanning several years or more, making it hard to track paradigmatic change.

The bulk of current work, however, focuses on realized or prospective status within specific sectors of innovation: artificial intelligence (AI), nanotechnology, biotechnology, and militarily relevant technologies such as hypersonic aircraft, directed energy weaponry, and so forth. Similarly, there are bibliometric and other studies of the emergence of Chinese science, its dimensions, roles, and degree of integration, as well as leadership in various fields. These point to the potential for Chinese growth in science, technology, and innovation. Naturally, it is useful and purposeful to benchmark the realization of this potential: Where is China now? Where will it be in ten years' time? Thirty? Clearly, the further out one wishes to go, the more prospective is the assessment of what attainments China may reach and when.

This study follows a different tack in at least two ways. The first is to shift from a specific focus on China's status in one or more fields of technology to the more general question of what is China's systemic *propensity* toward innovation, not just a consideration of either its current achievements in, or *potential*, for innovation in particular fields. In contrast with innovation potential and discussion of the scale and quality of inputs to innovation within China, innovation propensity inquires instead into the ability of China's system to fully elicit that inherent potential.[1] That is, going beyond numbers of Ph.D.'s, research and development (R&D)

[1] Furman, Porter, and Stern (2002) developed the concept of *national innovative capacity* (emphasis in the original) composed of three elements: a common innovation infrastructure ("cross-cutting factors contributing to innovativeness

Figure 1.1
Relation Between Innovation Potential and Innovation Propensity



budget as a share of gross national product, scale of research organizations and programs for fostering innovation that bespeak China's innovation potential, how well is China able to draw full value from these inputs, and how effective will they be in producing innovation going forward? Given China's size, rapid growth, increasing global integration and upskilling of its labor force, it is this that may well determine which of the two futures—Chinese equivalence with or dominance of the United States—may arise by midcentury.

Figure 1.1 provides an illustration of these concepts. Although it suggests a more precise theoretical distinction that may be realizable in practice between the assets for innovation available within the system and the propensity of the system itself toward innovation, it does provide one key insight. China possesses many of the inputs required to become a major—and possibly the leading—innovating nation. Future decades will likely find it located in one of the two upper quadrants. It will be the dynamics generated within the system, what we have termed the innovation propensity, that will determine which one.

The rapidity of China's systemic transformation both raises the importance of this distinction but also the difficulties in determining it. Trying to describe the nation's political, economic, social, and financial systems—to say nothing of its technological and national innovation systems (NISs)—is to shoot at a swiftly moving target. Further, the NIS may not be fully understood and assessed appropriately absent an understanding of the larger system of which it

throughout the economy [including] a country's overall science and technology policy environment"), specific innovation environments in a country's industrial clusters, and the strength of linkages between that common infrastructure and the specific clusters. The present report uses the term "innovation propensity" to place emphasis on the systemic aspects that are certainly part of the innovative capacity concept but which does not include elements such as the stock of technological knowledge and others also found within the latter term's formulation.

is one part. The theme of how institutions, incentives, and networks, among other concepts, play into a consideration of innovation propensity will be elaborated in the following chapter.

These issues motivate the second characteristic of this study that may set it apart from other inquiries into China's emerging technical prowess. We seek to create a prospective framework for examining China's innovation propensity going forward. We built a systematic approach to determining what observable measures might be the early indicators or precursors that would allow us to more accurately gauge the trajectory of China's rise to innovation prominence and how far it may go. We did so by drawing on an eclectic base of source material: prior studies of innovation in China; case studies of selected industries; examination of selected regions; an examination of the potential for bibliometric and patent studies; a foray into the "gray" literature represented by blogs, online discussions, company webpages, and short-form documents; and interaction with other researchers in the field who, while perhaps having been pursuing more specific questions, will have gained insights that provide clues to resolve at least part of the puzzle.

Outline of This Report

Our project was intended as a limited, systematic analysis of what measures should be used to assess China's propensity for innovation and among those measures, which might provide a dashboard of leading indicators of China's development as an innovation leader. In Chapter Two, we present a short overview of some of the most relevant topics the general literature on innovation provides for this study. We also present an innovation activity framework that was formed in the course of our analysis and that we will carry through the balance of this study.

Much has been written about China's science and technology in recent years, so Chapter Three provides only a brief primer on several major topics that have relevance for this study's objectives. Chapter Four provides main findings from the three case studies we conducted and places them within the project framework. These looked at innovation in pharmaceuticals, AI, and the fate of blockchain and distributed ledger technologies (DLTs) in which China originally enjoyed a first-mover advantage in implementation. The full cases for two of these are presented in appendices to this report.

Chapter Five explores primarily quantitative and media-based techniques for measurement and analysis of networks. This discussion underpins some of the recommendations we make for leading indicators of innovative propensity. These include bibliometric analysis of the academic literature on China in global science networks, a proposed method for inferring implicit networks of application and innovation from patent filings, and an experiment to gather information that might shed light on networks and communication through searches of the media gray literature.

Chapter Six draws the content of these investigations together within the framing presented in Chapter Two. Principal issues affecting innovation arising in the prior chapters are mapped to portray the complex web that produces innovation and determines its extent and effect. This is followed by a presentation of candidate measures for the matrix cells that represent the most important leverage points for determining the extent to which China's potential for innovation is realized, its innovation propensity. We conclude by presenting a selection from among the measures offered in Chapter Five that might be considered as a potential dashboard of indicators for better understanding China's development as a major source of technological innovation in the years to come.

We present in the final chapter some thoughts about innovation in China as well as why and how the results of this study might be of value.

CHAPTER TWO

The Nature of Innovation and the Location of Innovative Activity

Public policy targets innovation because of aspirations for its ensuing benefits. There is as well a belief that innovation can be "steered": that it might be possible to motivate more innovation than might otherwise occur and to motivate innovation in certain directions deemed to be of public and policy interest. A literature exists on what is usually termed innovation (or "science and technology") policy that addresses the relationship between public agency actions and the levels of R&D and innovation activity. In this chapter, we will briefly lay out several concepts that weave through this literature and that will be discussed in the Chinese context in the following chapters of this report. We then present a structure that frames many of these themes while also adding a dimension of "location" to help focus consideration of what aspects of innovative activity in China we should be investigating for indicators of innovative propensity.

What Is Innovation—and Why Should We Care?

Innovation is the application of new ideas or new combinations of ideas to improve on existing products and processes or to generate new types of both. Innovation is often linked to R&D, because R&D is a source of new ideas. The path from R&D to something useful through innovation is uncertain and often long, but innovation can take place independent of formal R&D activities (as defined, e.g., in R&D tax credit regulations). It can draw instead on both curiosity and inspiration to apply what is already known in new and different ways. It can take the form of "fixing" or informal tinkering with existing production lines. Companies can conduct R&D in hopes of fueling innovation or exploit R&D from others (referred to as "spillovers" because not all new knowledge is completely appropriable solely by the generators of that knowledge), as well as other sources of inspiration (Singh, 2018).

Innovation can be incremental and evolutionary with small improvements on or variations to something that already exists. It may also be radical and revolutionary, resulting in wholly new products (such as today's race to perfect autonomous vehicles) or processes (such as precision agriculture) or both (such as the use of nanotechnology to make new pharmaceuticals). Radical innovation has been associated with Schumpeter's concept of "creative destruction" (Schumpeter, 1942), risk taking, and transformational change in which new ways of doing things replace old ones (Aghion et al., 2005).

Innovation can also be fractal, in the sense that it can produce general-purpose technologies (Bresnahan and Trajtenberg, 1992) that become platforms on which other innovations can be developed. As an illustration, the assembly of the internet spawned the World Wide Web as a superapplication or platform that hosts many kinds of applications, some of which themselves enable specific kinds of innovation. Some platform technologies give rise to "ecosystems" of complementary technologies and products (Gawer and Cusumano, 2014). Apple has done this with its iOS operating system; China's Baidu is trying to build an ecosystem around its Apollo platform for automated vehicle technology.[1] Current policy debates over emerging 5G cellular protocols, technologies, systems, and applications very much fit this mold.

In this study, we will focus primarily on process and product innovation with an emphasis on new or improved technologies. This has been the vector for the most rapid and profound change arising from innovation. In accord with the thrust of most studies of comparative innovation, we will not primarily touch on the other three of Schumpeter's innovation archetypes, namely, new sources of inputs, new markets, or innovation in management and organization (Schumpeter, 1934).

Economic Benefits

At the most basic level, economies grow largely from either an increase in population (and concomitant growth in inputs—*extensive* growth) or productivity (*intensive* growth). Innovation is a means for taking available inputs and creating greater value with them through improvements either in process or in the nature of goods and services produced. Because the demographic profiles of developed nations have shifted into their modern, lower population growth patterns, innovation has grown in importance as a driver of growth.

The benefits of innovation accrue domestically by offering greater variety of products and reducing the cost in time, labor, and materials for producing them. Innovation may also affect trade balances with innovative goods and services being perceived as providing greater value. Growing global market share further enhances the opportunity for economic growth beyond what the domestic population could support. After oil price spikes in the 1970s, the United States was shocked by the inroads to its own domestic markets by imports of innovative motor vehicles perceived by consumers as providing greater value than U.S. products. Similar unease was manifested during the period of Japan's strong performance on international markets with its innovative consumer electronics products, led by the transistor radio, an advantage that persists today although now shared with other Asian "tigers." In today's globalized pattern of trade, innovation can be a major determinant of presence and market shares for manufactured goods.

Beyond the immediate economic effects stemming from successful development and marketing of innovation applications, the dynamism of a nation's economy is itself a source of state power in the 21st century especially to the extent it is gained through technological innovation. Such growth enables the support of various state expenditures ranging from military arms and forces through foreign aid assistance and other means for gaining influence (Shatz, 2020). Therefore, the consequences of innovative activity and performance go beyond just economic considerations. It may be said that the new competition between states is who can out-innovate whom.

State Power: Hard and Soft

In considering the wellsprings of national power in the 21st century, Tellis et al., 2000, concluded that "a more comprehensive view . . . must include not simply resources and military power of the kinds traditionally measured, but new ones as well." Although ultimately concerned with the ability to generate military force, the work expands the conventional framework to include not only the usual measures of strength (gross domestic product [GDP], size, popu-

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[1] See Apollo, undated.

lation, etc.) but also qualitative variables that measure the ability to incorporate science-based knowledge. Therefore, they include measures of technology, enterprise, human resources, and financial/capital resources. They also incorporate in their calculus the means for turning such assets into actual advantages by speaking of a "transformative" dimension of national power that realizes the potential of the nation's "ideational resources." This relationship corresponds with the focus of this study in seeking to understand how China's ideational resources, in particular the assets contributing to its innovative potential, may be realized (transformed) by the dynamics of China's system. It is the latter that determines its innovation propensity.

In extending hard power, innovation provides the potential for a richer set of capabilities, magnifies results of their application, and can achieve previously unavailable efficiencies. Similarly, successful and wide application of innovations developed in the civilian sphere enhances soft power as well. These may be intangible but nonetheless effective in enhancing national prestige. A safe vehicle landing on the moon's surface has become a ticket for membership in an exclusive club of nations who have demonstrated the technical prowess, ability to marshal resources, and dedication of purpose to do so.

Soft power ensuing from a strong innovation base conveys tangible payoffs as well. Technology leaders set standards to which followers may find it expedient to conform. The world then incorporates the standards felt to be most beneficial to the setter of those standards. Further, it becomes more attractive and indeed important to file patents in nations whose own innovative prowess is recognized. High-performing innovating regions attract investors and capital resources not only from domestic organizations and players. And what may be perhaps the most significant soft-power asset, bright people with innovative ideas are attracted to others of their kind who have shown themselves to be capable of producing brilliant innovations. Silicon Valley has become a global attractor of the best and the brightest in information, communication, and other digital fields. This has a potentially significant effect on a nation's terms of trade.

National and Regional Innovation Systems

At its core, an innovation system depends on people with knowhow, materials, equipment, and other resources that allow them to innovate both successfully and meaningfully. Those inputs to innovation will vary in quantity and quality, and their effectiveness will also depend on how, and how well, they are organized. The concept of a regional or national innovation system[2] goes beyond these basic inputs to consider key types of organizations—universities and more broadly education for science, technology, engineering, and mathematics (STEM); laboratories and other facilities that may be in universities or in the private sector and that house equipment, computer support, and other infrastructure; and other enablers (which might even include legal support for intellectual property rights [IPR])—and the connections between them (OECD, 2010). Also, meriting explicit consideration is finance for innovation that comes from government agencies or the private sector (companies, investor groups, or philanthropy) in varying amounts and mixes.

These factors—fundamental inputs, organizational capacities, and finance—are shaped by public policy. Policy bears on the amount of public and private funding for R&D, the support for technology transfer and commercialization, the ease of forming and leveraging

[2] The latter concept and term were proposed by Christopher Freeman (1987, 1995) and Bengt-Åke Lundvall (1992).

relationships between innovation workers and across establishments (and between public and private entities), legal infrastructure, the quality and availability of STEM education, access to and mobility of talent of different kinds, and, in these and other ways, the perceived rewards from innovation. The form of any policy can be prescriptive, in the sense of targeted industrial policy, or it can be more generally enabling, with less obvious targets for directing the precise vector of innovation. It can focus on building indigenous capacity or on generating commercially viable outputs—taking advantage of foreign capabilities—or both.

Innovation is not that easily generated, however; many efforts to replicate the successes of notably innovating regions or enhance the output of technical advances fail to achieve breakout. Innovation can flourish when there is a necessary and sufficient system to support it (Shi, Foster, and Evans, 2015; Wagner, 2008). Developing countries, for example, may put in place components of an innovation system, such as support for STEM education, but lag in providing the kinds of jobs that can use such education.[3] The components themselves depend crucially on the social dynamic that is both what determines how well the inputs of innovation are brought together and also the most difficult feature to reproduce. The practices observed in different countries reflect, in part, their differing sets of inputs to innovation, local institutional norms, as well as aspirations supported by public policy.

Beginning in the late 1980s, the idea of a "triple helix" emerged to capture the dynamic interplay of government, industry, and academia in supporting and advancing innovation (Etzkowitz and Klofsten, 2005). The model challenged the linear view that government funds R&D in academia and then industry commercializes the results—a set of phenomena that can and do occur, but more often ideas and people interweave among each sector that may play different roles over time. The triple-helix paradigm uses a communications theory approach to measure the dynamic as well as the innovation potential of regions. That model may be easier to observe in developed nations than in developing ones where immature markets may diminish the role of industry.

It is also worth noting that although the concept of NIS is now widely accepted, it may also be somewhat misleading. For one thing, those institutions that support one industry may differ from those that support another (Nelson, 1992). But more fundamentally, it appears that for reasons grounded in the phenomena leading to innovation, while it is useful in some sense to speak of innovating countries, innovation itself may be a more locally based activity.

All Innovation Is Local

Although there appear to be waves or fads in innovation that seem global—at this writing, AI is capturing imaginations, resources, and policy support around the world—the work itself (who does what, where, when, and how) is situated locally. Key organizations such as universities or companies often nucleate spheres of local innovation. Such organizations do not guarantee a local innovation ecosystem of any size or scope—having one may be necessary but not sufficient.[4] Various combinations of qualities can benefit different locales in different ways; a European study, for example, has spotlighted cultures of innovation, vision, key actors

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[3] This circumstance contributed to the historic tendency for many foreign students from U.S. universities to stay in the United States for work.

[4] For example, the considerable research strengths of Johns Hopkins University have not transformed Baltimore into a globally recognized innovation center.

and networks, physical and digital spaces for collaboration, and other factors that can couple technological and social innovation productively (European Committee of the Regions, 2016). Countless pilgrimages of officials and executives from around the world to Silicon Valley attest to broad interest in understanding why some areas can sustain wide innovation over long periods of time. Other U.S. locales (e.g., Boston and Cambridge in Massachusetts, Austin in Texas) have had their own success nurturing innovation, yet Silicon Valley is both exemplar and hard to replicate given its confluence of factors present in abundance that have fed what appears to be a self-sustaining culture[5] (Saxenian, 1996).[6]

Although the term "national innovation system" has gained more currency, it is probably more accurate to think in terms of linked regional innovation systems. In the United States, attempts to foster innovation clusters tend to engage local economic development interests. Universities tout their apparent benefits to their local economies, and local governments seek to encourage or support the siting of businesses near universities (and sometimes the siting of university satellite locations near businesses). Local incentives draw from local tax bases or existing private-sector players, and local governments often compete with their counterparts for the prize of a major installation. National laboratories draw from federal funding while contributing to the economies in which they operate.

However, the leading reason for the apparent regional focus of innovation comes from understanding the state of early knowledge. The information and the exchanges that occur in the intensely social activity that is innovation are not easily codified. It has long been observed that while scientists write papers, engineers make things (De Solla Price, 1965) and so transmission of their early state knowledge relies more on direct contact. Even scientific findings take a long time to find their way into print or other formalized media outlets. Initially, the type of information on materials, technique, phenomena, and possibilities that is the input and raw material for innovation is tacit. It is information passed among individuals along networks that themselves are fueled by mutual benefit and trust.

Networks and Innovation

Even in market economies, not all transactions are conducted through markets. Firms, for example, function at least in part as a mechanism for routinizing interactions through nonmarket means to lower costs and enhance efficiencies (Coase, 1937; Williamson, 1975). Similarly, not all exchanges between disconnected individuals or groups of information valuable for innovation are mediated through market means such as licensing or contracts. The literature on innovation has long recognized the importance of crossovers of experience and insight, as well as the limits funders of R&D experience in capturing exclusively the knowledge it generates. Such spillovers appear vital to the generation of new ideas and applications (Cohen, 2010). Detecting such networks is more difficult than tracking market-mediated exchanges, but their channels may reveal the social relationships and knowledge dissemination pathways critical to innovation.

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[5] One example of Silicon Valley "culture" that may speak to the power of institutions, both formal and informal, to affect regional innovation is the notable absence of noncompete clauses in its employment contracts (Nataraj et al., 2012).

[6] "The concepts of agglomeration and external economies alone cannot explain why clusters of specialized technical skills, suppliers, and information produced a self-reinforcing dynamic of increasing industrial advances in Silicon Valley while producing relative decline along Route 128" (Saxenian, 1996).

The study of knowledge networks, either for science or for innovation, has progressed greatly in recent years. That being said, the field still lacks an overarching theory tying network forms and characteristics to inputs and outputs. Yet, there is a good deal of empirical observation to draw on. Much of this effort has been directed to revealing networks of basic science research across national boundaries. These appear to be both broad and dense, reflecting much open sharing, easy entry and exit, and reciprocity.

Perhaps even as significant for the process of innovation, if not more so, is the nature of domestic networks, the linkages that define regions that appear as innovation hotspots. By their nature, the relationships making up such networks are harder still to detect. Universities may be involved, but innovation is largely driven by firms, large and small. Further, the relationships shift during the life cycle of an innovating field. Early connections may be between firms and university research teams but later shift as firms seek investment and then may well grow less publicly communicative as a firm or consortium nears the release of a product. In contrast to basic research networks for which output is well documented and most contributors are of one type (laboratory researchers generally working in the same field), innovation networks may be characterized by greater heterogeneity among participants with different patterns of clustering in complicated patterns of nodes and subnodes throughout the network.

Although innovation continues to occur locally and along local networks, the actors involved also connect and communicate with each other across organizations and even national borders. At first, this appears to be a paradoxical statement. The key to resolving it lies in the degree to which local innovators are able to draw on global knowledge assets and impart to them a type of locality that occurs when they are successfully applied within a region. At the heart of innovation lies the application of new or existing knowledge in new ways or to new purposes. To do so is a profoundly social act, one that "involves the regular and habitual cooperation of members of a human group. . . . The character of the cooperating group is profoundly affected at any time by its size, by the needs that are socially recognized, and by the relations between its members" (Childe, 1954). Actors seeking to create innovation within knowledge systems require significant flexibility and broad connectivity to draw on existing information about natural phenomena, techniques, equipment, and processes. Such knowledge, when employed, contributes to the development of novelty.

Innovation that advances the frontiers of knowledge and "takes the lead" globally requires two things: knowing what is currently known (and to whom to connect to find it out) and knowing the techniques to move beyond the known. These transactions occur within networks of knowledge and contact. In most areas of science and technology, significant resources must be expended to learn the "code" associated with a discipline. Access costs determine how likely it is for any practitioner (whether an individual, a laboratory, a university, or a corporation) to be at the leading edge. Connections reduce the cost of access and increase the efficiency of exchange. The observation appears to be especially true in the case of innovation for which early stage knowledge is either tacit, not easily codified, or both. Accordingly, the types of novel thinking or cross-pollination of ideas that lead to innovation depend crucially on the nature and capacity of networks. Indeed, one shared quality among regions noted to be innovation "hot spots" may well be the existence of networks with many nodes and a notable density of connectivity among them (Breschi and Lissoni, 2009).

The conventional understanding based on empirical studies of innovation is that to carry out this creative work, knowledge and people must be able to move relatively unencumbered to self-organize into groups, teams, and collaborations. Flexibility and connectivity are features that enable research practitioners to seek, find, and apply the bits and pieces needed to conduct research at the frontiers, incorporate existing knowledge into their work, and to organize in such a way that needed skills—even ones that are unanticipated at the start—are available to them. Innovating at the frontiers of knowledge requires solving problems in creative ways. The ability, then, to self-organize, to freely search, and to combine and recombine knowledge and teams in unanticipated ways, are often held to be crucial to the innovation process.

Given the purpose of this study, the issue of networks in China and how they compare to other innovating regions, both domestically and internationally, rises to prominence. China has sent people around the world to study the stock of current knowledge. Continuing and nurturing these connections—already made through travel and study abroad—could be essential to China's goal of working at the frontiers of knowledge. Yet, at least one aspect of innovation "with Chinese characteristics"[7] implies a role for higher-level coordination to enhance or perhaps supplant this self-organization process. The question is whether displacing self-organization in favor of more directive construction achieves greater efficacy. There is also the question of whether trust relationships within China are sufficient for effective operation of networks in any case. Trust, along with valuable knowledge, is the coin of the realm for network-based exchanges. Research suggests that the presence of higher levels of trust in a society has an effect on national income (Knack and Keefer, 1997; Zak and Knack, 2001). Networks may thus provide testimony regarding several key issues at the heart of any inquiry into the wellsprings of innovation propensity.

Politics and Innovation: Challenge and Response

Policy support for innovation can reflect high-level national goals. The 1980s saw an emphasis on competitiveness as a driver for support of investments in R&D and innovation, with an emphasis on trade (Sharif, 2006), although the rise of supercomputers at that time demonstrated that commerce, national security, and national prestige can blend in the arguments for government innovation support. The 21st century has seen growth in global attention to sustainability as a driver of innovation with multiple countries supporting innovation in renewable energy and other relevant technologies as products as well as innovation in more sustainable processes for production. In the United States, the increase in such support during the Obama administration followed by at least the intent to reduce it during the Trump administration illustrates the role that policy can play in shaping a national agenda.

Below the policy level, there is also the world of politics. Most studies of innovation have looked at stated, formal policies or specific actions taken by governments as main drivers or at least important elements of the system that produces innovation. Beyond that, the view taken of innovation, depending on the paradigmatic orientation of the analyst, is to apply the lens of economics, sociology, or organizational theory. Innovation may then have an effect on political outcomes. Politics are not frequently brought into the discussion of innovation at the micro level.

There may well be reason to reconsider this view as we will elaborate in the next chapter of this report. To set the stage, the consideration of politics arises from the disruptive nature

[7] The explicit terms used are "socialism" or "development" with Chinese characteristics. Given the importance placed on innovation in both framings, one may infer innovation also occurs within a framing based on "Chinese characteristics."

of innovation. This means that incumbents and elites, who may have risen in stature due to earlier innovation-based restructuring, both acquire political power and lose enthusiasm for innovation with the potential to threaten their incumbency (Mokyr, 1994; Taylor, 2016). To what extent will existing domestic political power successfully resist change potentially threatening to existing bases of that power? The dynamic play between innovation and power plays a role in determining innovation propensity. This is a theme we will explore in the case studies in Chapter Four.

Comparative Systems

There is one final consideration that makes the application of prior understanding of innovation systems to China problematic. Our inquiry is a search for evidence of China's innovation propensity going forward. This will depend, in part, on the resources available but perhaps more so on its systemic propensity to translate innovation potential into innovation outcomes. If so, the analysis needs to be based in large part on an analysis of China's institutions and processes for doing so. The balance of the literature on innovation places emphasis on those aspects of the innovation system that do not lend themselves to prior planning nor to the retention of some measure of decision authority within the upper levels of political, technological, and economic hierarchies. This brings us to a crux in considering the innovation system within China: To what extent should it be thought of as different from those found in the developed West?

The phenomenon of innovation and technological change was once something of a "black box" (largely because of the difficulty in applying the tools of the dominant neoclassical or marginalist economic perspective to the phenomenology involved [Rosenberg, 1982]). However, in the past 30 years, there has been considerable empirical research on the wellsprings of technological innovation. Although it is still not possible to cite a foolproof recipe for bringing innovation into being (witness the many attempts around the world to grow the "next Silicon Valley"), nevertheless we currently possess considerably greater knowledge of the typical characteristics of innovating regions as discussed in this chapter. But, whether conducted in Europe, North America, or even Japan and Korea, there is an implicit assumption in the majority of such studies about the nature of the larger political, economic, cultural, and social systems within which individual innovating entrepreneurs and firms, or the NIS itself, operate. Though different in detail, these regions largely resemble each other as advanced industrialized, liberal democratic countries. Therefore, researchers justly look elsewhere to explain differential innovation performance.

The rise of China to this point represents a puzzle of development and governance, called the "China paradox" (Rothstein, 2015). The assumption has been that development requires strong state administrative and bureaucratic capacity, low corruption, and free exchange of information. China scores low on all commonly used measures of levels of corruption, free exchange of information, and even, in some respects, quality of government. It may be possible to advance to a level of development, despite these factors, based on an imitative strategy as pursued during the first part of the post-Mao era. However, given China's ambition to move beyond its current position into a leading position in innovation, would success in doing so suggest an entirely new model of development that would upend most current assumptions?

A major thrust of the Chinese challenge, and consciously so on the part of China's leadership, is to present a new model of innovation "with Chinese characteristics." In other words, it is not sufficient to presume similarity of institutional structure with prior innovation case studies. The nature of the system needs to be regarded explicitly and a presumed equivalency resisted. This complicates the quest for leading indicators for innovation propensity. On the other hand, posing the question as we have as an inquiry into the capacity and effectiveness of systems and institutions allows us to examine the question explicitly. It makes us less likely to err on the side of implicitly presuming an equivalency across systems.

A Framework for Evaluating Forces for Innovation

Even the cursory treatment in the preceding overview highlights how many activities, processes, and policies could affect systemic propensity toward innovation. In our study, preliminary as it may be, as we examined different sources of information on innovation in China, both what happens and how, a structure emerged that would not only collate information but also provide a guide to relationships among different aspects of innovation. This was both an outcome of our effort and a tool we used to catalog what we learned along several lines of inquiry. The result is shown in Table 2.1. Although this emerged during the course of our inquiry, we present it now to guide the discussion in the balance of this report.

Table 2.1 presents an array that locates factors of importance for innovation in China. It illustrates the intersection between key conceptual categories and venues for the conduct, support, or instigation of innovation, both "apples and oranges." That is, innovation assets, actors in organizations, and system characteristics and dynamics at various scales and venues may cohabit within individual matrix cells.

The columns represent several different levels within which actors make decisions affecting the pursuit of innovative activities, either their own or by others. These columns begin, from left to right, at the level of the **"firm" or "laboratory"** that is intended to cover both enterprises and equivalent small-level working teams for engaging in innovative activity including those found in universities. At a higher level, there is the **market** or industrial sector within which firms and individuals seek to locate themselves as either current or prospective providers

Table 2.1
Framework for Representing Factors Relevant for Innovation in China

Theme	Innovation Factors	"Firms" and "Laboratories"	Markets	Networks	Local Authorities	National Authorities
Institutions	Structure					
	Policy					
	Informal					
Process	R&D					
	Invention					
	Diffusion					
Precursors	Funding					
	Incentive					
	Skills					

of innovative goods and services. It is also in the market that transactions take place through which potential innovators may obtain the tradable skills, goods, and services they may need to pursue innovative endeavors.

Yet, there are many nonmarket transactions that occur, especially in the transmission and generation of important ideas and the gestation of teams, which have a profound influence on innovation outcomes and the propensity toward innovation. Whereas the first two columns describe the realms most pertinent for the microeconomics of innovation, the column on **networks** is less tractable yet exceedingly important for both the generation and transmission of ideas and the formation of informal, de facto task forces for innovation. The commodities transferred across networks are the all-important innovation inputs of knowledge and trust.

The last two columns add the final major venues for innovation-relevant process in China, those of the **local**[8] and **national authorities**. The postreform Chinese economy, while notable for the resounding shift toward markets for organizing economic activities, still retains many important aspects of command within hierarchies that remained and, especially in recent years, have received ideological reinforcement. The commanding role of the party in the political sphere has not changed and so the institutions of policy remain firmly under control of the Chinese Communist Party (CCP). This power transfers into the economic sphere because the governmental control bodies at both the local and national levels are ultimately answerable to the party apparatus. This means that these elements of hierarchic command and control also must be accounted for in the field of innovation.

The rows of the matrix in Table 2.1 address the mechanisms of innovation. We divide them into three main categories that then map across the venues. **Institutions** describe the organizational framework for innovation operating in each venue. **Processes** of innovation take place within these organizations found within the venues. Finally, **precursors** are inputs into innovation processes, their raw material. We divide these themes into three subtopics each.

Institutions matter. "The coordination of economic activity is not merely a matter of price-mediated transactions in markets, but is supported by a wide range of economic and social institutions that are in themselves an important topic of theoretical economic inquiry" (Langlois, 1989). This is something that has become painfully clear over decades of sometimes disappointing results from economic policies, particularly in the realm of international assistance, designed to achieve specific ends without due regard to the nature or importance of existing local institutions through which the policies are intended to operate. This is especially the case in the realm of innovation, which depends crucially on learning, communication, teaming, matching incentives, and skill balancing among economic agents long before a good or service is offered on the market. This suggests a process that is evolutionary and not necessarily as strictly mechanical as sole reference to market-based mechanisms might suggest (Nelson and Winter, 1982). The nature of the institutions—and the dynamic change

[8] "Local" or "regional" authorities refer to those administrative levels below that of the national leadership. As a practical matter, we refer mostly (but not exclusively) to those entities at the highest of China's five levels of subnational administrative classification. These include its provinces, major municipalities, autonomous regions, or special administrative regions. However, the principal distinction being drawn is that between authorities who are responsible for applying a national perspective to policy and those who primarily have an interest in achieving distinction for their subnational area of responsibility. We use the term "authorities" as a convenient shorthand to include both the national and subnational governmental and CCP organs at each level. Convenient it may be, but much may be said (beyond the scope of this report) about the complex interactions among these two parallel hierarchies and their component entities.

within and among institutions—plays a role in determining how successful policies specifically directed to enhancing innovation may prove to be.

From this perspective, the first subcategory within the institutions theme is that of formal **structure**. How are firms, industries, sectors, markets, and policy authorities formally organized? As an example, policymakers in the former Soviet Union whose diagnosis of perceived shortcomings in innovation focused attention on the stage of transferring technical knowledge from design bureaus to production facilities. They created a new structural form, the science-production enterprise (*nauchno-proizvodstvennoe obedinenie*) placing both entities within one organization (with mixed results). Closely allied with organizational structure is the **policy** landscape. What formal rules, permissions, and agency exist within which agents may engage in activities and initiatives relevant for pursuing innovation? What are not only the rules but also the priorities and preferences promulgated by national or regional authorities that the Chinese firm must be cognizant of?

Finally, but perhaps most powerfully, is the realm of **informal** institutions, arrangements that exist among individuals and organizations that appear in no rulebook or set of written records but are nonetheless as strongly present as are the formal linkages. A political scientist David Ronfeldt offered a structure of human organization that encompasses tribes, hierarchies, markets, and networks (Ronfeldt, 1996). This ordering roughly recapitulates the evolution of the megastructures of human organization. Writers on the Chinese economy point out that in addition to the hierarchies present in the structures of government and party, the markets that have played a major role since the post-Mao reforms and the networks of knowledge and interaction that exist whether mediated by newer digital media or not, there also exists linkage through *guanxi*, an informal structure of relationships and obligations that may play a leading role in decisions, depending on the other factors entered into the equation (Gold, Guthrie, and Wank, 2002). This corresponds roughly with Ronfeldt's tribal institutional dimension and, with other considerations, justifies a place for formal consideration when inquiring into innovation in China.

The next major theme is again broken into three categories. Innovation occurs in stages. Although the interactions, activities, and information flow necessary to bring innovation into being are quite complex, it is convenient to view them falling into three processes or stages. The first is usually expressed as **R&D** but can be much broader. It encompasses both knowledge creation through formal R&D projects but also much less formal "fixing" on the production line and combining existing bodies of knowledge into new conjectures. This knowledge need not originate with the innovator but must somehow be drawn into the innovation process. The next stage is **invention**, first putting into place all of the necessary elements of skill, material, and other forms of know-how to create a new product or service. The next category, **diffusion**, speaks to what happens after the instant of invention. Does the invention remain a one-off, a curiosity, and no more, or is it accepted, disseminated, and widely adopted as a meaningful innovation? All three processes contribute to successful innovation outcomes.

The final set of three elements falls under the heading of precursors to innovation. Generally, and increasingly as innovative activities approach the current technological frontier in a field, **funding** is critical, the main lubricant of innovation. Availability of funding, sources of funding, and the conditions under which funding may be obtained are of considerable importance. Although not all transactions are fully transparent, among the three main precursors this is perhaps the least difficult to track. The next, **incentives** to innovate, is much more difficult. And yet, this is in many ways one of the key determinants influencing the degree to which innovative potential may translate into innovative propensity. Innovation is the work of many hands and many players at various levels. Other interests than merely being innovative come into play for each agent involved. There may be incentives present—but also disincentives that would channel effort into other directions. Of the many efforts to generate the next Silicon Valley, not a few have fallen prey to mixed incentives that allowed for gain—or the avoidance of risks perceived as being too great—to be obtained through other means.

The last subcategory, that of **skills**, is subject to the greatest academic scrutiny. Innovation, especially over the past century, has been less the province of the lonely inventor and more that of those who can assemble the most effective and purposeful teams, collaborations, or cooperative ventures possessing the necessary skills for invention and presentation to the marketplace. Knowledge and skill, along with trust, are the principal currencies of the networks that are so characteristic of highly innovating locales. Skills are embodied in human beings and so all issues of employment, training, and the organization of labor fall into this category.

In the framework of Table 2.1, as with all such architectures, the categorical boundaries between the framework's concepts are easy to distinguish in the ideal but actual practice does not conform to such neat compartmentation. In the following chapters, we visit different categories of information about innovation in China: existing literature on China, case studies of technology sectors, and preliminary attempts to craft quantitative analyses pointing to evidence of networks. In Chapter Five, we then provide a summation with a view to capturing in the cells of the matrix the full range of interactions and venues in which decisions affecting innovation may occur. We then, also based on the discussion in the next chapters, make an assessment of what measures might allow us to track these key interactions over time.

CHAPTER THREE

The Road Toward the Chinese Century

> "Cardwell's Law" states essentially that every society, *when left on its own* [emphasis in the original], will be technologically creative for only short periods. Sooner or later the forces of conservatism . . . take over and manage through a variety of legal and institutional channels to slow down and if possible stop technological creativity altogether. Technological leaders like 17th-century Holland or early 19th-century Britain lost their edge and eventually became followers. . . . Societies become increasingly risk-averse and conservative, and creative innovators are regarded as deviants and rebels. In some cases, . . . an iron bureaucracy either suppresses innovation altogether or channels it in directions deemed worthy by the rulers. In other cases, vested interests will use violence to block progress. . . . Cardwell's Law works because technological creativity is a delicate and fragile flower that needs just the right institutional environment to thrive. Yet in a truly dialectical manner, its very success usually destroys the environment it needs to survive. (Mokyr, 1993)

The quotation is apt for a chapter in which we use the framework of Table 2.1 as a guide to consider several topics that stand out as either peculiar to China, receive particular emphasis in the Chinese setting, or might point to an alternative Chinese model for the organization of innovation activity. The economic historian who authored this quotation strikes a more circumspect and temperate tone in his academic writings (see, e.g., Mokyr, 1994), but the statement stands as a terse outline of a construct within which to consider innovation in China and its relationship to innovation processes in the United States and other OECD nations.

In an era in which innovation has taken on such portent in consideration of policies for future economic and state power, the implications of the hypothesized fleeting nature of innovative ascendency is chilling. But for whom? On reflection it is not clear whether Cardwell's "Law" currently might most aptly apply to China or the West. Is China the highly motivated successor seeking through technological innovation to supplant the staid predecessors of the older order? Or is it a state that will find innovation ultimately constrained by the self-imposed insistence on maintaining existing elites and the continuation of set institutions while it is the current incumbent nations in the technological lead who continue reaping the benefits of creative destruction? Interestingly, the scholars following this line of inquiry find that Cardwell's Law may be disrupted through human agency to the extent that external political challenges are perceived as mounting a major threat to a nation's system or well-being. This "creative insecurity" may offset the conservative tendencies latent within political systems and so allow innovation to flourish at the expense of domestic incumbents (Taylor, 2016).

China, a notable source of innovation historically, has endeavored over the last 40 years to build up new innovative capacities and to steer their development and use. Development has been a policy goal throughout the period since 1949, but the desire for innovation-led growth took on special driving force once the post-Mao transformation was well underway. Indeed, it might be said that several aspects of the prior status quo were placed at risk, in the view of conservative CCP members, in pursuit of this objective. In more recent decades, the extensive (resource-driven and technologically acquisitive) approach to development has been supplanted by a desired shift to a more intensive (resource efficient and technologically innovative) pattern.[1] This goal has been detailed by General Secretary and President Xi Jinping: "To carry out the innovation-driven strategy, the basic thing for us is to enhance our independent innovation ability, and the most urgent thing in this regard is to remove institutional barriers so as to unleash to the greatest extent the huge potential of science and technology as the primary productive force" (Xi, 2014).

There is a large and rapidly expanding literature on China's development and performance as well as the particularities of its domestic arrangements. We do not seek to recapitulate that extensive literature here, even in microcosm.[2] In this chapter, we instead reflect on a few of the topics raised in the previous chapter and bring out some of the distinctive features of the innovation landscape as they appear to be evolving in China. The discussion will largely follow topics appearing in descending order along the vertical axis of Table 2.1.

Institutions: Formal and Informal

China clearly has made great strides in a relatively short time in raising its technology level. It is seen by many as swiftly becoming a member of the group of nations from which the bulk of leading innovation comes (European Commission, 2019). This is likely to prove even more the case in coming years. Yet, several aspects of China's economy, society, and policy set it apart from the other countries in this group. Some of these aspects may prove to be obstacles to enhancing China's propensity toward innovation, whereas others may be viewed as potential impediments to some while the Chinese themselves see them as potential points of advantage.

Unlike the United States, which has no single agency responsible for its innovation system, China has a Ministry of Science and Technology[3] under which is the National Natural Science

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[1] The year 1995 stands as a good marker for when a shift toward a more innovation-led, intensive pattern of growth became a priority with practical effect on resource allocations. See, for example, Suttmeier, Cao, and Simon, 2006, and Karaulova et al., 2017.

[2] Appelbaum et al., 2018, offer an accessible treatment of the government structure for R&D and China's national innovation system. Zhou, Lazonick, and Sun, 2016, presents vignettes on progress in several technology-dependent industries, Although now dated, Breznitz and Murphree's 2011 work is still useful for the politics among the players in innovation. Serger, Benner, and Liu (2015) discuss transition toward an innovation posture in China's universities.

[3] MOST presents its roles as:

1. MOST formulates and facilitates the implementation of strategies and policies for innovation-driven development, and plans and policies for S&T development and the attraction of foreign talent.
2. MOST coordinates the development of the national innovation system and the reform of the national S&T management system, and works with relevant government departments to improve incentive mechanisms for technological innovation. MOST endeavors to improve the national R&D system, facilitate the reform and development of research institutes, enhance the innovation capabilities of enterprises, promote military-civilian integration, and develop the consulting system for major national S&T decision-making.
3. MOST takes the lead in establishing a unified national platform for S&T management and a mechanism for fund allocation, evaluation and supervision of research projects. MOST works with relevant government depart-

Foundation of China.[4] Leadership has also come from the China Academy of Sciences (CAS), a major beneficiary of state funding. With a broader role than seemingly similar bodies elsewhere, although reminiscent of the role played by Academies of Science in the former socialist countries of the Soviet Union and Eastern Europe, CAS confederates a number of specialized institutes and laboratories, oversees a few universities, and connects broadly with STEM professionals (Chinese Academy of Sciences, 2016). CAS itself has evolved with China's innovation ecosystem (Suttmeier, Cao, and Simon, 2006; Zhan and Qian, 2016), helping to forge the national focus on innovation, and it launched an innovation-focused initiative in 2011, China 2020. Support for national security needs has been a factor in CAS history since its establishment, but in contrast to early separation of defense and civilian activity, modernization (e.g., through the Medium- and Long-Term Plan [MLP]) has been associated with technology development that integrates military and civilian considerations (Suttmeier, Cao, and Simon, 2006).

China has established its own version of national laboratories in the form of research institutes (Chinese Academy of Sciences, 2016). Some of those have an explicit military focus, such as the National University of Defense Technology and within it the National Innovation Institute of Defense Technology. Within the People's Liberation Army (PLA), a Scientific Research Steering Committee was established under the Central Military Commission in 2017 to help, along with a Science and Technology Commission, select research projects (Office of the Secretary of Defense, 2018).

Party Control

An inescapable feature of China's innovation system is the dual message of striving for excellence and innovation on the one hand while maintaining the primacy of party guidance (and control) on the other. No other single fact separates China more from the countries whose innovative performance China would like to emulate and match. Innovation with Chinese characteristics ultimately means reconciling these two thrusts.

Until recent years, the CCP, while omnipresent, has been relatively content to grant implicitly a relatively free hand to the type of decisionmaking by firms that it recognizes is required for an innovating culture to arise and persist. In the Xi Jinping era, however, there appears to have been a dissipation of whatever prior reticence existed to intervene more directly. The government role in

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ments to put forward policy recommendations for optimizing the allocation of S&T resources, build a diversified system for S&T investment, coordinate, manage and oversee the implementation of S&T programs (projects and funds) financed by the central government.

4. MOST formulates and implements national basic research plans, policies and standards, and organizes and coordinates major national projects on basic research and application-oriented basic research. MOST formulates and oversees the implementation of plans for major STI bases, participates in the formulation and oversees the implementation of plans for major S&T infrastructure, leads the efforts to develop national laboratories, lays a sound groundwork for scientific research, and promotes the open access to and sharing of S&T resources.
5. MOST formulates plans for major national S&T projects and oversees their implementation, coordinates the R&D and innovation of key generic technologies, cutting-edge frontier technologies, modern engineering technologies and disruptive technologies, leads the efforts to tackle key technological problems, and promotes the demonstration and application of major R&D and innovation outcomes. MOST coordinates the efforts to implement or participate in international mega-science programs and projects.
6. MOST takes the lead in formulating plans, policies and measures for the R&D and industrial application of high and new technologies and the promotion of agricultural, rural and social development through S&T. MOST analyzes technological demands in priority areas, proposes major tasks and oversees their implementation" (Ministry of Science and Technology of the People's Republic of China, "Organization").

[4] National Natural Science Foundation of China, undated.

resource allocation appears to have increased in recent years with the central government leading the trend and relying on the local authorities for execution (Lardy, 2019). And more state intervention can only happen on the basis of decisions emanating from the CCP. Some have argued the Chinese leadership has in effect abandoned structural reforms that would enable China to make strides in basic research and breakthrough technologies in favor of applied innovation engendered by domestic demand (Economy, 2018). Others point to weak institutions other than the CCP as being the "single drag on China's potential to excel at innovation" (Magnus, 2018). The argument is that complementary innovation stemming from radical, platform innovation (on the order of the iPhone) engenders changes that are disruptive, unpredictable, and prone to experiment and failure—not a milieu that a party that has been designated to provide leading-edge guidance would seem likely to embrace naturally. Reform may take the form of the administrative and organizational changes most familiar to those raised in a command-type system. These may serve to enhance efficiency on the margin but not necessarily lead to the type of disruptive, leading-edge innovation China craves (Magnus, 2018). It is harder for good companies to thrive in a world in which bad companies are not allowed to fail (Economy, 2018).

State Enterprises

This last consideration raises the issue of state-owned enterprises (SOEs). There are SOEs or nominally privatized firms in which governments hold majority stakes in other parts of the world. In China, they possess the numbers, priority, and prominence that make them a major force across industries.

The numbers and scale of privately owned enterprises (POEs) have burgeoned in recent years. However, remaining SOEs are not considered to be vestigial by China's leadership. In 2018, the ownership share of total capital in Chinese firms was 55 percent state, 33 percent private, and 12 percent foreign (Piketty, 2020). The share owned by the state changed little in the prior dozen transformative years.[5] Although the market economy has been growing in China, and although the government has begun to foster enterprise-centered funding (e.g., loans and tax credits) (Melass and Zhang, 2016), the persistence of SOEs can provide formidable competition. SOEs attest to several decades of the Chinese government picking and supporting winners, and they have received steady infusions of government support (Liu et al., 2017). The role of the government is harder to discern (but presumed not absent) in the seemingly more independent tech sector (Heubl, 2017), which includes world-leading internet-related companies. China's targeted plans and policies support the development of new or emerging markets, recognizing the positive relationship between market size, market shares, and spending on both R&D and innovation (Acemoglu and Linn, 2004). They are not averse to and instead encourage the appearance of large market players.[6]

A study looking at the technical and structural effects of China's total factor productivity[7] growth highlights why the persistence of SOEs in many sectors may prove problematic for

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5 In 2006, the shares were 58 percent state, 25 percent private, and 17 percent foreign owned (Piketty, 2020).

6 The United States had traditionally focused more on how markets operate and the potential adverse consequences of market power (Aghion et al., 2005; Gans and Stern, 2003). This has somewhat attenuated in recent decades as current consumer benefit has become the guiding principle, but not because of a perceived desirability or predisposition toward enhancing size.

7 Just as labor productivity is calculated by comparing economic growth to the growth in hours worked during the same period (if the ratio between the two grows, labor is judged to have grown in productivity), total factor productivity compares

innovation. The authors find that since the global financial crisis of 2008, China has seen a reverse in technological progress by this measure and attributes the cause to resources allocated to low-growth sectors (Cai and Fu, 2018). They recommend that "China should continue to phase out backward capacities in sectors with excess capacity . . . and offer reasonable incentives to guide the flow of factor resources to tech-intensive and efficient sectors" (Cai and Fu, 2018). These low-growth industries are often the sectors that see the greatest concentration of SOEs, an organizational type that continues to receive favor from the state.

The SOE sector has its champions inside China. (Others may quietly hold the view that pressure on China from the Trump administration to abandon large-scale campaigns such as Made in China 2025 may prove a net positive for China precisely because of the heavy state direction and so presumed squandering of resources associated with them.) But the competitive forces that empowered China's surge over several decades are also seen as being countered by a tendency to pump resources into ailing SOEs and slow investment by more productive firms. On the contrary, President Xi has argued that SOEs "should be supported and not abandoned" and that "we will support state capital in becoming stronger, doing better, and growing bigger" (as quoted in Lardy, 2019).

Corruption

One of the hallmarks of the early rise of Xi Jinping to paramount party leadership was his drive against corruption. Questions were raised from the onset whether this campaign was motivated solely by the desire to remove corrupt elements from the state and party or if the campaign was a convenient cloak for a move against potential leaders of anti-Xi factions. Nevertheless, the perception of corruption within China was so great that this drive received widespread approval from the public and proved an early source of popularity. Corruption can have a direct effect on innovation by adding a level of risk to entrepreneurial activity or, in the case of entrepreneurial success, imposing a tax in the form of graft and rake-offs by local or national government or party authorities. The perception of a crackdown on corruption itself may further affect innovation activities by paralyzing firm management and government bureaucrats with fear of possibly being charged with behaving in a corrupt manner (Gan, 2018).

In 2012 and 2013, before the beginning of the Xi Jinping era, China was given low scores on an index of perceived public-sector corruption scoring 39 and 40, respectively, out of a maximum of 100 points on Transparency International's Corruption Perceptions Index (Transparency International, 2020). After six years of the formal anticorruption drive, the most recent scores in 2018 and 2019 were 39 and 41, respectively. These scores ranked China 80th out of 180 countries (with Taiwan ranked 28th and Hong Kong 16th). That ranking compares unfavorably among those nations considered to be potential leaders in technology and innovation. Russia, the inclusion of which in an innovating-nations major-league table might be questionable, ranks 137th.

Any such single evaluation, especially an index not only measuring perceptions but also taking into account several factors and weighting them differentially, must be not taken as definitive evidence. Nevertheless, the consistency of the ranking and the distinctiveness of China's place compared with innovating nations in North America, the EU, and the Asia

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overall growth to the growth in all factors of production. It has frequently been used as a proxy for technological progress because it is technically the residual of what remains to explain economic growth when growth in all other factor inputs have been accounted for.

Pacific region suggest that this factor bears watching and should be taken into account as possibly playing some role in determining China's propensity to realize its potential as an innovating region.

Rule of Law

Rule of law also has aspects of importance for innovation. Beyond the issue of corruption or the ability to establish and sustain IPR is a fundamental question of whether it is possible to enforce contracts in a court of law. This is by far not an issue that arises solely in China. In the United States, for example, the costs for such defense and enforcement are not infrequently quite expensive. This raises a practical if not necessarily legal barrier to attaining redress. That, in turn, affects how innovators may balance risk before entering into contractual relations with other parties (partners, suppliers, investors, licensees, etc.) and vice versa. In Mexico, as an example, some firms will seek to purchase advanced equipment from foreign firms rather than local manufacturers because the perceived risk of being cheated is lower.

In China, the rule of law is tempered by the fundamental precept that courts, rather than existing as a check on the executive powers of the state, are themselves an arm of state power. This makes it problematic to "fight city hall," especially when local, regional, and national government may have a preference for the course of economic consequences to proceed along a desired path in opposition to what an innovating entity may desire and have a legal right to pursue. To the extent that this is the case going forward, it could well weigh on perceptions of risk associated with innovative activity.[8]

Informal Institutions

Several of the topics above suggest that in addition to formal institutions that may exist *de jure*, there are also informal institutions *de facto*. How rules are applied, what people come to understand are the unwritten rules, and a calculation of where interests lie may have a profound effect on venues, processes, and activities that affect innovation.

> It might be said that the undesignated institutions which evolve gradually as the unintended and unforeseeable result of the pursuit of individual interests accumulate in the *interstices* of the legal order. The interstices have been planned, though the sediments accumulating in them have not and could not have been. In a society of this type we might distinguish between the external institutions which constitute, as it were, the outer framework of society, the legal order, and the *internal* institutions which gradually evolve as a result of market processes and other forms of spontaneous individual action. (Ludwig, 1971)

If innovation "with Chinese characteristics" retains and indeed relies on direction from higher-level organizations for the trajectory of innovation in China, this consideration may seem to put China at a disadvantage and thus provide potential impediments to innovation propensity. These may come in two forms. The formal, hierarchical substitutes for what would otherwise be informal evolutionary processes of self-directed and self-assembled associations and understandings (in many respects the quintessence of innovative regions) might prove to be less effective than the more ad hoc processes they are meant to supplant. Further, state measures put in place to bring into being greater political control to social and economic trans-

[8] See Bailey et al. (2020) for analysis of 2010–2019 court decisions on software copyright infringements.

actions beyond innovation might inadvertently create impediments to the types of informal institutions, associations, and networks that appear to be crucial for high rates of innovative activity. This is not a small consideration as China appears increasingly to be employing applications spawned from advanced technology to enhance social monitoring and control. But in any case, this consideration motivates attention being paid not only to the rules as laid down in law and regulation but also the rules potential innovators actually play by.

Policies

China has been on and continues along a trajectory pointing to the primacy of innovation-led development. The 13th Five-Year Plan (FYP) (2016–2020) addressed sustainability broadly and innovation as a cornerstone of China's development (Koleski, 2017). The details found in these plans attest to a bigger national than market role within China's economy compared with other technology leaders, even as it seeks to promote market growth.

> The Chinese government is seeking to use innovation to accelerate efforts to move Chinese manufacturing up the value-added chain, reestablish China as a global center of innovation and technology, and ensure long-term productivity. On May 19, 2016, the CCP Central Committee and State Council released Guidelines for China's Innovation-Driven Development Model that builds upon the 13th FYP and establishes broad goals for China's economy to become an "innovative nation" by 2020, an international innovation leader by 2030, and a world powerhouse of scientific and technological innovation by 2050. (Koleski, 2017)

The 13th FYP focus on "indigenous innovation" evoked objections from the United States and other governments because of concern that it suggests an orientation toward displacement of foreign firms and technologies (Koleski, 2017).

China's FYPs are complemented by targeted initiatives supporting innovation, such as "Made in China 2025" providing for government support to ten sectors[9] and "Internet Plus" supporting information infrastructure (internet, mobile communications, cloud computing, internet of things [IOT]), including overseas growth of Chinese firms (Koleski, 2017). When supporting an industry, the Chinese government has frequently been an active player in linking technology producers with users, underdeveloped capital markets, and state-owned financial institutions (Melass and Zhang, 2016).

Overall, China continues to steer more of its innovation from the top down compared with the United States. From the mid-1980s through the early 2000s, the National High-Tech ("863") Program aimed to build economic and security strength and leapfrog (i.e., move rapidly from a backward state to state-of-the-art without intermediary stages), with emphasis on information technology (IT); biology, agriculture, and pharmaceutical technology; materials and manufacturing; and environment and energy (Ministry of Science and Technology of the People's Republic of China "Programme"). The 2006 MLP responded to China's "heavy reliance on foreign technology" (Cao, Suttmeier, and Simon, 2006) and aimed at world-leading S&T stature by 2050 but to an "innovation-oriented society" by 2020. The MLP related the

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[9] The sectors are (1) new energy vehicles, (2) next-generation information technology, (3) biotechnology, (4) new materials, (5) aerospace, (6) ocean engineering and high-tech ships, (7) railway, (8) robotics, (9) power equipment, and (10) agricultural machinery (Koleski, 2017).

Chinese term for "indigenous innovation" to novel innovation, integrated innovation (blending existing technologies in new ways), and "reinnovation," which involves assimilation and improvement of imported technologies (Cao, Suttmeier, and Simon, 2006).

Within this large thrust, several other matters of policy choice might affect innovation propensity.

Intellectual Property Rights

Intellectual property (IP) is an arena shaped by policy, from the basic creation of a property right to an idea as an incentive to innovate (Gallini and Scotchmer, 2002) to the terms, conditions, and defense of that right. Moreover, there is a complex relationship between IP and competition policy, which complement each other in supporting the development and operation of markets.

China's posture toward IP has been evolving, and over the long term it has recognized such rights more and even encouraged creation of IP in its recent plans for AI. In 2017, for example, Huawei alone was the world leader in patent filings, a year when 44 percent of global patent filings were made by Chinese entities (Rosen, 2019); in 2018, Huawei set a record with 5,405 applications to the World Intellectual Property Organization, a year when 50.5 percent of all patents came from Asia (Reuters, 2019). China has patented aggressively in the area of rare earths (Ng, 2019), where it also benefits from physical access. Chinese entities applied for 25,911 patents, compared with 9,810 from the United States, as of October 2018.

China has seemed to support Chinese IP rights relative to those of foreigners.

> China maintains a pattern of first welcoming foreign investment into strategic sectors to gain foreign technology, intellectual property, and know-how then restricting investment in those sectors as domestic firms become competitive. This policy creates market space for China's new firms by pushing out foreign competitors. (Koleski, 2017)

That said, the Chinese National Intellectual Property Administration established a mechanism for punitive damages for infringement in 2018 (Rosen, 2019). As of 2019, there was an IP Tribunal within the Supreme People's Court for appeals, and its first case addressed infringement claims of a French headquartered automotive supplier (Lu, 2019). China has also stimulated academic activity through a counterpart to the Bayh-Dole Act[10] in the United States (Reuters, 2019). Nevertheless, in the Chinese milieu its version of granting IPR to academic research has been claimed to sometimes have the effect of freezing out competing technical solutions rather than boosting proliferation of innovation and wider application of patented IP (Tang, 2006). Government-supported research institutes and major universities are the largest holders of Chinese patents, in contrast to companies (Liu et al., 2017). In general, China's IP regime to date has been held to be sufficiently ambiguous or burdensome that it entails large costs of compliance and so creates an uncertain environment. The World Bank finds that this renders Chinese IP regulations less than optimal for encouraging innovation investments, technology transfer (especially of frontier technology), patent commercialization, or spillovers (Prud'homme, 2017).

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[10] The Bayh-Dole Act of 1980 clarified that contractors, such as universities, conducting federally funded research could retain ownership of the IP they developed. Previously, depending on an assessment made by the funding agency, they could be required to sign ownership over to the government.

Policy comes into play in how China conceives of the incentives for innovation. As a general matter, among technologically innovative developed countries, intrinsic rewards stemming directly from the results of the effort have been seen as more important than external rewards to such creative work as research and innovation (Schmid and Wang, 2017). China, however, uses external rewards widely as a motivator.

> While innovation might not be responsive to traditional pay-for-performance incentives, in the PRC patenting and publishing appear to be . . . China has established an innovation incentive mix that includes tax breaks for innovative firms, allowing universities to commercialize intellectual property developed during government-funded research projects, subsidization of the patent application process, financial incentives to Chinese nationals that file patents abroad, and direct rewards to researchers. (Schmid and Wang, 2017).

> The officials-rank standard (*guan benwei*)—alternatively "government official-oriented"—refers to a ubiquitous socio-political hierarchy that affords deference and prestige to government officials and other forms of official ranking. This rigid and pervasive socio-political system determines one's professional rank, pay, perks, status and power. The officials-rank standard acts as a mediating variable in that it shapes the way in which the incentive environment affects patenting and publishing. (Schmid and Wang, 2017)

Such incentives play out across the innovation space. For example, academic and laboratory researchers who participate actively in Chinese technology standards development (discussed in the next section) can earn bonuses, more readily approved travel, or credit for promotion, as well as access to research grants (Breznitz and Murphree, 2013).

Related practices, in turn, have been linked to those that are counter to accepted research and professional ethics—and call into question the sheer counts of outputs as well as their quality. "Chinese scientific publications have been tainted by plagiarism, falsification and fraud" (Schmid and Wang, 2017). Further, the Chinese academic system has been associated with low-quality journals, although Chinese graduate students in U.S. programs have been comparatively productive (as measured by publications), likely due to a selection effect (Gaulé & Piacentini, 2013). Nevertheless, the *guan benwei* system, in keeping with most evaluation systems, would appear susceptible to the dictum, "that which is measured improves; that which is not measured does not."[11] Such a system might in practice actually prove antithetical to innovation.

Standards

The manner in which industrial standards are set usually falls below the radar of casual examinations of innovation. However, standards can have considerable influence on patterns of technology development and hence innovation.

China supports engagement in international standard setting more strategically than the United States, at least in the 21st century. It coordinates standards-related activity with its promotion of R&D, both part of national industrial policy (Suttmeier, Yao, and Tan, 2006; Breznitz and Murphree, 2013; Murphree and Breznitz, 2018). Competitive advantage can be reaped by those whose technologies are embedded in, or closest to, what is captured in a

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[11] The statement or some variant has been attributed to several leading figures including Lord Kelvin, Peter Drucker, Karl Pearson, and Thomas Monson.

standard. The United States has long deferred to industry-based standards setting. Its National Institute of Standards and Technology does not play the active role of the Standardization Administration of the People's Republic of China (International Organization for Standardization). Hence, this government body holds China's membership in the International Organization for Standardization, while the private American National Standards Institute holds that of the United States (International Organization for Standardization). Bureaucratic as opposed to political mechanisms have dominated standards-related decisionmaking and initiatives in China, leveraging the 1989 Technology Standards Law, acknowledged to be outdated (Breznitz and Murphree, 2013). (The European model is closer to the Chinese model than to that of the U.S. and only recognizes UN- or ISO-based standards as international standards.)

The Chinese approach is different from that of the United States and other countries (and arguably misunderstood). Rather than maximize returns to IP (embedded in standards), per se, the Chinese develop agreement on technologies and on minimal charges to lower costs (treating IP as an input) in a context of cost-sensitive manufacturing—and they have acted to establish this approach as a new global norm (Kania, 2019b). Further, the Chinese have taken advantage of a difference in approach between the United States and Europe. "No longer willing to be standards takers or to accept U.S. norms at face value, Chinese firms are beginning to challenge accepted U.S. practices and leadership in technology standards" (Breznitz and Murphree, 2013; Murphree and Breznitz, 2018). A prospect looms of China siding with Europe against the United States in disagreements over international standards. The Chinese have pursued in parallel domestic standards setting and participation in international technical committees and working groups. "Today, the Chinese may have an advantage over the United States (and U.S. firms) in international and domestic standards bodies—not because of favoritism, but because of their understanding of the system and the laws that govern it" (Breznitz and Murphree, 2013). The Chinese have even developed standards-setting training programs for engineers and managers. Nevertheless, shared standards are critical for trade, and often for advancement in R&D, so there is much room for negotiation in this sphere.

Geopolitical Considerations

The blessings of peace are manifold, but in the history of technology, military procurement has been a great spur to innovation. This connection may affect China's innovation as well, given the primacy of the PLA in the calculations of both government and party. China began a major modernization of its air, sea, land, and space forces in 2015 (Ministry of National Defense, 2015). In recent years, leadership has made it clear that it expects Chinese firms and innovation teams to be cognizant of the requirements of the PLA and the possibilities for new inventions, even those in the commercial sphere, to have dual applications.

The increase in military spending in recent years could potentially provide China with a great advantage over other economies that aim toward leadership in sectors of technology.[12] This was certainly the case over the last century for the United States. No other advanced country (or the European Union as a whole) that has tried to gain advantage in innovation has had the great benefit of the relative scale and scope of the U.S. military budget. China has been increasing its R&D budget and stating an intent to lead in innovation, but unlike others other

[12] In this connection, see the discussion in Kania, 2019b.

than the United States and possibly Russia, it possesses the potentially large advantage of the demand function of military technology and applications.[13]

Balanced against that, China has a way to go before it approaches the absolute scale of U.S. military investment, procurement, and R&D. A good deal of its near-term military budget will need to go toward closing the current gap between the U.S. and PLA military systems by its own reckoning of relative advantage (Cooper, 2018). There is also a chance that placing a greater emphasis on innovation for the military could have a distorting effect on China's innovation enterprise writ large. Although certainly not the same system as that of the Soviet Union in the late Cold War era, one way of describing the shortcomings of that nation's pursuit of both military and technological superiority is that subordinating the latter so much to serving the needs of the former engendered both myopia and lack of a sufficiently resilient innovation base outside the military sphere. This worked to the detriment of both the technological and military ambitions of the Soviets with neither objective achieved.[14]

This look beyond China's national frontiers extends in another dimension as well. The innovation system has changed with the rise of a global network of both researchers and corporations whose actions are not conducted with reference to national goals or priorities. These international actors tend to seek attention, reputation, and connection at international levels spanning the globe. The result has been the creation of networks with characteristics beyond the reach of the nation-state and that create their own ecosystem of knowledge creation and innovation. There will be implications if China emphasizes a national approach to innovation that possibly reduces its participation in the international network that partly impels the drive toward the frontiers of many industries, technology fields, and scientific studies.

Investment in R&D

This research is an inquiry into what present trends may portend for innovation in China. It presumes no large dislocations or sudden shifts in either China's fortunes or global affairs (although these may well occur). As such, the large question of investment for R&D receives less attention than other systemic factors in describing China's innovation propensity. Barring major surprises, China is likely to be a large generator of innovation funding. Nevertheless, the mechanism and provenance of that funding may affect both innovation propensity and outcomes.

State Investment

China has engaged in a local economic development approach, albeit one that features local governments acting in ways that support national plans and strategies. The establishment of special economic zones (SEZs) in the 1980s helped to foster a socialist market economy, and local governments help to finance local activity (Crane et al., 2018). The Torch Program

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[13] A survey of the literature on this topic may be found in Mowery, 2010.

[14] Speaking about increased intelligence and counterterror spending in the United States following the 9/11 attacks, Koh (2007) notes, "There is also the risk that the diversion of resources to develop anti-terror technologies may slow down innovation in society as a whole, by drawing talented people from more economically productive areas, by crowding out investment dollars, and by creating a climate of intolerance that will impede innovation. That, in turn, may well play a role in reducing economic growth in the long term."

beginning in the early 1990s and intended to foster technology transfer (with an emphasis on information technologies) yielded technology parks in 53 cities (primarily the largest cities and provincial capitals) (Hu, 2007). In a somewhat more targeted way, the City of Hangzhou partnered with the Wanxiang Group to develop an industrial park, with aspirations to become an innovation cluster (Dossani, Graf, and Han, 2017). The new national emphasis on AI has stimulated local efforts to host relevant activity (e.g., a $2.1 billion technology center in Beijing to support AI research); more generally, "156 state-level tech zones scattered across the country are providing similar facilities to support industries deemed national priorities" (Bloomberg News, 2018).

Perhaps because proliferating industrial and technology parks draw from mixed sources of support, observers have suggested that they compose an innovation archipelago lacking the kind of linkages that would make the most of spillover benefits (Melass and Zhang, 2016). But their number and scale do speak to a broad pattern of investment and capacity development.

The proliferation of technology parks has been accompanied recently by growth among small- and medium-sized enterprises. This development also reflects more recent Chinese efforts to support entrepreneurs (World Economic Forum, 2016). For example, a national program launched in 1999, the Innovation Fund (the Innofund) for technology-based small- and medium-sized firms, saw substantial budget growth beginning in 2007. However, there is little evidence that receiving such funds improves a firm's chance of survival, promotes innovation, or provides a strong signal to follow-on investors (Wang, Li, and Furman, 2017).

Corporate Investment

Investment related to R&D and innovation does not come solely from governmental sources. In 2017, China's total spending on R&D rose 12.3 percent to RMB 1.76 trillion ($254 billion). The amount funded by businesses, including foreign-owned entities, kept pace with this overall growth and accounted for the lion's share of it, RMB 1.36 trillion ($196.4 billion) (Normile, 2018). Private sourcing of R&D finance may now be entering a secondary phase of R&D investment in the sense that those firms that were originally, at least in part, the beneficiaries of prior state expenditures on R&D are now becoming major funders themselves. But this may have an effect on the overall thrust of R&D in China. Whereas the amount of this funding represents a funding level 44 percent the size of that in the United States in 2016 according to OECD data, the portion that went to basic research was only about 16 percent (at market exchange rates) of the total invested by the United States (Normile, 2018).

It remains to be seen what the effect of this differential emphasis will be. One perspective argues for differentiating commercial success from innovation, per se.

> China is dedicating an unprecedented amount of funding to research and development (R&D). . . . By avoiding spending on basic research and foundational technologies, income is being generated less as a result of novel technologies and more as a result of new applications or business models . . . China's commercial success has outstripped its progress in technology innovation. (Kennedy, 2017)

Although Chinese companies have succeeded with the kinds of innovation that do not depend on R&D, the trade-off is that there are fewer companies (e.g., Huawei) that are recognized as world class in R&D (Liu et al., 2017). R&D investment and related revenues have been used as indicators in a Chinese system for certifying high-tech companies, which entitles them to government funding (Liu et al., 2017).[15]

China's own investments have been complemented by investments of others operating in or doing business with China. The rise of global sourcing (and outsourcing)—reflecting perceived cost advantages from basing manufacturing in developing countries and the perceived business benefit of having a local presence in a country with a large and growing market—led U.S. companies to produce parts and sometimes complete products in China. Setting aside how the Chinese policy context for associated direct foreign investment and joint ventures has evolved over time, especially through forcing more investment in R&D and technology transfer than foreign firms may have chosen for themselves, this activity proved to be a major vector of technology transfer and inspiration for innovation, first imitative and then competitive (Jiang et al., 2018).[16] Moreover, unlike the post–World War II catch-up tacks of Korea and Japan, "China has created a new model that exploits its comparative advantages in modular, low-cost manufacturing and access to foreign technology" (Melass and Zhang, 2016).

R&D, Knowledge, and Skill Building

China has developed expansive plans for building out higher education, notably in STEM, and associated academic research. It also continues to support Chinese study abroad, primarily in STEM, through the China Scholarship Council[17] under the Ministry of Education. In 2006, China launched the MLP for the development of science and technology (2006–2020), signaling the nation's commitment to rely more on "brain" than "brawn" to bring China into a strong, leadership position (Cao, Suttmeier, and Simon, 2006). The Central Leading Group for Coordinating Talent Work, a high-level task force newly established by the Central Committee of the Chinese Communist Party (CCPCC) within its organization, led the implementation of the National Medium- and Long-Term Talent Development Plan (2010–2020). The formulation of the plan highlighted the urgency that China placed on achieving five goals: (1) transforming China's population dividend into a talent dividend, (2) pursuing a shift from a "made in China" to a "created in China" model, (3) focusing less on attracting foreign capital and more on attracting human capital, (4) emphasizing the importance of "software" rather than "hardware," and (5) shifting from an investment model to an innovation model. In addition to providing guiding policies and strategic goals, the plan recommended national talent development targets, specified sectors in which talent is in great demand, called for establishing national programs to support and nurture the development of talent in various fields, and prioritized areas in which improvements in policy and institution-building are necessary to better employ talent (CCPCC, 2016).

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15 "The Chinese approach to technology upgrading has been to take the technological level in foreign multinationals as a benchmark and then fund research in SOEs, CAS institutes, or key universities to reach and hopefully even leapfrog these technologies. This approach has rarely led to the development of groundbreaking and disruptive technology. Furthermore, it seems to have worked only in sectors where the government can manipulate the market" (Liu et al., 2017, p. 661).

16 International joint ventures "generate local technological learning, as well as access to intellectual property and foreign capital."

17 See, for example, China Scholarship Council, undated.

In 2015, the CCPCC and China's State Council released an innovation-driven development strategy. In pursuit of innovation, some of China's programs supporting science and technology were reorganized, reforms were begun at the Chinese Academy of Sciences, and innovation in education was encouraged (Liu et al., 2017). At the same time, in 2016, the CCPCC issued the "Opinions on Deepening the Reform of the Institutional Mechanism for Talent Development" to accelerate the talent-driven nation building, stimulate fully Chinese people's innovation, creativity, and entrepreneurship, and attract talent from all walks of life to fulfill the cause of the party-state.[18] This move implied the initiation of a transformation of China's economic development model from one that was labor-, investment-, energy-, and resource-intensive into one that is increasingly dependent on talent, technology, and innovation (Cao et al., 2020).

Identifying Factors in the Innovation Activity Framework

This chapter reviewed topics regarding China's NIS that are woven into the technology innovation framework of Chapter Two. In keeping with the research strategy outlined in Chapter One, in this and the following two chapters we will glean themes and factors of importance for innovation arising from these discussions to place within the Table 2.1 matrix. In Chapter Six, we will begin with the completed table to make arguments about which factors would most affect innovation propensity and how we might measure them.

In this chapter, we will focus principally on the two right-hand columns, Subnational and National Authorities. Although later chapters will certainly reflect back to the matrix cells we now discuss (and vice versa), doing so will provide a systematic approach for convenient presentation.

Institutions

The formal **structural organization** of institutions and the relationships among them is one of the more straightforward among innovation's important themes.

- Regional governments in China consist of provinces, prefectures, counties, and then either towns or villages in descending order of hierarchy. Parallel to each is the corresponding CCP organization. These, too, contain structures of significance for innovation. In addition to the governing bodies themselves, they maintain **agencies and organizations**, such as regional business promotion and support organizations, that have a role in fostering (or retarding) innovation. Further, regional governments may be formal **stakeholders** in regional level enterprises, especially SOEs, but also less formally in local POEs.
- At the national level, there is again the dual structure of governmental and party organs topped by the governmental **Council of Ministers** and the CCP **Central Committee**. Here, too, are to be found many organizations devoted to the study, promotion, and fostering of innovation. Many specific functions—funding, R&D, priority targeting—are specific items addressed in other rows of the Table 2.1 structure.

[18] The CCPCC issued the Opinions on Deepening the Reform of the Institutional Mechanism for Talent Development (in Chinese) (Central Committee of the Communist Party of China, 2016).

Beyond the formal organization of innovation institutions are the **policies** that govern them. Further, policies may be de jure or de facto. This makes this aspect of institutional framework more complicated than that of formal organization and structure.

- The case studies discussed in the next chapter, as well as others in the literature, point up the importance of the regional dimension of policy. While major policy initiatives may not be the remit of local governments and party structures in China, this level is responsible for translating such policies into actions. What comes out most strongly is how the pressure to achieve admirable results meeting national leadership's expectations has the effect of creating **competition among regions**. This, in turn, translates into local policy actions, both formal and informal, that affect innovation: what sectors are favored, who has access to resources, which firms gain favor over others. It is of considerable importance to determine whether competition for favor on the part of regions looking toward the national level, or on the part of firms seeking the benefits that result from being favored by local authorities, engenders innovation in the sense envisioned by Schumpeter's creative destruction or is instead a different type of competition potentially detrimental to innovation.
- The primacy of the CCP and its unitary nature means that the venue for policy formulation, including that affecting innovation, comes at the national level. There are three main avenues for action. First is the central **allocation of resources**, which is closely related to the enunciation of **priorities**. How much is to be spent and where are primary decisions left to the senior leadership in China. The extent to which R&D funding is directed to sectors most closely identified with the PLA, or public health, or informatics is heavily affected by choice at this level. To be sure, increasingly as China grows more prosperous there are alternative, private avenues for spurring and supporting innovation. But even if we put to one side the difficult question of what "private" might actually mean for firms in China, central authority decisions will affect such firm- or laboratory-level considerations. Even in the era of reform, the central authorities still find recourse to the mounting of **campaigns**, large-scale efforts of indirect mobilization seeking to influence those decisions not directly under their purview.[19] This could be viewed as a different manifestation of an "indicative" planning approach such as that developed in France in the decades immediately following World War II.[20] The primacy of the party in China, however, so vastly exceeds the authority of any other national organization as to make its "suggestions" and messaging as part of national campaigns a forceful consideration in local decisions.

If it had not been clear before, the experience of decades of policies and investments implemented in lesser developed countries as well as the results of introducing market pricing

[19] In addition to the current campaign promoting Xi Jinping Thought, other notable campaigns from China's past include the Great Leap Forward and the Hundred Flowers Movement. Similar campaigns from the Soviet past included Khrushchev's Virgin Lands and Gorbachev's Anti-Alcohol campaigns. These were all large-scale, headline campaigns but the same style was applied at less consequential scales as well. They differed in the extent to which they were accompanied by or even focused on direct government actions and initiatives, but all contained some degree of social mobilization as well.

[20] Indicative, as opposed to directive or command planning, sets targets or goals to serve as objectives over a period but does not actually produce plans for individual production or supply decisions. Rather, the idea is that sharing a general direction or vision will in itself serve a coordinating function in an economy and reduce a degree of uncertainty in making those decisions.

in the former Soviet-type economies shows that in addition to the formal institutions around which economic life is structured there are also **informal institutions** that may profoundly affect outcomes. Policies that have worked elsewhere and would appear to be well conceived to operate within the formal institutions of a different economy may fall well short of their prior success in that new setting.

- Anecdotal information suggests that it may be at the regional level that informal structure, interests, and tacit norms operate most strongly. Regional leaders need to be seen as faithfully implementing the directives emanating from national agencies but must also reconcile them, and their own perceived standing, with facts on the ground. The regional actors, especially in wealthy, dynamic regions such as Shanghai and Shenzen, have considerable resources at their disposal for affecting a range of outcomes. They therefore exert considerable **influence**, including the potential for enjoying **graft** from companies operating in their sphere. It is also the regional authorities who may enjoy considerable informal sway in determining how **staffing of agencies** designed to support innovation endeavors may come about, perhaps contrary to a strictly meritocratic process operating according to formal criteria for evaluation and placement.
- The national level also has its share of informal structure determined by a series of **power relations** among individuals, the **role of the PLA** and its interests not only as recipient of goods and services but as producer of those goods and services as well, and the clash of **ideology and intraparty debate**. Clearly, these issues play out in every society, not just China's. They would be worth examining in any innovation-leading nation to truly understand prospects and the potential course for future innovation. But among none of these countries is there as strong a role for a unitary group of actors at the top as there is in China.

Innovation Processes

We categorize as "**R&D**" all generation of knowledge useful for innovation. This may range from interrogating nature as part of formal research activities to collaborating directly or indirectly with others in network-mediated generation of new ideas derived from existing knowledge.

- In China, as elsewhere, both regional and national governments may establish organizations to serve as venues for knowledge creation such as **universities** and publicly supported **laboratories** and research organizations. Inheriting the Soviet model of universities providing education and the Academy of Sciences and ministerial institutes carrying principal responsibility for fundamental research, in the Chinese structure it is still the case that universities have not yet come to play the role that they have in many innovating regions in the West and other parts of Asia.
- The national government maintains its own systems of **universities** and **national R&D assets** such as design bureaus, laboratories, and other organizations. In addition, R&D based on its procurement and priorities may generate **spin-offs** to other sectors and private firms. Through a similar process called **spin-on**, government procurement can give a boost to innovations developed outside its own system but adapted to meet government-set priorities. This is important in the national defense value chain. Finally, and most important, the national government is still a substantial **provider of R&D funding** in China. As in the United States in which state R&D funding was also formerly dominant,

private sector R&D spending is now preponderant.[21] Yet, funding by the state carries the potential for disproportionate influence on the direction of China's R&D.

Invention is the act of bringing new knowledge, or a reconceptualization or combination of existing knowledge, into realization in a novel application. It is the essence of what is usually thought of when the word "innovation" is used. Yet, it is a process in itself, distinct from the knowledge creation or assessment of usefulness through adoption that taken together yield innovation.

- A hallmark of regional level invention in China is the proliferation of **S&T "parks"** as well as innovation **incubators and accelerators**. These are variations on the theme of providing space, equipment, and resources to early stage inventors. Supporting services such as business consultation and other elements of the ecosystem of innovation support may be colocated in such spaces. China is not alone in this practice and, as in other countries, the results have been profound in some cases, decidedly mixed in others. These initiatives are largely the province of regional authorities.
- National authorities can allocate resources directly but can also exert a strong indirect **demand-pull** influence over the directions of innovation through procurement decisions and the issuance of tenders. The history of innovation has also seen periodic recourse to **prizes and other direct incentives** for meeting specific milestones through new inventions. The rewards for high patent activity granted by China's government outside market returns may be seen as a variation of this classic policy. Of course, the largest role for any nation seeking to boost rates and effects of innovation is through the setting of **IPR regulations** and their enforcement.

The final step in the chain leading to innovation is the actual application of an invention and its subsequent **diffusion**. The iPhone and the Newton were both Apple inventions. One diffused widely through adoption by purchasers while the other failed to do so.

- Some of the more frequent stories told of regional authorities in China is their desire not only to gain early identification but also engage in active **promotion of potential winning firms and innovations**. This may prove an advantage in some cases but is also a double-edged sword. Undue influence too early in the growth cycle of a sector may affect its trajectory in ways that stifle innovation. There is also the risk of picking wrong and perhaps causing indirect damage to initiatives that might otherwise have proven capable of success.
- The national level may engage in a variety of indirect **export promotion** activities. Even more indirectly, it is responsible for **visa and access policy** between China and the world. Policies governing degrees of access influence the extent that exposure to demonstration effects and other channels of knowledge enhancement come into play.

Innovation Precursors

After considering the structures supporting innovation and the processes involved, we turn now to review the active ingredients from which innovation is derived. These are the life-blood precursors of funding, incentives, and skill. Although issues of **funding** do not often appear

[21] Of total R&D spending of RMB 1.76 trillion ($254 billion) in 2018, businesses—including foreign-owned corporations—spent RMB 1.36 trillion ($196.4 billion) according to official Chinese statistics (Normile, 2018).

at the forefront in narratives about innovation in China, on the margins this can determine which innovation teams are able to bring their vision to realization.

- The Chinese state, both nationally and regionally, is involved in early stage funding of private enterprises. A frequent model is for the state to provide **initial venture capital (VC)** and for the enterprise to transition away from state-owned status to private status when judged capable of existing independently. This more than raises the question of what it means to be a "privately owned" enterprise in China, particularly as the equity structure of the resulting firm may make the actual trail of ownership far from clear (Balding and Donald, 2019).[22]
- National authorities may also play the role that would be typically be performed by VCs and other **early stage funders** elsewhere. But the national government does much more. One of its programs is to **fund state key laboratories** (国家重点实验室) in both the public and private sectors. Such key laboratories are designated by field and the funding covers both research and administrative support.

The second major group of precursors to innovation are not only key to determining true innovation propensity but also quite difficult to quantify: What affects the **incentives** for innovative behavior and renders conditions for implementation conducive?

- One of the classic principal-agent relationships[23] in China is that between the national and lower-level authorities. Localities carry out the will of the center but have interests of their own. They have an incentive to be seen conforming and gaining **national leadership approval**, but their interpretation of how best to carry out the priorities and policies of the center may be influenced by a variety of incentives. Leaving aside issues of bribery and corruption, there is still a great interest to ensure that their region has a comprehensive basis for success in those areas that might not receive priority attention but nonetheless are a *sine qua non* for being viewed as efficient managers by both the state authorities and the local population. This provides them with a strong incentive to utilize influence and resources to **bet on winning firms**, **innovation teams, and sectors** to show results. Chapter Four will demonstrate this effect in the case of innovation in pharmaceuticals.
- At the national level, one of the still uncharted areas is how individuals and society will react to **new measures of social control** being put in place.[24] To date, this appears to be accepted by Chinese citizens as presented, namely, to fight crime as well as to provide adequate warning of those acting in an antisocial manner such as manufacturers who adulterate food supplies. Although a potential entrée to enhanced control over expression

22 In the case of ICT giant Huawei, 1 percent of shares are owned by the firm's founder and 99 percent by the workers' union. However, a court case has made clear that the latter only applies to profit-participation apportionment and has no influence on corporate governance (Balding and Donald, 2019). Further, the shares are held in common by the union with no claim on the resulting income stream or ownership by individual union worker-members. Of course, it must also be borne in mind that in China unions are not independent. They are social organs answerable to the state and the party.

23 In economics and political science, this refers to a relationship in which one actor (the agent) acts on the behalf or at the direction of a responsible authority (the principal) but without perfect information on either side. The agent may act, either knowingly or inadvertently, in a manner not entirely consistent with the intent of the principal while the latter lacks sufficient information to detect the disparity.

24 A leading example is the government's social credit scoring system (社会信用体系) first announced in 2014 (State Council of PRC, 2014).

Table 3.1
Identification of Important Factors for Innovation Related to Local and National Authorities

Theme	Innovation Factors	Firms and "Laboratories"	Markets	Networks	Local Authorities	National Authorities
Institutions	Structure				- Regional govt. agencies - Stake in local POEs	- Agency responsibility - Central committee - Council of Ministers
	Policy				- Results vs. other regions	- Priority setting - Campaigns - Resource allocation
	Informal				- Influence, graft - Staffing of agencies	- Power relationships - Role of PLA - Role of ideology and debate
Process	R&D				- Regional govt. "laboratories" - Universities	- Spin-off and spin-on R&D - National R&D assets - Budgeting R&D support - Universities
	Invention				- "Parks," incubators, accelerators	- Prizes, incentives - Patenting regulations - Demand-pull
	Diffusion				- Selective winner promotion	- Export promotion - Visa and access policy
Precursors	Funding				- Region as VC, bank	- State as VC, bank - Natl. key lab designation
	Incentive				- Natl. leadership approval - Bet on "winning" firms, sectors to show results	- Consequence of social control
	Skills				- Teaching, training	- Teaching, training - Skill preferences

of political thoughts antithetical to CCP interests, many Chinese view this as not necessarily impinging on the type of technical conversations that surround innovation. But both perception and reality may change over time with possible effects on the types of messaging that exists on the frontiers of innovation. A climate in which individuals find the need to second-guess may have an effect on that margin.

The area of **skills**, education, and human capital formation is one of the most studied and measured aspects of innovation. Many of the standard measures of innovative potential revolve around output measures of advanced degrees per thousand population, number of annual STEM graduates, and so forth. When it comes, however, to innovative *propensity*, these raw measures of output and enumeration of cadres do not give us as full a picture as we might wish.

- Local authorities play a significant role in **teaching and training** skills through educational and occupational organizations of various types. This is true on the national level as well. In the latter case, they can engage in various instruments from funding through to admission requirements pitched toward educational organizations to focus on building skills for which these authorities have indicated a **preference**—chemical engineers, for example, over archaeologists.

The discussion of this chapter may be summarized at this point in Table 3.1. In the next chapter, we shift focus from the larger, macroscale environment for innovation in China to the sectoral level with three case studies. These will also yield some insight into the firm and innovation team and market and network venues in Table 2.1.

CHAPTER FOUR

Gleaning from Case Studies of Sectoral Innovation

In the prior chapter, we examined the general literature on R&D management and innovation policy in China and began populating the framing matrix presented in Chapter Two. The approach could be described as top down. In this chapter, we continue to flesh out the matrix from a bottom-up perspective.

Because of our topic's enormous scope, we selected three cases for examining the environment surrounding innovation in specific technology or industry segments. Fuller exposition on the two first case studies may be found in the appendices to this report. The intention was not to write comprehensive examinations but rather to understand what we could gather from existing sources about innovation, its precursors, and systemic enablers. In this chapter, we review the major themes that emerged from these selected case studies. Such studies should be combined with the more quantitative approaches touched on in the next chapter to answer the questions we have raised previously. This holds particularly true if we are to detect signs of an alternative system for innovation emerging from China's distinctiveness—or instead find a more or less consistent application of the generally accepted empirical model albeit confronting different types of impediments distinctive to China's situation. The distinction will have bearing on assessing China's innovation propensity.

We selected two main fields for study. AI has been given extraordinarily high priority in China by leadership at both the national and regional levels. It is viewed as a core technology with application in many fields going forward: health, transportation, finance, trade, and myriad fields of manufacture. It is, in addition, a technological field that has received considerable emphasis in the realm of security and defense, and not only in China. It is therefore potentially a crucial example of how innovation occurs and is planned for in a sector that has received near-unique policy attention.

Pharmaceuticals, on the other hand, is an industry that while specifically mentioned in key policy documents on the development of S&T in China, does not carry the same relative importance for government plans. It is key to affecting health outcomes in China as well as potentially moving up the value chain in export fields of major significance. The industry has been called to attention for both reasons. But our conjecture was that this might provide a case for examining how innovation operates in an arena of clear importance not yet receiving the same level of attention or special assistance, both formal and informal, that would pertain in the nascent AI field. For reasons stated in the prior chapter, lacking high-level priority in China may affect both innovation activities and outcomes.

We also include a briefer vignette that is not in itself a full case study. Therefore, it is reported in full in this chapter. Teams located in China were among the leading innovators in the field of DLTs ("blockchain"). Yet, this early lead was not sustained. We examine why this may have proven to be so.

Each of the sections below provides the leading findings of the two cases presented in full in the appendices and the blockchain vignette. After presenting the three, we then highlight those aspects that help fill in the cells of the Table 2.1 framework.

Artificial Intelligence: Driving to the Future's Leading Edge

AI is a set of technologies that may revolutionize economic and political systems globally. China is rapidly developing and deploying these technologies and has the ambition to become a global leader in AI by 2030 (State Council of PRC, 2017). Understanding the current state of AI is difficult not only due to the rapid pace of change, but also because the most meaningful current applications in the business world are rather mundane and lead to incremental improvements in operations. The field is still far from being fully realized.

Several aspects of the AI innovation system are critical for the future of AI in China: policy, data availability, algorithm development, talent and skill, organizational culture, and business ecosystem. Also, attention to exports and international competitiveness measures whether Chinese firms effectively use AI to gain and expand their foreign market share.

Initially, China's national policy documents focused on big data and the IOT, while AI was mentioned in passing along with other technologies of interest. The policy focus shifted in mid-2010s, driven by AI technological developments and high-profile events such as Deep Mind's defeat of Go champion Lee Sedol in 2015, rapid advancements in human language recognition and autonomous driving, as well as national security and defense considerations. In 2017, China's State Council issued the "New Generation AI Development Plan," which put AI at the front of China's technological ambitions. The plan set ambitious goals to grow the core AI industry to 150 billion RMB, the related industries to 1 trillion RMB by 2020, and become a world leader by 2030. China's AI policy is an integral part of a larger network of industrial innovation policies, such as the FYPs, Made in China 2025, and Internet Plus. The focus on industry is notable and explains why most of the specific policy measures and progress benchmarks are directed at the enterprise level. Some observers believe that focus on application is a strength of the Chinese policy (Lee, 2018), whereas others note that the relative lack of attention devoted to fundamental research may limit China's long-term ability to benefit from the AI revolution (Hao, 2019). On a practical level, national-level government policy facilitates the supply of capital to firms and research organizations and incentivizes local governments to follow suit. At the same time, the overarching nature of AI as well as the resources involved may have hampered policy coordination and even caused bureaucratic infighting between different national agencies (the National Development and Reform Commission [NDRC], Ministry of Industry and Information Technology [MIIT], Ministry of Science and Technology [MOST], etc.) that aspire to play a dominant role in setting and implementing AI policies (Ding, 2018b).

Local governments followed suit by setting their own ambitious goals; combined local-government targets significantly exceed the national goal. Local-level AI policies are often integrated with the industrial strengths of the region. For example, Guandong focuses on smart manufacturing and robotics, whereas Fujian focuses more on the IOT and big data. As expected, the most affluent municipalities, such as Shanghai, set the most ambitious targets and marshaled multibillion-dollar financing vehicles to spur the development and deployment of AI. Local governments compete in attracting firms and talent by offering generous financial incentives, government procurement contracts, and access to data. The most ambitious aim to create innovation clusters around several big firms and research organizations (e.g., Zhongguancun in Beijing, Lingang in Shanghai). Policy-setting does not stop at the province/city level but trickles down to city districts and even individual firms, which seem to be adopting company-wide AI policies at a higher rate than their foreign counterparts according to a recent survey (Loucks et al., 2019).

Data and algorithms are the two fundamental parts of the AI technology itself. China benefits from large amounts of data that can be used to train algorithms, generate predictions, and evaluate algorithm performance. A recent report analyzed the availability of data along five different dimensions—quantity, depth, quality, diversity, and access—and found that China is very well positioned in terms of quantity, depth, and access to data while lagging in quality and diversity (Sheehan, 2019b). As expected, the strengths resulted from the sheer number of people living in China, high internet usage, and government policies that allow for access of data from public spaces through smart-city projects. The weaknesses resulted from the relative ethnic homogeneity of the Chinese population (albeit somewhat mitigated by diversity in terms of income and lifestyles) as well as disadvantages in terms of data quality due to underinvestment in enterprise software and digitization of data. Overall, this means that Chinese companies that can access and effectively use the available data will have the upper hand in the Chinese market. However, the insights learned from data on the relatively homogenous domestic population may be less useful for creating products and services targeted at foreign audiences. To address this issue, China is actively promoting the internationalization of its internet giants by incorporating digital elements in its Belt and Road Initiative and developing infrastructure for smart cities, including surveillance and policing applications. Alibaba was the first Chinese company to implement its extensive “City Brain” service (Alibaba Cloud, undated) in Kuala Lumpur, which gives it access to real-time traffic data to train its AI algorithms (Beall, 2018). The Chinese government facilitates data sharing between government and private firms as well as among private firms through specialized data exchanges. Private firms employ staff to manually label huge amounts of data that are later used to train algorithms.

Algorithmic sophistication may be another matter as algorithm development and advanced hardware remain China’s weak spots (CISTP, 2018). The latter remains a significant bottleneck in China’s AI development, especially in light of the escalating tensions with the United States that threaten to curtail access to advanced chips from that source.

China has many qualified AI researchers and engineers. Estimates range from 50,000 based on an analysis of LinkedIn profiles (LinkedIn, 2017) to over 200,000 (CISTP, 2018). Only a small fraction (5.9 percent) work for private firms. Assessing talent quality is difficult. One way is to look at the distribution of researchers who coauthor reports at leading conferences. Chinese-born researchers coauthored over a quarter of upper-tier reports at the Conference on Neural Information Processing Systems—one of the most prestigious conferences in the AI field. At the same time, all the Chinese-born researchers who coauthored reports selected for oral presentations were affiliated with U.S.-based organizations. Even within the upper tier of Chinese researchers, the majority went to U.S. graduate schools and were affiliated with U.S. organizations, whereas only a third were affiliated with organizations in China (Sheehan, 2019a). This suggests that China has the necessary human capital for raising top-level AI talent, but is not yet able to match the educational and working opportunities of the United States. The government addresses this shortage by offering material and professional incentives, but the effect has been mixed. To ensure long-term talent supply, the Chinese Ministry of Education approved a new AI-focused major that was adopted by dozens of colleges and universities.

The ability to combine policy incentives, data, algorithms, and human capital effectively in the service of innovation also depends on organizational and structural aspects both at the level of individual firms and the wider business ecosystem. Anecdotal evidence from the largest Chinese firms suggests that companies' internal structure and corporate practices may be a drag on the efficient use of data. A well-known essay on Tencent's strategy and operations notes that the company has not been able to take advantage of its enormous data resources because its customer data are scattered across different departments that do not share (Li, 2018a).[1] The report attributes this failure to organizational structure, underinvestment in algorithm research, and redundant processes. This is unsurprising: large firms like Baidu may have as many as 14 levels of individual contributors and ten levels of management (Zhi Hu Forum, 2015). In addition, China's censorship demands place a heavy burden on internet companies to police their own content, which not only increases the direct cost of business, but, more important, incentivizes additional levels of supervision and more hierarchical enterprise structure, at least in firms that produce and disseminate digital content.

The fiercely competitive environment for domestic market share pushes China's private firms to focus on quick rollout of underdeveloped products, thus emphasizing marketing and sales at the expense of technological innovation. The upside is that companies became agile at rolling out new products and then tweaking them in response to consumer feedback. This leads to a heavier tilt toward product development and engineering at the expense of research. Prominent AI venture capitalist and researcher, Lee Kai-Fu, argues that the field is in the "age of implementation" in which the ability to capture economic rents and create better algorithms will be determined by data availability rather than sophisticated algorithm research by top-level engineers and computer scientists. In other words, even if one starts with suboptimal algorithms but possess plentiful data, these algorithms can be improved to match and exceed those with superior original design. "Once computing power and engineering talent reach a certain threshold, the quantity of data becomes decisive in determining the overall power of the algorithms" (Lee, 2018). On the other hand, the past suggests that fundamental change in technology does play a crucial role in innovation and that companies relying solely on incremental improvements and customer feedback could not maintain a competitive edge over the long run (Christensen, 1997).

China's AI business ecosystem has been dominated by internet giants due to market forces that tend to favor economies of scale and network effects, as well as government policies that place a strong emphasis on the creation of "national champions." The first group of national champions included Baidu (autonomous driving), Alibaba (smart cities), Tencent (medical imaging), iFlytek (intelligent voice), and Sensetime (intelligent vision).[2] The government is also experimenting with a number of platforms such as All-Nation Artificial Intelligence Venture Capital Service Alliance (全国人工智能创业投资服务联盟) meant to increase the technological and financial linkages between the different elements of the innovation system. The large private internet companies take the lead in determining the most promising technologies and applications and jointly set technological standards while fiercely competing. The delineation of "national champions" resembles the development of business networks in other Asian countries, but China's AI model seems to be more fluid. Innovations occur at multiple nodes

[1] For an excellent English language summary, see *ChinaAI Newsletter* (Ding, 2018c).

[2] The current group of national champions has been expanded to 15 (Chin, 2019).

of the network, and the leading companies actively compete while contending with start-ups (Greeven, Yip, and Wei, 2019).

The international competitiveness of Chinese firms is another indicator of their ability to effectively use AI. Chinese internet giants seem to focus their efforts on developing markets, another of Schumpeter's five categories of innovation beyond creation of new products and processes.[3] India is a case in point. By 2018, Chinese digital apps were dominating the android applications market by holding five spots out of the top-ten most popular apps in Google Playstore and 44 spots in the top 100. Bytedance's TikTok short videos app holds the top spot in the domestic Indian market (Shaikh, 2019b). Notably, Chinese media giants found their strong suit in localization by focusing on Indian users that prefer local-language, user-generated content. They also tend to localize their teams and form partnerships with local music and media companies that allow them to quickly develop and implement new products that are tailored to local consumers.

Business-to-government and government-to-government segments are developing and have received foreign attention over concerns about large-scale surveillance and civil-military cooperation in China, as well as China's export of these technologies abroad.[4] Within the civilian domain, Chinese companies are currently exporting AI-powered technologies for smart cities (O'Rourke and Choy, 2019). Government-to-government exports include national security projects abroad, such as in Venezuela and Ecuador, both of which featured facial recognition technologies. To date, 18 countries, including Pakistan, Kenya, UAE, and Uzbekistan, received Chinese intelligent monitoring systems (Ramirez et al., 2019).

Despite notable successes, China faces important challenges in becoming a leading innovator in AI. Although government policy emphasizes technology adoption and "scientific development," it is yet unclear to what extent its political system will become an impediment to successful technology adoption. The Chinese Academy of Sciences developed an AI-powered system to monitor and evaluate public servants in China. The system, called "Zero Trust," was built to detect suspicious activity both at the personal level and at the project level. During a limited trial in 30 counties, it identified over 8,000 government employees engaged in misconduct. In response, some local governments decommissioned the system to "avoid large-scale resistance among bureaucrats" who "may not feel comfortable with the new technology" (Chen, 2019). Although not a basis for far-ranging conclusions, "Zero Trust" illustrates how entrenched interest groups within Chinese bureaucracy may stall the deployment of technologies that affect their power and interests. In addition, China is currently facing difficulties in mastering advanced technologies in semiconductors, which may become an obstacle in its AI development. China has been able to purchase the necessary technology from abroad, but recent U.S. government actions against ZTE and Huawei and, in the longer term, the Commerce Department's plans to put export controls on some AI-related technologies including semiconductors show that unfettered access to foreign technology may not be given (Department of Commerce, 2018). Finally, while the shortage of top-level talent and potential resistance to technology adoption are not significantly affecting the development of AI in the short term, they may become more important in the long run.

[3] See discussion in Chapter Two.

[4] For an overview of the PLA's use of AI, see Kania, 2019a.

Pharmaceuticals: Regional Interests and Industry Structure

Although Tencent, Alibaba, and Lenovo have become global powerhouses in communications, media, and IT, China lacks an equivalent in the development and marketing of new drugs and other medicinal products.[5] China's aim is to shift its pharmaceutical industry up the value chain to become an industry based on innovation rather than low-value, low-quality production. However, it has not yet become a major innovator in pharmaceutical development (Ni et al., 2017). Chinese pharmaceuticals have not reached an innovation capacity for developing new drugs and the quality of its generics industry has yet to meet international standards broadly. Both will require higher market concentration, stronger industry standards, and a government and regulatory environment that encourages private investment in the pharmaceutical industry.

After decades of industrial policy to develop an innovative pharmaceutical sector, the industry in China is heavily fragmented, leading to significant quality shortcomings. This market fragmentation has meant that China predominantly exports upstream active pharmaceutical ingredients (APIs) and has largely failed to break out of low-value production. Strengthening the domestic pharmaceutical industry by increasing market concentration would enhance export capabilities.

Among the cases we examined, that of pharmaceuticals shows the influence of the regional layer of governance most forcefully. Local governments are often competing and pulling industrial policy in different directions. The contradiction between greater reliance on market mechanisms with necessarily more firm-level decisionmaking and the retained primacy of the CCP has never been fully elucidated or resolved in the post-Mao era. Frequently, the local level of government is left to work out the actual implementation of the broad directives coming from the central organs. This leads to uncertainty on the part of firms as well as the local governments. Though now a bit dated, Breznitz and Murphree, 2011, present a compelling picture of decisionmaking at a local level left not only to interpret what might be the true measures for success in the minds of their superiors but also appropriate tools for active engagement with the firms and industries under their purview. In the case of pharmaceuticals, this appears to have led to two conflicting outcomes.

In the first case, pharmaceutical firms are to be found across all regions and administrative levels in China. There is no significant concentration, no equivalent of Shenzhen in electronics or Shanghai in IT when it comes to this industry. Being designated as an industry of interest to the national authorities, regional leaders wish to make certain that they have a hand in this market. Compared with other developing countries, the variable of government support has arguably been one of the more notable factors governing pharmaceutical and biotechnology development in China. However, the return on these investments is mixed. That is due in part to the long lead times required for innovation in the pharmaceutical industry. Drug research itself tends to be a lengthy process, added to which are the periods required for clinical trials. Even then, success is far from guaranteed.

This suggests the second conflicting outcome. Given a choice, the local authorities would prefer to assign preference and resources to industries in which returns might be more quickly forthcoming. The government has committed to increased pharmaceutical R&D funding to stimulate the industry. But the result of the two conflicting local interests means that most

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[5] The case study from which this section derives was performed in early 2019, before any changes that may have been instituted as a result of the COVID-19 pandemic that first appeared late in that year in the city of Wuhan.

existing pharmaceutical producers and laboratories are of small scale. SEZs and knowledge clusters have helped create a certain degree of knowledge and skill diffusion, especially among the contract research organization (CRO) segment. But small firms are problematic for China's stated high-innovation strategy because their scale prevents them from establishing sufficient profits to fund major R&D investments in a sector notorious for the high cost of its investigations. Yet, there is a potential circularity in this argument: Does innovation lag because the firms are small or is it the case that firms are small because innovation lags? Almarin Phillips suggested a mechanism by which industry structure is the result of the competitive learning process rather than a necessary precursor to innovative activity (Phillips, 1971). If so, it is an occasion to once again raise consideration of the institutional realities of the Chinese system before blindly applying this apparently general finding. One may "compete" successfully in China not necessarily through passing the market test or in more effective development or learning of technique but may also do so in gaining priority and preference from regional authorities. Hence, there exists a potentially self-sustaining trap for the pharmaceutical industry, at least under the circumstances that presently persist in China.

Although China is the second-largest global drug market by total revenue, spending on R&D for innovative products is low by international standards. There are no Chinese companies among the ten largest generic pharmaceutical companies in the world (Pharmaceutical Technology, 2019). Furthermore, R&D varies significantly by region, with most of it concentrated in eastern coastal cities and provinces. This might be due to the role played by foreign firms in China who tend to be localized in those regions. About half of all inventions in the realm of biotechnology, which partially overlaps with pharmaceutical development and production, are owned by foreign partners (Zhang, Cooke, and Wu, 2011). China derives very little of its pharmaceutical export revenue from truly innovative products (Huang, 2015).

Private investment in R&D is increasing. Although there are signs of growing VC activity, returns on R&D investment for Chinese companies are currently too low to support an innovative pharmaceutical industry. In yet another conflict that needs somehow to be reconciled between local and national governments, raising these returns risks tension with China's other efforts to control drug costs. Further, China is still developing its IP laws. Although it is moving in the direction of strengthening IPR, it remains to be seen how highly local pharmaceutical entrepreneurs are likely to weigh the protections they would seem to afford. Patent battles would need to play through the courts and it may not be the case that firms would care to hazard their chances or willingly bear the cost of such litigation. Corruption is reportedly rife throughout the health care system (Hvistendahl, 2013).

All this notwithstanding, there are indications of the presence of innovation networks in pharmaceuticals with some firms gradually beginning to show dominance. This may again be as much due to political and governmental favor as any other proximate cause. One example is the Jiangzhong Pharmaceutical Group Co. (江中制药), one of the largest traditional Chinese medicine (TCM) pharmaceutical firms selling over-the-counter products in China. It has adopted a strategy similar to other Chinese pharmaceutical enterprises by leveraging Chinese government subsidies and state-backed investment vehicles to develop. It is a subsidiary of China Resources Pharmaceutical Holdings Company Limited (CR Pharma)—one of China's largest pharmaceutical companies.[6] When CR Pharma bought Jiangzhong Pharma

6 CR Pharmaceutical, undated.

in 2018, it was one of China's largest mergers and acquisitions (South China Morning Post, 2018). The company has built an array of public–private partnerships with Chinese medical universities and private health care groups. It has funded and built China's largest TCM university, for example (Liu and Li, 2013). Its "China National Engineering Research Center for Protein and Drug Technology" (中国蛋白质药物技术国家工程研究中心) received financial support from major national projects, including being designed as a "national key laboratory," which affords it special status for preferential government loans and research grants (Liu and Li, 2013).[7] Jiangzhong and CR Pharma are involved in several health care equity funds that leverage state backing to invest in small and medium enterprise (SME) pharmaceutical firms in China (South China Morning Post, 2017). Such tight networks involving the national and local governments, state-backed equity funds, universities, and private industry are growing more common.

Blockchain Technology: Where Did Everybody Go?

Blockchain or DLTs represent an unusual field of innovation given that the key "blueprints" for DLT were made publicly available without licensing fees in 2008 and 2013 (Buterin, 2013; Nakamoto, 2008). DLT innovation represents a case for which China possessed early advantages and was, indeed, an early mover. By 2016, blockchain technologies received direct acknowledgment in China's 13th FYP, referenced as one of several technologies that were supportive of "informatization" and with the potential to reverse declining domestic and global economic growth prospects (China State Council, 2016). However, the fact that much of this innovation potential failed to be realized in fact illustrates one way in which systemic innovation propensity may affect innovation outcomes. Policy and political considerations worked to limit and stifle innovation in this realm. Some of this resistance stemmed from reasons similar to those causing other governments' anxiety, but some decisions and policies stemmed from circumstances peculiar to China.

China Takes a Lead in Blockchain Technology—for a While

The underlying technology concept reports (Bitcoin and Ethereum for DLT and Smart Contracts, respectively) were made publicly available, free to download, and in the case of Ethereum, intentionally malleable for users to experiment with to develop their own applications. With IP freely available, the demand for blockchain innovation was driven by market conditions and the hunt for applications beyond the largely speculative markets for cryptographic monies ("cryptocurrency"). Cryptocurrency was essential to the functioning of the first publicly utilized blockchains since currency availability incentivized early blockchain adoption even if those currencies were not easily convertible into U.S. dollars or other globally recognized ready cash. Validation in these public blockchains is a computationally and energy intensive process (Hileman and Rauchs, 2017).

Cryptocurrency demand drove early experimentation with efficient cryptocurrency "miners"—computers dedicated solely to calculating correct solutions to cryptographic "hashes" (exceedingly difficult-to-decipher strings of code). Much of the early effort was located

[7] China had roughly 220 national key laboratories as of 2018, and the central government planned to increase to 700 by 2020 (Xinhua, 2018a).

in China. Economic policy holdovers from the prereform era led certain regions in China to operate at below global-average electricity pricing. A study of energy subsidies from the first few years of China's cryptocurrency mining suggests that pricing was subsidized from 6 to as much as 35 percent below market rates (Liu and Li, 2011). The comparative advantage was utilized lawfully and sometimes unlawfully to generate revenue for privately operated mining teams ("nodes") (Franco, 2015).

China had inadvertently subsidized the world's largest blockchain market for miners, node developers, and graphics processing unit (GPU) and application-specific integrated circuit manufacturing. As a logical consequence of being "the mint" or the dominant money supply issuer for leading cryptocurrencies, agglomeration within China's blockchain industry, currency exchanges establishment, miner and processer heat exchanger improvements, and leading-edge blockchain programming occurred almost in lockstep with the growing global popularity of nonfiat currencies (e.g., Bitcoin, Ethereum, Litecoin).[8] By 2016, leading venture capitalists and financial technology start-up specialists were predicting that China would be a dominating world leader in DLT and would also supply the innovation necessary to "leapfrog" traditional finance used by Western banks (Shin, 2016).

DLT Intellectual Property Holdings

Despite China's initial advantages in DLT leading to a network of supporting manufacturing and a first-mover advantage in block mining for public blockchains, its firms have not dominated international blockchain patents. China's financial and regulatory institutions have responded to developments in DLT with a mix of concern and measures aimed at fulfilling preexisting social stability goals. These responses have disincentivized financial blockchain development, encouraged some of the China's blockchain programming talent to emigrate toward more welcoming regulatory environments in Japan and elsewhere, and cast doubt over China's commitment to foster blockchain development despite paying lip service to, and funding, blockchain R&D. Table 4.1 provides an overview of the world's major blockchain IP holders. China's reform-era approach of identifying and supporting national champions (龙头) for industry representation seems consistent with existing patent data in that it harbors a single dominant holder of blockchain patents, Alibaba Group. China does have other blockchain innovators (Beijing Tiande Technology Company [北京天德科技有限公司], China Unicom, and Wuhan Phoenix Blockchain Technology [武汉凤凰区块链技术], among others), but these firms only have a fraction of patent holdings compared with Alibaba. Collectively, China's blockchain IP is notable in global terms but far from the market dominating position some had expected it to possess given its initial advantages.

The number of cumulative patents alone does not speak to the quality of the technology nor the extent to which the DLT innovations have been adopted by the nascent industry. These totals are one piece of a more complex picture of China's blockchain IP holdings—in some years, it has led all other nations in generating or filing DLT-related patents (Sugiura, 2018). However, nation-specific filings may be less reliable than firm-specific totals since many non-Chinese firms like nChain Holdings and Mastercard simultaneously file blockchain patents with their home country and with China to avoid "first-to-file" risks that are specific to China's

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[8] The value of a fiat currency largely derives from the value that a governmental authority ascribes to it and so derives from the trust placed in that authority: It is money because some government says that it is and that government retains the trust of those who will accept this currency in exchange for goods.

Table 4.1
Global Top-Ten Blockchain IP Owners by Firm: 2010–2018

Company[a]	Nation(s)	Primary Industry	Firm-Filed WIPO Patents
nChain Holdings Ltd.	European Union	Blockchain programming	295
IBM Corp.	USA	Software/hardware	142
Alibaba Group	China	e-commerce	112
Mastercard Inc.	USA	Finance credit	77
Walmart	USA	Consumer retail	62
Visa	USA	Finance credit	43
Coinplug Inc.	Korea	Blockchain programming	27
Siemens	European Union	Industrial manufacturing	26
Microsoft	USA	Software	24
British Telecom	European Union	Telecom/ICT	22

NOTE: Patent data obtained from World Intellectual Property Organization (WIPO, undated).
[a] Company names and patent totals included same-named holding groups and limited liability companies.

domestic IP laws. The data hint at the industries in which DLT applications have been identified and suggests that China—unlike the United States and the European Union—has not led in diversification of applications outside e-commerce. There may have been some innovative applications of DLT to China's distinctive food supply-chain management problems to ensure veracity in meat and vegetable sourcing (Lim, 2018), but these represent enterprise adaptation and not necessarily fundamental innovation. Even in this narrow application, major innovation is driven instead by non-Chinese firms such as IBM and Walmart.

China's Blockchain Anxiety

China's regulatory response to the 2008 introduction of DLT reflects dual enduring commitments to tightly control IT and to manage foreign currency and capital controls to fulfill state planning objectives. The collision of a DLT framework—near-total decentralization of communication and governance, democratic resolution of blockchain governance, immutability of transactions and notes, vigorous protection of speech or notes made onto a blockchain—with a system seeking to endorse the primacy of single-party governance saw regulators attempting to reconcile two contradictory systems with one another. The regulatory anxiety over the emergent technology falls into the following two main areas:

- **Compromising central bank controls:** The State Administration for Foreign Exchange (SAFE or 国家外汇管理局) tightly regulates currency movements with a goal of moderating capital flight. It set approval thresholds of $50,000 USD or RMB 300,000 per person per year with higher thresholds for firms (U.S. Department of Commerce's International Trade Administration, 2017). These capital account measures could be circumvented through cryptocurrencies. At Bitcoin's peak price in 2017 (Higgins, 2017), it would only require three bitcoin-for-dollar transactions to exceed the then-current limit on reviewable foreign currency exfiltration. Because these transactions could be generated with some degree of anonymity from RMB to Bitcoin and then into a global reserve currency like USD, the exchange can occur without any state oversight, eschewing traditional brick-and-mortar market makers, and leaving no report trail beyond what is encoded into the blockchain.

- **Circumventing the People's Republic of China (PRC)'s "Great Firewall":** Public blockchains, distinct from private or permissioned blockchains, are considered unhackable and immutable to censorship. Unlike the immediate concern of capital controls, for which China could already take stock of an existing market, the issue of censor-resilient information remains largely speculative and includes concerns regarding public protest and unsanctioned political organization facilitated and financed via a public blockchain.

DLT and PRC Currency Regulation

In response to growing concerns over unregulated capital flight through China's three dominant cryptocurrency exchanges, BTCC, OKCoin, and Huobi, in 2017, the People's Bank of China (PBOC) issued a circular requiring the exchanges to comply with a 2013 policy issuance that classifies virtual currencies as nontender (People's Bank of China, 2017). RMB could be used to buy any virtual good, but a virtual good cannot be used as tender to buy RMB, euros, USD, etc. This ruling jeopardized the fundamental revenue model for an exchange market that operates on principles of international arbitrage. China's block miners would be left with nonconvertible monies for their computational efforts, leaving little incentive for the domestic industry. Subsequent PBOC working reports did little to send encouraging regulatory signals to international or domestic audiences that the country was a stable investment ecosystem. One such 2018 report dismissed the capacity for blockchain to provide decentralized governance—and perhaps provided a theoretical requirement for central government validation of users and blocks—stating that public blockchains "often need to introduce a trusted central mechanism outside the blockchain to assist" (Xu and Zou, 2018). PBOC and SAFE opposition to the currency-related aspects of blockchains on the stated grounds of principled money supply management may also be partially informed by an ulterior motive: to eliminate currency competitor programs from the domestic market before introduction of a yet-to-be-named officially accepted PRC cryptocurrency, sometime in the future (Jia, 2019).

At almost the same time as the exchange bans, Japan, a regional competitor in DLT and cryptocurrency exchanges, moved in the opposite direction (Hamilton, 2018). Japan did not go so far as to raise cryptocurrencies to serve as legal tender, but it did give them de facto endorsement as suitable payment for goods or as a currency substitute. By the end of 2017, Japan had authorized 11 of these exchanges. The move helped incentivize use and payment acceptance by Japan's three largest banks; MUFJ, Mizuho, and SMBC. China's 2017 regulatory response sent the Chinese nationals acting as its exchange operators, along with their associated capital and expertise, overseas. Japan, South Korea, Singapore, and Hong Kong became the direct beneficiaries (Zerohedge, 2017). Although it is important to consider that cryptocurrencies remain but one realm for applied DLT, China's near-reflexive policy reaction to ban the profitable application of the technology due to concerns over financial stability and the immaturity of domestic financial markets would seem to severely curtail the chance that domestic financial markets using DLT will receive the chance to mature.

The PRC's leading financial organs have expressed an interest in further developing DLT-enabled financial instruments (Bloomberg News, 2018), but it remains to be seen from where the programming and managerial labor force will be derived following the initial treatment of China's 88 shuttered exchanges. Two years after the exchange ban, China's largest exchanges remain functional, with offices in the mainland, but with operational staff and commerce conducted outside the borders. In the single year following the 2017 PBOC regulation, RMB trading in Bitcoin shifted from 90 percent of the global volume to less than 1 percent (Scott, 2018). Chinese citizens have reportedly found successful alternative means of peer-to-peer transfer to still convert RMB into other currencies, but these mechanisms come with all the associated risks of utilizing unregulated financial instruments and incurring less favorable exchange rates. The high-profile nature of China's ongoing anticorruption campaign, and macroinstability in several other nations in 2017, may have also generated plausible cases for DLT to be viewed as a destabilizing technology that further biased China's regulatory response, as "capital controls, illegal activities and protection of its citizens from financial risk are some of the main reasons cited" in PRC policy guidance (Chew, 2018).

DLT and PRC Information Regulation

Conceptually, DLT may provide significant limits on censorship. Ledgers maintained on myriad computers and requiring cryptographic validation of any alterations present a significant barrier to a censor or hacker hoping to redact or alter information encoded on a blockchain. A censor might be able to publicly deny a DLT user from knowing about the ledger, but the ledger contents—images, speeches, and other documents—would remain immutable (Mattila, 2016).

In a notable case, a Beijing University student issued a 2018 open letter regarding a longstanding faculty harassment case (Hagen, 2018). Although the letter was quickly censored on social media, the full contents in English and Chinese were encoded on the Ethereum Blockchain, a cryptocurrency similar in nature to Bitcoin, for a onetime storage cost amounting to less than a dollar (Shen, 2018). The potential immutability of a public blockchain and traditional concerns over censorship seem to have generated at least some interest by Chinese state organs. Following the letter's posting on Ethereum and Western media coverage, an official PRC media regulator and censor, the National Radio and Television Administration (国家广播电视总局) Broadcasting Research Institute, posted several job openings in July of that same year inviting applicants with dual English-Chinese language abilities, understanding of blockchain technologies, IOT devices, and an "ability to extract relevant data from the user's viewing log" (NRTA, 2018). Although employment of blockchain-literate analysts is not an explicit evidence of a connection, the National Radio and Television Administration's interest in blockchain and its mandate to regulate short-form and long-form media content suggest that its censorship requirements may now include blockchain links, notes, and other forms of media embedded on blockchains.

As a threat to the effective management of state messaging, even the PLA has taken notice of the potential of DLT. It has warned that blockchains may complicate official and wartime messaging stating, "It is difficult for us to deal with the enemy by means of simple 'psychological intimidation,' 'confusing' and 'information fraud'" (Yu and Qi, 2018). The expansion of web-enabled blockchain readers or application programming interfaces (APIs) such as *Block-Explorer* that are accessible to laypersons and can be used without any requirement to own specialized tokens or currency means that citizens with network access may consume uncensored media or news sources that provide an alternative to state-sanctioned outlets. DLT alone does not alter basic internet or mobile accessibility requirements necessary to read and edit blockchains. But the existence of DLT, combined with some of the free speech and protest use cases to date, causes China to investigate its potential for public disruption.

Application of DLT within China's political system is not impossible. Alibaba Group's aggressive innovation in the field of e-commerce points to the capacity for DLT to be applied to permissioned (not public) blockchains intended to enhance data security between IOT devices. However, China's tendency to favor an industry domestic or global champion over a competitive domestic player may have generated a lack of diversity in China's blockchain industry. The European Union and the United States enjoy a larger number of blockchain innovators who compete directly to apply DLT (similar to the Visa and Mastercard competition in consumer credit) or are developing applications far afield from electronic payments (such as Walmart).

In addition, a bias toward protecting immature domestic financial markets to limit capital flight and corruption (but also conveniently coinciding with the CCP's desire to maintain sole political control including of the "commanding heights" of finance) directly limited or delayed experimentation in financial securities. It is ironic that a market opportunity for public blockchain adoption was created by an unintended consequence of command economy-era energy subsidies and then summarily eliminated due to residual command economy imperatives. For a nation that has struggled with means to cope with the "shadow banking" phenomenon, the off-balance-sheet investment of funds in unregulated wealth management of products (Zhang, Cheng, and Griffith, 2014), a ban on alternative means of financial investment may seem counterproductive. It is unclear to what extent the regulatory response by China hamstrung its blockchain dominance. Even after the 2017 regulatory response, blockchain technologies received direct mention by President Xi Jinping when he referenced innovative technologies that China should grasp or master (Xi, 2018). And some of China's leading blockchain proponents have attempted to rebut the negative aspects of blockchain's early association with cryptocurrencies, and the concerns over violation of capital controls, by arguing that blockchain and the transparency of embedded financial contracts may be a mechanism to fight corruption and aid financial regulators (Jianghong, 2018).

Presently, China does not lead the world in cumulative DLT patents despite having several initial advantages that conferred first-mover privileges to its industry. China's DLT talent base, including venture capitalists, blockchain solidity programmers, and financial technology experts, has been incentivized by its policy to look abroad for work, funding, and start-up opportunities. However strong these centrifugal forces are, China still has top-tier firms and organizations that can retain talent, can claim some blockchain IP within the rapidly developing industry, and enjoy growing state support for financial and commerce-focused blockchains governed by PBOC and SAFE. Perhaps like other technological fields, single-party domination of China's political economy represents a tax, but not a full barrier, to DLT innovation.

Factors in the Innovation Activity Framework

As in the prior chapter, we distill several of the recurring issues that arose from these case studies to further fill the Table 2.1 matrix of factors important for innovation in China. We proceed down the matrix rows concentrating on the left-most columns pertaining to individual innovating organizations and markets.

Institutions

- Referring once more to the theme of formal structure and organization, at the level of the individual firm or laboratory performer in China, is the firm an **SOE** or is it in the class of "privately" owned enterprises? Is the laboratory part of a nonindustrial **state entity**? To what extent is the structure designed to operate on principles of **hierarchic control** (as, indeed, almost all firms or laboratories are to some extent) versus being designed for autonomous decisionmaking cognizant of and responsive to market signals and technical opportunities?

- Assessing the structure of markets would include understanding the market **size**, the **industrial organization** of its supplier and recipient firms, and the degree to which **competition** exists with domestic or international rivals.

Considering policies as another element of a NIS:

- Firms are subject to policies that affect their degree of de facto **autonomy** in decisionmaking, both SOEs and POEs. These formal policies and informal guidelines may emanate from both local and national authorities. Further, the **size** of firms will most certainly be determined by their success in the market or in gaining favor and resources through hierarchic channels. But a policy seeking to affect size (perhaps biasing toward smaller firms to enhance competition or larger firms to create champions of innovation), all other things being equal, will certainly affect the nature of firms. Finally, firms possess their own degree of agency in China. Their own **strategy** for targeting their endeavors will affect innovation performance and goals. For example, do they seek to compete on export markets or are they focused on production for domestic customers?
- Markets, too, are extraordinarily sensitive to policy. One of the principal issues is the **enforceability of contracts** in courts of law. In China, courts are not a check on the power of the state but rather organs of state power. Policies may also affect **ease of entry** into a market. And the extent to which suppliers may become **horizontally or vertically integrated** is an outcome determined only in part by the cumulative outcome of market transactions; policy and regulation play a large role as well.

Institutions that exist de facto through commonly held practice and understandings, rather than de jure, also have the following bearing:

- **Management attitude toward risk bearing** at the firm or laboratory level is one such informal institution. This may well vary from setting to setting, enterprise to enterprise, based on a large set of prior learnings and local norms. It may govern how willing local decisionmakers are to put in place novel approaches for production or design. The entrepreneurial spirit that characterizes China today differentiates it from the nation governed by the norms current in the period of Mao's rule and bodes well for its prospects. How well do they encourage innovative activities on the margins and how much retraction may occur if managers detect a shift in the wind? Similarly, one of the hallmarks of management in highly innovative firms is its recognition and **support of innovating workers**. Another aspect of informal structure is the **organizational culture**.[9] Depending on how they are defined, these three elements are clearly related, but separating them into managerial perceptions of hazard, the nature of relations between managers and workers,

[9] As per Schein, 1990, "Culture is a pattern of shared basic assumptions, invented, discovered, or developed by a given group as it learns to cope with its problems of external adaptation and internal integration that has worked well enough to be considered valid, and, therefore, is to be taught to new members of the group as the correct way to perceive, think, and feel in relation to those problems." This is similar to the concept of "routines" in evolutionary economics (Nelson and Winter, 1982).

and the organization's conception of its role and mission permits several entry points for gathering and evaluating phenomena that may be of various degrees of observability.[10]

- China today operates within a marketized economy, as do the United States, France, and Japan. Yet, although market-clearing pricing and the interplay of supply and demand drive these markets, there is more than a passing **government interest in outcomes**. This has been observed most strongly in some of the missteps made in the financial sector where the government has interceded strongly (Yand, 2018), but there is also evidence of the government seeking to influence which firms turn out as winners in sensitive sectors of the real economy as well (Breznitz and Murphree, 2011).

Innovation Processes

Conducting R&D and developing other sources of knowledge.

- Within firms and laboratories, usable knowledge that can feed innovation comes from formal **R&D** activities, that is, specific activities intended to produce new understanding and information. But it is well understood that new knowledge can come from "learning by doing," learning by using and "**fixing**" on the line—the tuning of existing processes. Such opportunities for gaining knowledge arise from activities primarily intended to fulfill other purposes.
- Within the market, important knowledge for useful innovation may be obtained through **contract R&D**, paid for by a firm but conducted by an outside entity. Further, it is possible for firms to enter into early stage, **"precompetitive" joint R&D**. In the United States, prominent examples would include Sematech, the semiconductor design and manufacturing consortium in Austin, Texas, and the Clinton administration's Partnership for a New Generation of Vehicles within the automobile industry. This may be more difficult to broker in fields of technology more focused on software than manufacturing. A clear component to make any or all of these means for conducting firm-level R&D is some ability to define and protect **IPR**. Uncertainty of the ability to do so may call the value and viability of R&D as a strategic asset into question and thus diminish the drive for its production. This varies across fields, however. Not all innovations are protected through patents and other formal declarations of ownership. When fields move quickly or IPR is weakly defined, other expedients such as trade secrets or maintaining a lead are relied on more. In China, this may be a principal driver for gaining market share quickly at the expense of more finely tuned development of products and seeking vertical integration.

The next link in the chain for producing innovation is the actual act of invention, the first assembly of knowledge and technique that results in a manner that results in novelty.

- At the level of the team, inventions may have several characterizations. Is it a **general-purpose** invention, such as the steam engine, a **platform** on which many further inventions may be based, such as the internet? Sometimes inventions are typed as being either **evolutionary** extensions of what has gone before or **revolutionary** novelties that break the chain and supplant what has come before. Current advances in battery energy storage come as steady evolutionary changes whereas the development of the iPhone was entirely

[10] It is a joke with a large kernel of truth that in Silicon Valley, an innovating team is viewed with some suspicion by potential backers if its members have not already failed at least one time, preferably twice, before.

disruptive. As might be expected, the latter changes are both the rarer and the most difficult to carry out organizationally and financially—but may prove the most impactful.

- At the stage of invention, **IPR** once again rises as a major concern for how a market may develop. Markets serve the invention step by supporting **research partnerships and consortia**. Invention may also be brought about through the agency of **early stage VC**. They operate in tandem with networks to provide would-be inventors with **ecosystems of supporting** services.

The nature and pace of an invention's diffusion through successive adoptions (and often subsequent technical development) complete the full process of innovation.

- At the level of the firm, diffusion rarely is simply the case of plugging in some new apparatus and moving forward: each act of adoption may come to resemble in microcosm the steps in its original invention. Whether the innovation is of a **process or a product** may affect diffusion speed and penetration. Firms championing acceptance of their innovation may engage in **promotional activity** to disseminate awareness and reduce barriers; they may also benefit from **feedback** provided by initial users. The **role of internal champions** within an adopting organization often proves key and will, in turn, depend on incentives, perceptions of risk, adequacy of information, and other factors that arise from other cells in the Table 6.1 matrix.
- The market is the principal venue for diffusion. The circle of adoption and use widens through **sales and licensing** of innovative processes and products. **Entrepreneurship** comes most forcefully into play and is fostered by incentives and institutions that will elicit the necessary skills and allow them to flourish. Perhaps nothing has more characterized the change in China's system than the evolving role played by entrepreneurship and the conditions that allow it to flourish.

Innovation Precursors

Although the availability of funding for innovation in China may appear to be less of a constraint than in countries of smaller market size, slower growth, and less recourse to noncommercial funding sources, the form and source of funding may influence innovation.

- At the most basic level, firms and innovation teams can fund their activities from accumulating their **own resources**, **private-sector** funders, or the **state authorities**.
- Contractual relationships between funders and recipients of funds and the active search conducted by both sides occur in markets. VC is a broad term that we use to capture traditional early stage venture funding, angel investment, and private equity placement. Beyond domestic sources, **foreign direct investment** may fund innovation. Finally, if the innovation is occurring within firms, it may be funded either by issuing **shares of equity** (stocks) or by raising **debt** (bonds).

Incentives to innovate are ultimately the spark for all that may follow.

- Firms and organizations engaging in innovation are often treated as unitary actors with more focus placed on market interactions among them and between them and their customers. But they are complex organizations in themselves. They are hierarchies but also networks, miniature markets but also collections of different tribes, and so contain the full panoply of human organizational structures laid out by the political scientist David Ronfeldt, 1996.[11] So, a central issue is of **principal-agent** relations. This refers to the asymmetry of information and incentives that exists between owners, both formal and informal, of organizational assets and the agents they depend on to carry out tasks. Both asymmetries may affect translating innovative potential into actual propensity to innovate. To be sure, some aspects may be easier to quantify than others. Differential **returns to employees**, **management**, **and owners** will surely be part of the equation. But just as fundamental will be the issue of risk bearing and **risk sharing**. The agents who feel themselves most at risk and unable to share the burden with others in the organization will be the critical link on the path of innovation.

- We place in the market venue those considerations of the **balance between risk and return** that exist externally. In the controversy over China's role in the future of 5G network technology and operations, questions of firm independence and incentives have also arisen. It is not yet clear (nor need it necessarily be the same in all industries or technology sectors) how private firm managers conceive of the **tradeoff between bottom line** performance and other **needs that may be expressed by state or party organs**, either locally or nationally. This aspect of socialism with Chinese characteristics is still unfolding. The first principle enunciated in the usual list of 14 tenets of Xi Jinping thought is that the CCP should be assured of leadership over all forms of work in China (Noi, 2017).

The last row in the Table 2.1 matrix refers to the necessary skill input required for cutting-edge innovation.

- A modern workforce, especially one engaged in innovation activities, requires more than technical and cognitive skills. Even if not directly involved in innovation itself, the increasing sophistication of technical means even in routine production requires ever more and different skills from workers at all levels. Whether in China or in the OECD, there are perceived skills gaps especially in realms such as critical thinking, active listening, and complex problem-solving (ARM, 2019). For that reason, as in the case of AI discussed in this chapter, issues of **skill retention**, **development**, **and training** affect innovation in both the invention and diffusion processes.
- In the labor markets, the focus is on the skills that workers embody. If innovation in both science and technology flourishes when new ideas are brought into contact with conventional production and design activities (Uzzi et al., 2013), then measures of market **mobility** become important as first-order proxies for the **diffusion** of skills. Market-mediated movement of individual workers and the skills they possess also proxies the potential for spillovers of knowledge that they also possess.

[11] Ronfeldt characterized the course of institutional development for human interaction as stemming from tribal relations, through hierarchies in their various forms from early hydraulic civilizations through to late monarchies, then the rise first of markets and then, somewhat presciently, networks that interlaced all the previous modalities.

Table 4.2
Identification of Important Factors for Innovation Related to Individual Firms/Laboratories and Markets

Theme	Innovation Factors	Firms and "Laboratories"	Markets	Networks	Local Authorities	National Authorities
Institutions	**Structure**	- Balance of market/ hierarchy - SOEs and POEs - State and private "laboratories"	- Market size - Industrial organization - State of competition			
	Policy	- Degree of autonomy (S/POE) - Big firm vs. small firm - Strategy: niche, target	- Enforceability of contracts - Barriers to entry - Horiz./vert. integration			
	Informal	- Mgmt. attitude toward risk - Support of innovating workers - Firm/laboratory culture	- Govt. interest in outcomes			
Process	**R&D**	- Formal R&D - "Fixing" on line, learning by doing	- Contract R&D - IPR protection - Precompetitive joint R&D			
	Invention	- General purpose; platform - Evolution vs. revolution - Drivers	- IPR protection - Research partnership, consortia - Early stage VC			
	Diffusion	- Process vs. product - Promo activity - Response to feedback - Role of internal "champions"	- Sales - Licensing - Role of entrepreneurship			
Precursors	**Funding**	- Own /private /state	- VC funding - Foreign DI - Stock market			
	Incentive	- Principal/agent issues - Returns to employee, mgmt. - Risk sharing	- Risk/return balance - Conflicts of profit vs. state goals			
	Skills	- Skill retention - Skill development, training - Skill acquisition and mix	- Mobility - Diffusion - Spillovers			

The considerations laid out in this listing, and the particularities raised in the cases discussed above, lead us to fill out the first two columns of the technology activity framework as shown in Table 4.2.

In the chapter that follows, we discuss how to determine issues of importance for innovation in China in the realm of networks and network interactions.

CHAPTER FIVE

Quantitative and Digital Evidence of Networks in China

Chapter Two presented general information on the importance of knowledge networks for both science and innovation to motivate their presence in the innovation activity framework of Table 2.1. In Chapters Three and Four, we provided information used to populate entries under the columns representing the individual firm/laboratory, market, local authority, and national authority venues within a regional or national innovation system. In this chapter, we return to the discussion of networks to complete populating the innovation activity framework. In Chapter Six, this framework will be the basis for the discussion of how to measure the most important elements included in the framework matrix and for the nomination of candidate indicators for China's innovation propensity.

The discussion of networks, however, presents significant challenges. They have come to prominence comparatively recently in the study of knowledge and innovation and by their nature leave only ephemeral footprints. Both the general literature on innovation networks and the specifics for China, while both subject of significant inquiry in recent years, are far from being as rich as that for the discussion of the other venues heading the matrix columns. Therefore, the discussion in this chapter has a somewhat different character from that which preceded it. Because of the importance of networks on one hand and the relative paucity and recent vintage of available information on the other, we have focused on the problems of measurement (anticipating the need to do so to carry forward the measurement discussion in the next chapter).

In this chapter, we take three excursions into different available quantitative and digital data sources to explore means for defining and quantifying proxies for measurement of the presence and effectiveness of networks. Prior discussion highlighted the importance of knowledge and innovation networks within China and their connection to global counterparts. The nature and health of innovation networks in a region may provide in itself a useful proxy for many interactions and activities that might otherwise be difficult to detect or measure, particularly for conduits of informal and tacit knowledge. At the same time, we note again the necessity to apply caution in the comparison of patterns observable in developed, liberal democratic societies to those observed in China. The methods in this chapter were selected as potentially shedding direct light on the nature of networks connecting China both within and without while perhaps also illuminating the role of networks in China as a distinctly different innovating nation.

We first present an analysis relying on access to bibliographic data. Research workers collaborate with both knowledge partners and industry partners. In China, collaboration with knowledge partners may occur on the local, national, and international scales while with industry partners the connections are more likely to be local (Lyu and Liefner, 2018). Bibliometric analysis is more likely to tell us about patterns within formal knowledge collaborations than in the industrial collaborations vital for innovation.

For addressing these innovation networks, we outline a more prospective methodology, this time relying on patents, and the information contained within their filings. The intent is to determine if this may bring us closer to a focus on industry collaboration and implicit industrial networks.

Finally, we report results of an experiment in mining the "gray" literature—blogs, online comments, newspapers, company documents, etc.—to determine the extent to which such information can form the basis, along with other metrics, of measuring the development, structure, and trajectories of innovation-supporting networks in China: What is being said within networks connecting innovation workers when they "speak" among themselves?

Bibliometric Analysis of China's Position in Networks of Science

This report concerns itself with technological innovation and not knowledge generation per se. Yet, the two are inextricably linked. The linear model most famously presented by Vannevar Bush (1945) of basic research feeding applied research that then yields technological development has long been displaced by a more interactive reading of the relationship between scientific and technological advances.[1] But the role of knowledge creation and use in innovation is indisputable. This is an important consideration for interpreting China's rise to prominence in both science and technology.

In contrast to the initial post–World War II experience with national growth, and then the pattern of development evinced by the Asian Tigers several decades later, China's rise has coincided with the growth of a global network in knowledge generation and dissemination operating over and above national-political systems (Wagner, 2008). As social theorist Karl Polanyi (1944) referred to the Great Transformation of social and political change that occurred with the rise of the market economy, Schot and Kanger (2018) conceptualize a second Deep Transition as one emerging with the rise of the knowledge economy. This transition is characterized as a rise of networks as social structuring forces—an organizational form described as a counterpoint to hierarchies and markets (Castells and Cardoso, 2006; Powell, 2003). The disruptive changes wrought by the rise of a knowledge-based economy favor growth of practice of science and technology and reliance on knowledge created in R&D activities. Both the knowledge economy and science and technology tend to self-organize into networks under emergent conditions also judged to be favorable to discovery.

The organizational imperative of networks influenced a shift in the scientific process from small, individual-investigator experimentation, to cooperative, collaborative, and team-based activities now dominating R&D. The shifts in knowledge connectivity are also influenced by exogenous political changes and globalization of industry and finance. Growing wealth worldwide has meant more countries than before are funding, conducting, and participating in R&D, which contributes in a virtuous cycle to additional opportunities for collaboration (OECD, 2018). Concomitant social changes in participating knowledge communities include a commitment to openness, transparency, and availability of large data to accelerate knowledge creation.

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1 See, for example, Layton (1977) for exposition of a more complex web of relationships between the two.

Many analyses of China have assumed a national approach to understand the implications of China's rise, comparing it to patterns observed elsewhere (e.g., the Asian Tigers). The arrival of a global network of collaboration is both contemporaneous and symbiotic with China's rise. It also establishes a system that creates for China a set of challenges to its national plans for S&T prominence. The global network has its own internal rules of participation (Wagner, 2008). It operates as a network as opposed to a national command-and-control hierarchy, which marked earlier incarnations of science systems. China (and other nations) join into a global system that embeds rules of openness and reciprocity as a condition of participation. Thus, the challenge for China is not simply that of establishing a competitive NIS as it was envisioned in the 20th century, but, as it seeks its place at the frontiers of science and technology, of adapting to rules at the global level. To the extent that China seeks to limit and control access to knowledge and to control connections among scholars, participation at the global level may be in contradiction to the nature of China's national vision.

This introduces a confluence of factors that may affect China's innovation propensity—and our ability to understand it. There is the increasing importance of networks confounded by the difficulty in observing them. Add to this the more organic relationship between scientific and technological knowledge, particularly in the flow of different categories of knowledge. Finally, there is the value that China has received from rapidly entering into global knowledge networks while perhaps facing increasing, domestically generated pressure to maintain some distance from them out of national and geopolitical considerations.

There will be no single, sufficient way of assessing or analyzing the components of this skein. This suggests a research strategy making use of what data are available and approaching from several angles. Before seeking to infer indirectly from patent data the presence of networks involved in the transfer of tacit, early stage technical information, we first look at formally codified knowledge generation and transfer in bibliometric data. (For greater detail and more information, please refer to Appendix C.)

Impact of China's Published Work

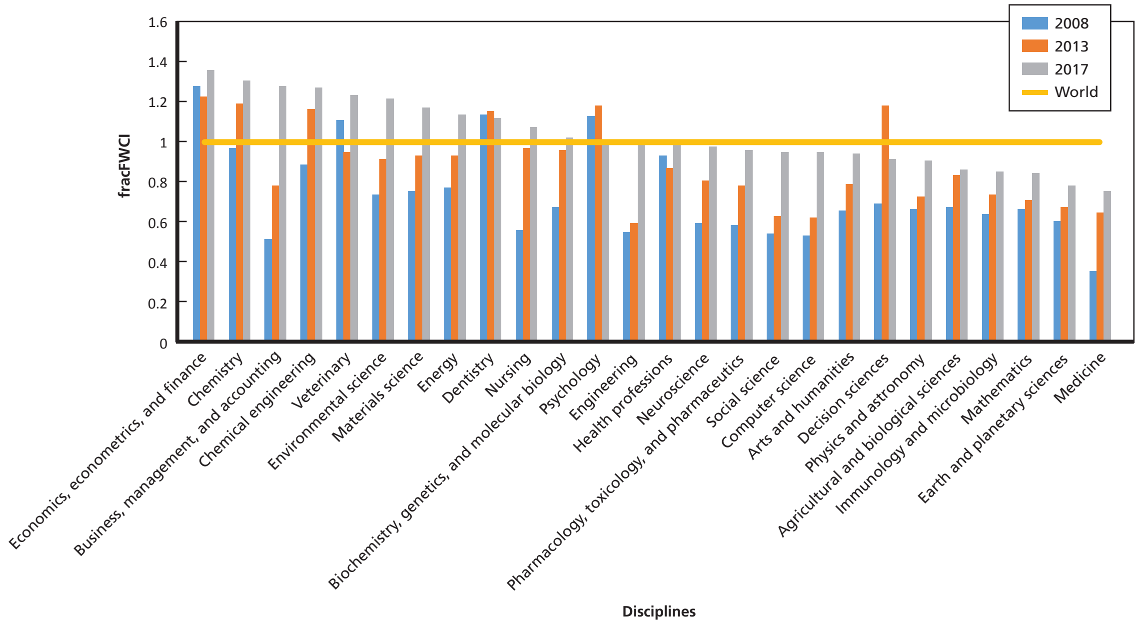
The U.S. National Science Foundation relies on the Scopus database to provide information on scientific publication trends. We drew from the same database for this study. Scopus indexes reports from a select set of high-impact journals chosen because they adhere to accepted standards of practice including rigorous peer review. Of the global total of reports registered in Scopus in 2017 (the last year for which we possessed full data), one-fifth were authored by Chinese scholars. Of this share, 22 percent were coauthored along with at least one foreign partner.[2]

Scholarly publication is one measure of capacity to create knowledge. A second is the willingness of other researchers to reference published work. Scopus measures "impact" by counting citations to other reports. Some may be cited thousands of times, but most are cited only a few times, if at all. We drew on these data to trace the impact of China's formalized knowledge output at the world level.[3]

[2] The foreign partner could be a Chinese national who worked overseas. The counts were made by address and country or record rather than the actual nationality of the coauthor.

[3] The citations we discuss could have come from either domestic or foreign reports; no effort has been made to distinguish between them.

Figure 5.1
Rate of Citations to China's Work Compared with World Average, by Discipline



SOURCE: Data from Scopus, 2008–2017.

Citations to papers from China do not correlate with the size of output by discipline but rather to growth.[4] There may be several reasons for the divergence between output and citation strength. One is that industry may well use the output of research without citing it. Engineering, materials science, and physics research may be put to practical use in production and manufacturing, and so have an effect, but not in academic citations. A second may be that the faster-growing fields are connecting more at the international level to draw on the latest work: international connections are more likely to result in citations.

At the discipline level, to allow an apples-to-apples comparison, citations are added up by discipline and then divided by the number of reports in a field to measure "field weighted citation impact" (FWCI), thus normalizing among fields by size and propensity of a discipline to use citations (since some disciplines use them more than others). Reports with more than one country in the author address lines are fractionalized by country so we can examine the share of the count that may be attributed to China (abbreviated as fracFWCI).

Figure 5.1 shows the fracFWCI for 26 disciplines for each of the three years studied. The highest citation impacts for Chinese output are in the disciplines of economics, chemistry, and business. The figure also includes a horizontal line indicating the world average citation level, again normalized by field. In 2017, China's total citation impact was above the world average in ten disciplines. In the other 16, China fell below the citation impact world average although it exhibited strong growth in impact in several.

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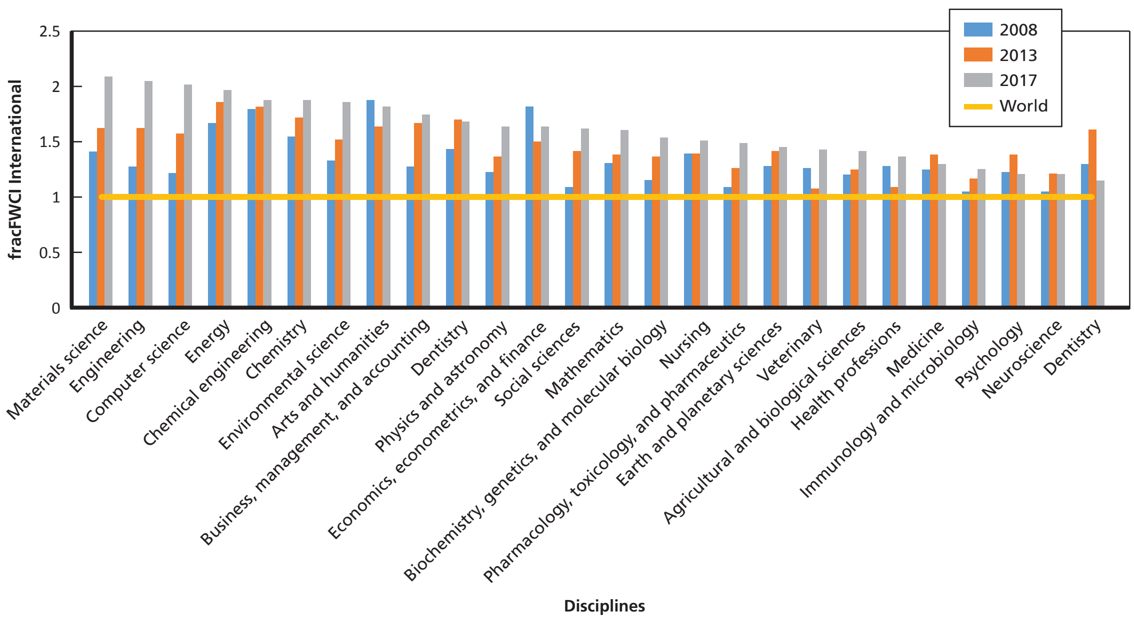
[4] Economics, dentistry, psychology, and veterinary science were growth areas in 2008 with higher citations than other fields. By 2017, citation impact was highest in growth areas of business, medicine, nursing, and then the largest field, engineering.

Figure 5.2
Rate of Citations to China's Internationally Coauthored Work Compared with World Average, by Discipline



SOURCE: Data from Scopus, 2008–2017.

We find a different pattern when we focus only on international coauthorships with at least one Chinese address. Figure 5.2 shows that in 2017, China's internationally collaborative impact was above the world average in every discipline. Growth in impact could be seen in most disciplines with the largest growth in computer science. Among the 26 disciplines, economics was the most internationalized, with more than 50 percent of output being coauthored with foreign partners.

There may be several reasons for this divergence of impact. For most countries, internationally coauthored papers are cited more than domestically published work. An attention effect may be at work because the authors each have an audience of others who may read and cite their work. A second reason is that international collaboration can be competitive and therefore more challenging than solely domestic publication—if only because it usually requires knowing a foreign language, thus limiting the pool of potential participants. A third reason may be that faster-growing fields, being somewhat "newer," may have begun with an international focus, producing work at a higher level of relevance to the global system.

Because China's students and researchers have gone abroad in large numbers to study and conduct research, they gained connections with foreign coauthors. The connections are part of a global network of linkages among researchers. The addresses of scholarly authors provide a way to visualize who is connected to whom. Mapping each of the links into a network gives an idea of China's knowledge exchange and information diffusion pathways.

We can peer more directly into the nature of these networks. Table 5.1 shows the network measures for China's participation at the international level over the decade studied.[5] We

[5] See Appendix C for fuller discussion. "Nodes" represent the sum of network members, whereas "degree" measures which members are more connected to others within a knowledge network. A higher degree is an advantage for staying on top of developments wherever they occur. "Density" shows the ability of any node to reach other actors in the network—often

Table 5.1
China's Network of International Collaborations

Year	Nodes	Average Degree	Average Weighted Degree	Network Diameter	Density	Average Clustering Coefficient	Average Path Length	k-Core Neighbors
2007	80	18.575	1037	2	.235	.799	1.765	38
2009	111	30.234	4342	3	.275	.704	1.761	60
2011	126	37.921	14389	3	.31	.714	1.706	86
2013	131	42.29	21745	2	.325	.876	1.675	
2015	163	66.798	28869	2	.412	.884	1.588	
2017	146	48.64	20041	2	.335	.851	1.665	

see steady growth of Chinese authors as participants in a network with scholars from other nations. In 2007, China had collaborations with 80 countries; the number of nations grew substantially over the decade to number 146 collaborating countries in 2017. (It is interesting to note that 2015 showed a stronger networked relationship than 2017; it is not clear why either this spike or subsequent drop occurred.) The average degree measures the structural cohesion of the network; this measure more than doubled over the decade suggesting that China played an increasing role in connecting nodes to one other. The average weighted degree measures the "reachability" of any node within the network: the measure shows that China and its collaborators were able to reach each other with just a few "handshakes," meaning China was increasingly connected. The average weighted degree suggests that the network within which China operates became much richer in connections over the decade. The network diameter and density were very low, perhaps an artifact of the data-collection process that limited the search to Chinese reports.

Table 5.1 also shows the average clustering coefficient. With a theoretical maximum of 1, this measure suggests that many of the parties are connected to each other multiple times with Chinese researchers participating in clusters of teams with collaborating countries. The k-core neighbors are those countries that are most intensively interconnected. The number of k-core neighbors rises rapidly as new nodes are added, suggesting that nodes are connected multiple times to other nodes in the network. China is connected in nearly the same pattern as the scientifically advanced countries of France, Japan, and Germany.[6]

In 2008, China's bilateral and multilateral linkages with the United States numbered more than 29,000 reports. By 2017, the number of cooperatively authored papers by someone from China with someone from the United States, according to the Web of Science,[7] num-

these connections are used to search for knowledge or identify new partners. "K-core relationships" show which players are more intensively connected to one another, suggesting the formation of a group or intensifying development activities.

6 The periphery of China's network is populated by many small countries often less developed in S&T. A review of some publications shows that these are multinational research projects in which China and developing countries work together, often under the leadership of an international organization such as the World Bank or United Nations.

7 Web of Science is a citation database drawing on multiple sources. See Clarivate Web of Science, undated.

bered 114,000. Materials science topped the list of coauthored reports in 2017, followed by electronics, electrical engineering, and chemistry.

These brief excursions suggest possible means for measuring at least some of the factors in the technology activity framework. China's rise as an important power in knowledge generation appears at least prima facie to have been coincident with increased density of global patterns of knowledge diffusion. Although other potential explanations have been discussed, formal knowledge production by Chinese authors as evidenced by scientific reports may have benefited qualitatively by an exchange with foreign-based colleagues (and vice versa).[8] Any pullback from this pattern for domestic or geopolitical concerns may come at a price. At a minimum, the bibliometric data might provide at least one of the sensors for changes that might also hint to systemic effects on innovative propensity. The change noted above between 2015 and 2017 could perhaps be just such a signal warranting greater attention and further inquiry.

Although this section focused on possible markers of knowledge networks derived from bibliometric data at the more formalized end of the knowledge-generation spectrum, in the next we explore a less traveled path. It presents a prospective method to elicit implicit networks through which flow the tacit, not-easily-codified, early stage knowledge that is a principal currency within technological innovation in industry.

Patent Applications Citations: Possible Marker for Implicit Innovation Networks

In the previous section, we applied bibliometric analysis to infer knowledge networks. These data are less applicable to understanding networks of the second type we have discussed, those within and among firms and industries. We now outline a prospective method for using patent data to probe for such networks by inferring them from data routinely included in patent statistics.[9]

Patent data have been used to identify the origins of useful technological innovation. They may also be used to determine priority of invention and so ascribe the first-use application of technology to new and important ends, by country. But they may be able to tell us something more.

When a patent application is filed in any country, the receiving office evaluates the patent claims to determine and classify the technical areas the inventor believes are related to his or her invention. Patents are awarded only to those inventions demonstrating useful application. This evaluation is performed by professionally trained technical specialists. Internal systems within patent offices constrain the examiners to behave in a predictable and regulated manner when categorizing technologies. To assist the patent examiner in finding the "best" relevant prior art to attack the claims of a patent application, the U.S. Patent and Trademark Office and patent offices around the world have developed highly detailed classification systems to categorize and characterize technologies. These systems have been around for more than 100 years and have functioned to categorize technologies in an indexable manner.

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8 Appendix C also provides some initial findings on collaborations between researchers in different cities within China.

9 This work draws on prior work performed by Richard Silberglitt and Christopher A. Eusebi. Published findings resulting from earlier explorations of this method include Eusebi and Silberglitt (2014) and Silberglitt (2019).

Although the definitions of technologies can vary by nation and have changed over time, recently these systems have been converging to a single system, the Cooperative Patent Classification (CPC) system.[10] Because the characterization of individual patents is performed with the objective of reducing the patent examiner's work in the future, there is incentive to perform initial categorization correctly. There are also mechanisms within the patent offices to correct misclassified patents and patent applications (Eusebi and Silberglitt, 2014).

The patent offices' formal categorization system has been used to classify tens of millions of technical documents. Classification is not merely a single technical descriptor of where to file any specific patent. It is also used to categorize the claimed areas of science and technology application provided in the document that have been recognized as valid by the patent examiners. To some degree, therefore, one may infer from such descriptors an implicit network of knowledge and art for which the innovators have provided evidence as being the proper reference and context for understanding the nature of the new art that they propose in the patent. In a sense, the connections between the art proposed and various areas of application represent a cognitive map of how innovators, and those with whom they interact, see their inventions being applied. Counting the interaction of these classifications in the patent system provides a representation of technologies' application and interaction over time.

The joining of patents in one technological area with those in other technological areas occurs as a function of time when a technology continues to diffuse into new, industrially important areas as shown in Figure 5.3. As cumulative patents in a technological area grow in number over time (the S-shaped curve), the network of associations with other areas of art and application accepted in patent claims grows denser (the spiral networks assayed at particular dates during the period of patent growth). Based on this effect, therefore, it may be possible to trace not only the cumulative growth of patents over time, as has been done heretofore, but to also infer the degree of industrial or application connectedness, that is, a network of knowledge and industrial relations, for different countries' patents.

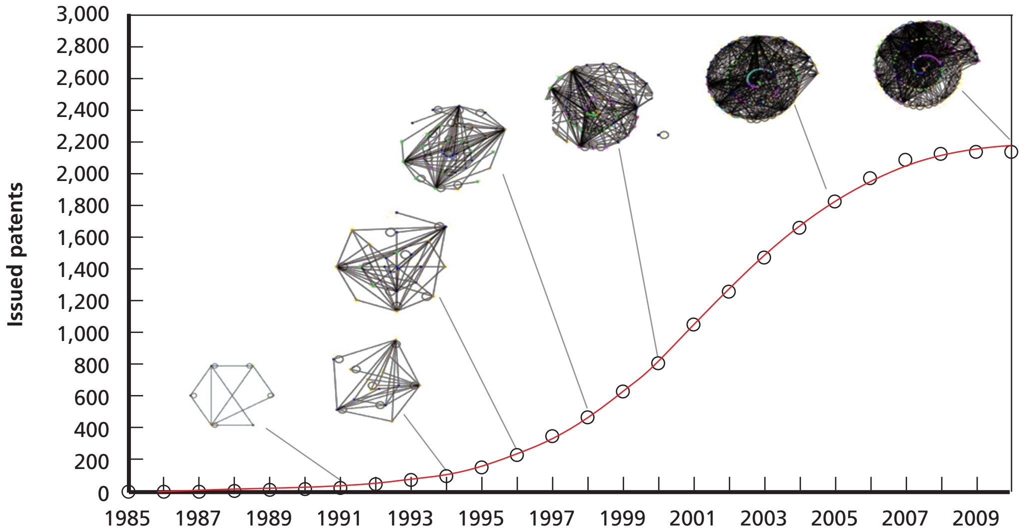
Although the technology networks for different countries (i.e., those comprising patents that were filed first in a country) share common general characteristics such as the technology areas represented, the detailed number of connections in the network between technology areas can differ and so may reflect differences between countries in how technological innovation occurs. The number of connections in the network between technology areas can be a measure of technological innovation. Specifically, inventors in different countries are often attempting to solve different problems based on the economic motivations in their specific environment. The number of connections in the network between technology areas can be a measure of the breadth of the conceptual framework within which their innovation has been conceived. And this, in turn, may allow us to infer the structure (density, heterogeneity, expanse, etc.) of the network in which they operate.

This reasoning has the potential for providing two assets in the search for measures of innovation propensity. The first is that mappings of this character potentially provide us with a quantifiable definition of innovation leadership and so address how to track and characterize China's global role in innovation. Searches through many different fields of technology as represented by patent data tend to reproduce patterns such as those represented in Figure 5.4.

The figure shows a pattern in which the United States filed the first patents in a particular field, in this case machine learning (CPC code: G06N 20/00, chosen to supplement the

[10] See Cooperative Patent Classification, undated.

Figure 5.3
Evolution of Inferred Network from Patent Interconnection as a Function of Patent Number over Time



NOTE: This figure was developed using a hierarchical method that clusters networks having the highest similarity in the tree structures of their class and subclass representations, as categorized by the patent examiners. More specifically, the clusters shown in the figure were defined using the Wakita-Tsurumi method in NodeXl. The "nautilus" spiral structures of the figure are artifacts of the display method and have no special significance.

SOURCE: Eusebi and Silberglitt, 2014.

discussion of AI in Chapter Four). The United States then builds on this art with additional patent filings. Only later do the first patents begin to be filed in China, after which China exhibits a steeper rise leading to near parity in numbers of filings as the field develops or, as in this case, China surpasses the United States in both patenting rate and total.[11] Mappings such as this may serve to provide an operational definition for innovation leadership in a technology field. In fact, the pattern of the United States demonstrating leadership according to this metric is reproduced across a remarkably wide number of fields.[12] Of course, this enumeration does not speak to the quality of the patents themselves or to the actual substance contained within them. That brings us to the second asset such mappings may convey.

One of the strengths of economies such as China's in which some of the appurtenances of command remain, owing to the primacy of the CCP and an ideology of innovation with

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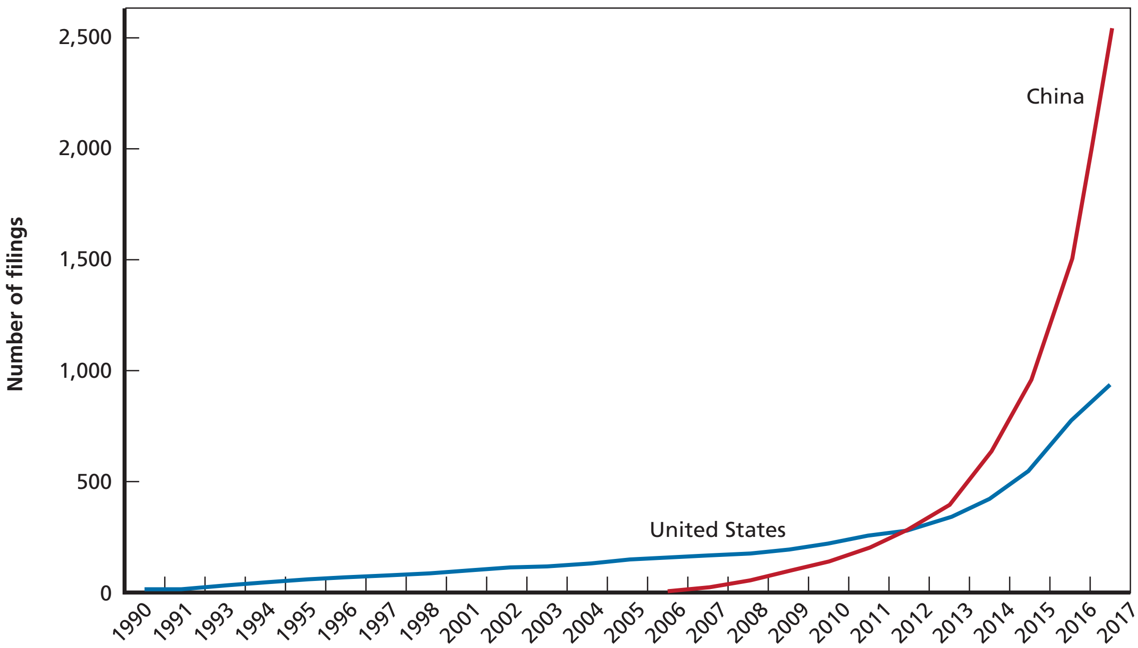
[11] The great increase in Chinese patenting inevitably raises the question of patent quality. There are several reasons to believe that China's numbers are not inflated unduly by "junk" patents. The World Intellectual Property Organization data show recent patent approval rates in China as being 30–40 percent, falling in the middle of approval rates across countries. Further, the rate of growth of patents granted to Chinese inventors in other countries was greater than that of domestic-only patents from 1995 to 2014. Chinese comparative performance is meaningful even if adjusted for population size and income level. And foreign citation of Chinese patents has shown considerable growth, even if again adjusting for the factors named above (Wei, Xie, and Zhang, 2016).

[12] Christopher A. Eusebi, personal communication, phone, September 27, 2019. Also supplemented by more detailed examination of early stage patenting yet to be published.

Figure 5.4
Cumulative Patent Filings in "Unsupervised Machine Learning," China and the United States, 1990–2017



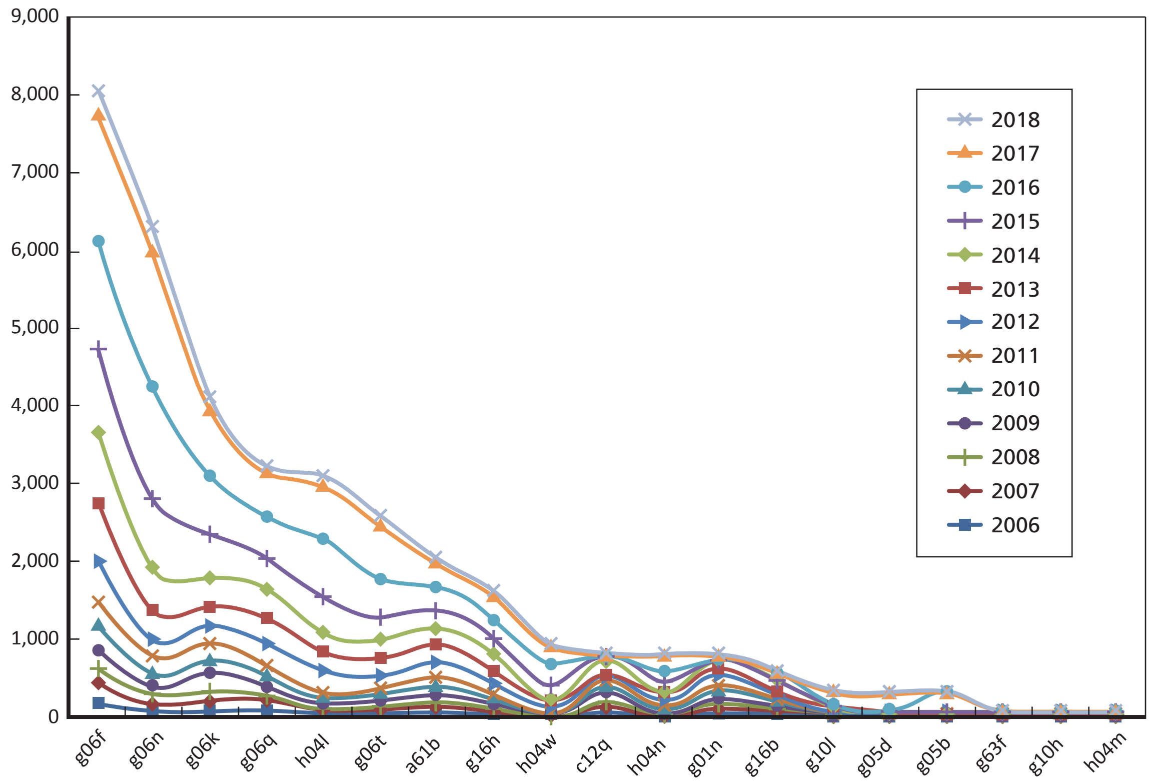
NOTE: Because there is an 18-month delay in publication of patent applications, 2017 is the last year with complete data.

Chinese characteristics in which government organs play potentially an important directive role, is that they can allocate resources swiftly to areas that have been granted priority. They are systems designed in such a way as to be quite effective in crash programs. (Effectiveness does not necessarily equate with efficiency, however.) To the extent that such helpful hints from government organs may indicate the thrust of a field's innovation and the purposes to which it may be put, the connections are likely to reflect those priorities. This may also result in a revealed map of industrial connectivity, such as the ones we have presented, that reflect less density in the connections to widely dispersed fields of potential application. To put it differently, technology networks of economies with more elements of command may change in line with governmental priorities while changes in such networks in countries with a greater role for market and network-intermediated transactions may be defined more by their expected economic incentives. The former may reveal patterns with fewer nodes and connections between those nodes than the latter. Indeed, one may see such patterns in many innovation areas.

Continuing with the example of machine learning, we see rapid growth in the cumulative number of filings in both countries, starting about 2014 for the United States and three or so years earlier for China. Since filing a patent application requires an investment in time and resources, the increasing number of machine learning filings is an indication that both countries regard this as an area of potential value.[13]

[13] The Chinese government has placed considerable weight on numbers of patents as an indicator of performance for firms and innovation teams. It has also made resources available, both money and legal assistance, for the filing of such patents. Thus, the incentives may differ between patent filers in the two countries, as may the quality of the issued patents.

Figure 5.5a
Cumulative Total References to Most Frequent Technical Areas Cited in U.S.-Origin "Unsupervised Machine Learning" Patents by Year, 2006–2018



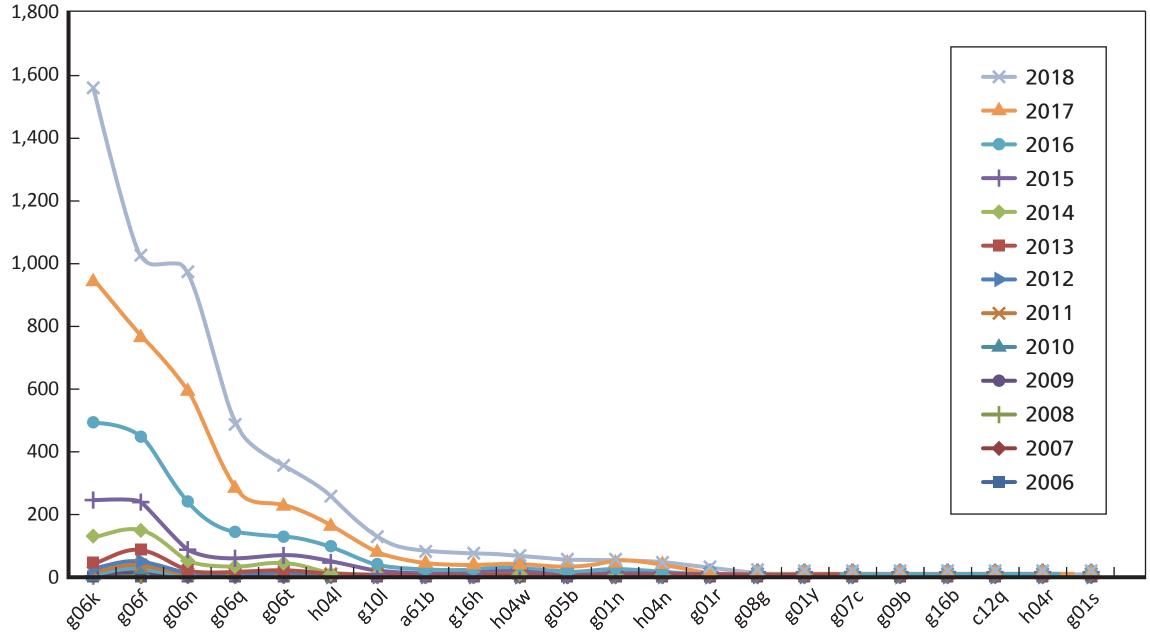
NOTE: The vertical axis shows the cumulative total of patent references as it existed at year's end, by year. The horizontal axis arrays from left to right the technology areas referenced most frequently in each country's population of patents by year-end 2018. The points along the horizontal axis use the technology area's three-digit level of classification within the CPC taxonomy.

The cumulative numbers of patent filings in the United States and China were roughly equal in 2012, but the application focus of the two countries differed.[14] In Figures 5.5a and b, we provide a representation of the connections that are inferred from patent filings in each country. It shows the cumulative total of technical areas referenced on the front page of machine learning patents granted by originating country for 2006–2018. Numbers of citations were aggregated by year and the highest areas of citation were arranged from left to right.

Even though the United States has been surpassed by China since 2012 in total patents granted (Figure 5.4), U.S.-originated patents show much broader dispersion across areas of application. By 2018, with only 40 percent of the number of China's filed patents, the United States still showed nine technical fields with 1,000 or more total references in its patents compared with two or three for China. Note that even though there are thousands of art areas listed in the CPC taxonomy, different specific applications may still fall into the same classification, hence large numbers for the most often-cited fields. This means that not only were

[14] For example, in the United States, 11 percent of patents were in the field of diagnostic and surgical applications (a61b) compared with 1 percent in China, while the relative share of applications for recognition of data and record carriers (g06k) was four times that of the United States and was by far the most frequently cited CPC application code. The most cited category for the United States was electrical digital data processing (g06f), a share matched by China.

Figure 5.5b
Cumulative Total References to Most Frequent Technical Areas Cited in China-Origin "Unsupervised Machine Learning" Patents by Year, 2006–2018



NOTE: The vertical axis shows the cumulative total of patent references as it existed at year's end, by year. The horizontal axis arrays from left to right the technology areas referenced most frequently in each country's population of patents by year-end 2018. The points along the horizontal axis use the technology area's three-digit level of classification within the CPC taxonomy. (The two central digits between the first and last letters in each group are read as a single number.)

there relatively fewer areas of art cited in Chinese machine learning patents compared with those from the United States, there were relatively fewer specific applications mentioned as well.

Figure 5.6 provides an aggregate view from all years, 2006–2018, on areas of claimed application for machine learning in patents from U.S. and Chinese filers.

Nearly 80 percent of Chinese patent filings in machine learning fall into only six technical classes, whereas the corresponding number for U.S. patents falls into nearly triple that number and cover many more areas of technical art overall. This could suggest that U.S. filers may be looking for new uses for this emerging technology, whereas Chinese filers focus on a narrow set of existing applications, or that the industry networks in the one case are of a different character than in the other. (The two explanations need not be mutually exclusive—indeed, they may be closely related.) The U.S. approach casts a broad net that may lead to innovative applications of machine learning that are outside the existing areas of the Chinese focus.[15] Further investigation may confirm that such characterization of the application focus of emerging technologies provides not only an indication of a country's interests, but also a window into its approach to technological innovation.[16]

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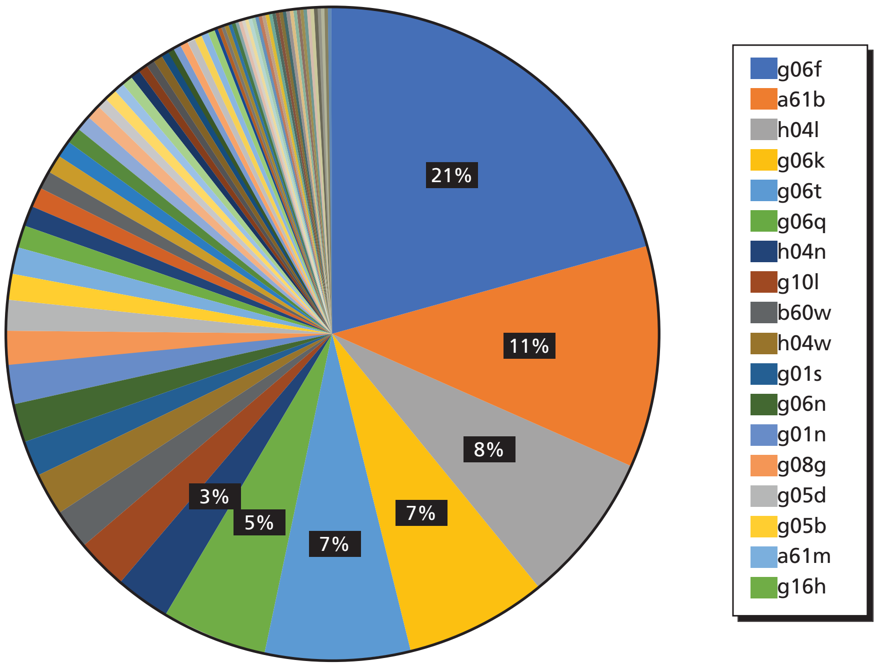
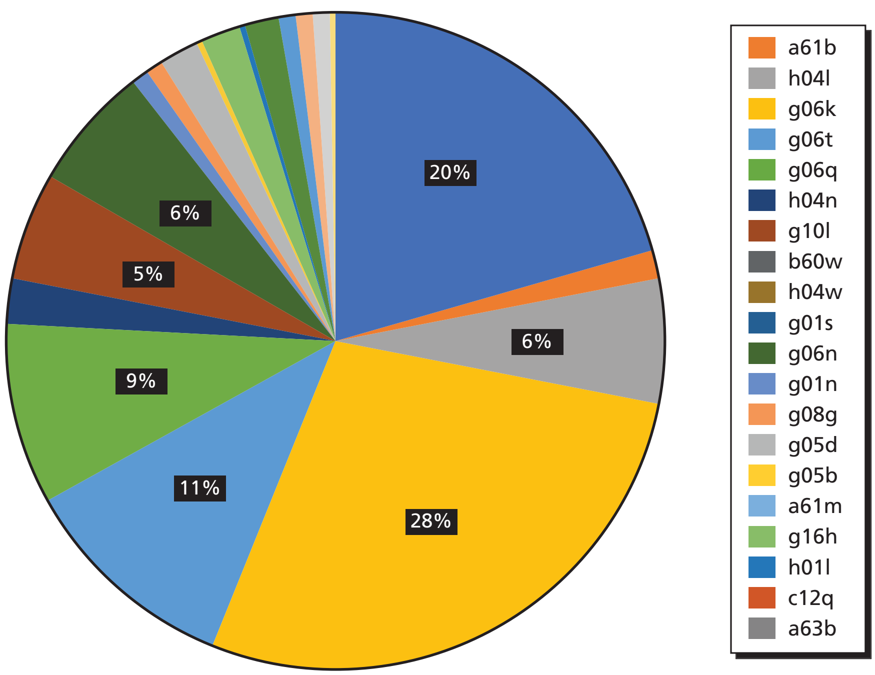
[15] Of course, which approach will yield greater value will depend not only on the breadth of focus but also on the quality of machine learning development and implementation in each country.

[16] The pattern shown in machine learning is actually atypical of most patent comparisons of this nature. More often, although China has entered a period of more rapid growth in filings after a late start, the larger number of total filings

Figure 5.6
Cumulative Dispersion of Technical Classes Cited in U.S. and Chinese Patents, 2006–2018





NOTE: Upper chart = the United States; lower chart = China. The legends on the left array the technology areas referenced most frequently in each country's total patents, 2006–2018. The slices in the pie charts show the three-digit level of classification within the CPC taxonomy. (The two central digits between the first and last letters in each group are read as a single number.)

Inasmuch as innovation networks are bidirectional, meaning innovation flows in both directions between nodes, the topography of the networks may be important in the pattern of innovation in economies. For example, in the United States, improvements in the areas of customer service delivery or diagnostic medical devices may inform and lead to innovative improvements in machine learning. The lesser diversity in the application of machine learning in China might temper the growth of innovation in this area. However, it is also possible that the focused dedication of resources into a limited number of technical areas may lead to faster development in areas such as machine learning.

The value of inquiries along these lines would require further evaluation. There most likely exist potential sources for error in analysis or interpretation to creep in. It has been assumed that the receiving patent offices are using the same methodologies to define the technologies within the applications. Therefore, one source of error in the formation of these bespoke country innovation network mappings may be in the way that the local patent office defines the technologies within a patent application.[17]

Such caveats aside, this investigation provides grounds for more detailed study of the patent literature coupled with other techniques to come to a fuller understanding of the nature and operation of Chinese domestic innovation networks.

Picking Up the Trail: Evidence of Networks in the Gray Literature

Bibliographic citations and patent filings are both formal codifications of knowledge transfer along networks. To explore the possibilities for gathering data arising within less formal conduits, we conducted an experiment in examining the types of information available in the gray literature.[18] Though time and resources were limited, we wished to test the concept that it might be possible to develop qualitative measures of important innovation-relevant phenomena otherwise difficult to quantify. In particular, we wished to see how it might be possible to infer the presence and nature of innovation networks in China.

Given the intense official scrutiny of online media in China, it was not at all clear how feasible or rewarding such a quest might be. Further, we employed no sophisticated search tools, pattern-recognition software, or intelligent automated analytical algorithms. On the other hand, the Soviet print media, long before the presently much broader digital means for communication were available, was scrubbed and scrutinized as much as is today's media in China. Nevertheless, much could be learned about innovation from looking diligently through

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remains with the United States. In addition to machine learning, 12 other unrelated patent areas exhibiting a similar pattern of a larger Chinese cumulative total were examined. These, too, yielded the same pattern of dramatically narrower reference to technical art (CPC) classes for applications. This reduces the likelihood that the phenomenon is an artifact of late catch up by Chinese inventors.

[17] It may be possible to determine if this is a problem by evaluating patent applications which are first filed in China and then filed in the United States or the European Union. Because the U.S. and EU patent examiners will perform their own evaluation of the technical areas defined in the patent application, a statistical comparison of changes in CPC codes could indicate if there is a source of error in these definitions. There are mechanisms to calculate the "distances" between patent CPC codes or technical areas. These can be used to calculate a distance metric for an error calculation.

[18] The term refers to written or digital evidence beyond formal reports and books. This includes all forms of social media, blogs, webpages of groups and companies, chatrooms, bulletin boards, and so forth.

open-source media in which Soviet technologists, managers, and government officials "talked" among themselves (Popper, 1989, 1990).

We necessarily needed to limit the scope of our inquiry. We restricted ourselves geographically to the region of Tianjin. We did so to test whether our approach could work in regions outside those most frequently treated by analysts and foreign observers. Tianjin itself may be at times overlooked in innovation literature specific to China. The original five SEZs of Shenzhen, Zhuhai, Shantou, Xiamen, and Hainan often receive attention since these regions were chronologically the first to be established as zones for entrepreneur-led innovation. They became special state designees in the early 1980s and so are best known. Tianjin was eventually designated a "coastal development zone" in 1984 and incorporated into a broader economic development plan championed by CCP General Secretary Zhao Ziyang in 1988. However, research on Chinese development and innovation can gravitate toward SEZ municipalities since the coastal development plan was less focused on commercial experimentation and more on how China could "embrace the doctrine of export orientation" through economies of scale in labor-intensive processes (Yang, 1991).

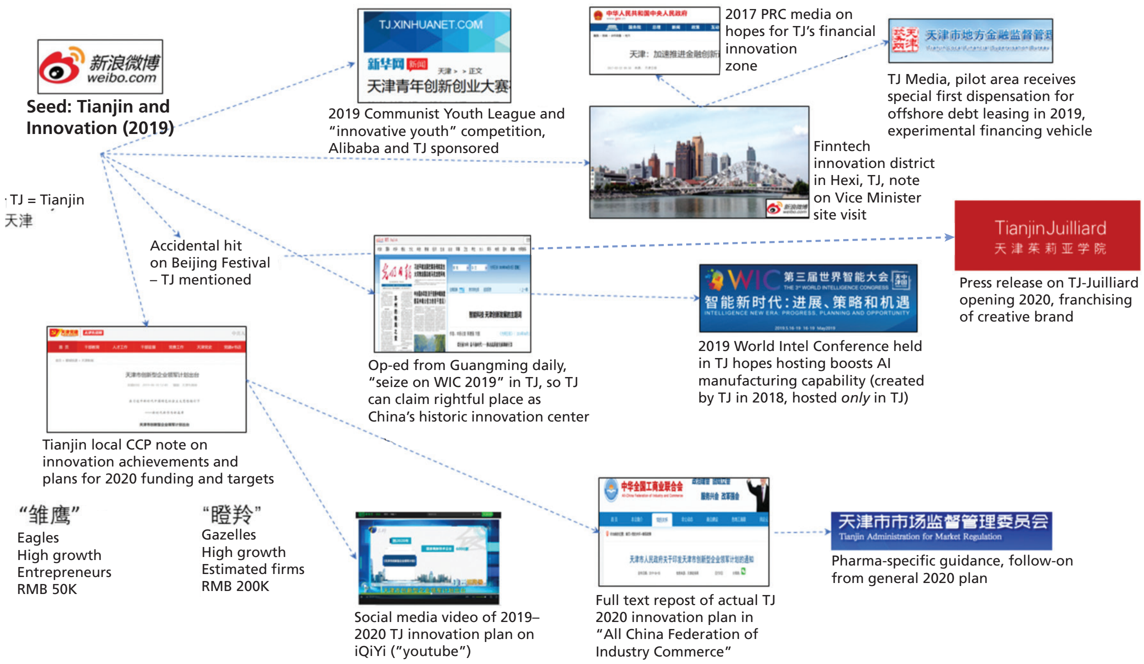
Tianjin's capacity to innovate may be of special relevance in the 2020s because the municipality experienced the sharpest decline in growth among all of China's regions between 2015 and 2018 (*The Economist*, 2018). Tianjin is also uncommon among major Chinese cities in that it already possesses a service sector exceeding more than 50 percent of gross regional product, a threshold often targeted by China's economic planners in an effort to potentially avoid a "middle-income trap," an economic condition marked by declining growth levels in traditional industries and an overreliance on factor-intensive firms to achieve marginal growth (Huang, Morgan, and Yoshino, 2018). To overcome these declining growth rates, and to capitalize on some of the city's inherent strengths such as port access and a maturing service sector, Tianjin's network of government, business, and entrepreneurial actors is being challenged to innovate and compete.

Both in competition with other Chinese regions and abroad, Tianjin's status as a slow-growth region has led the local government to push several innovation initiatives in the past two years. To detect evidence of networks around two initiatives in particular—the World Intelligence Congress (WIC or 世界智能大会) and *Tianjin's Leading Innovative Enterprise Plan* for 2019–2020 (Tianjin 2020 or 天津市创新型企业领军计划) (Tianjin Municipality, 2019)—we reviewed gray literature such as microblogs, short-form video content, and industry and company press releases. We sought to develop a picture of the actors engaged across Tianjin's economy to identify, promote, and finance commercial innovation in Tianjin.

Gray Literature Search Method

The search operators "Tianjin" and "Innovation" in simplified Chinese characters were employed across two major social media platforms: Sina Weibo (新浪微博) for microblogging and iQiyi (爱奇艺) for video short-form content. Recently active innovation threads covering posts and conversation threads in the spring and early summer of 2019 were reviewed. For both media forms, search on major innovation themes reflected a bias toward search engine optimization that narrowed conversation to the two major topics highlighted above: the recently announced Tianjin Municipality's *Leading Innovator* plan for 2019–2020 and news regarding Tianjin's annual World Intelligence Conference. We therefore treated these as "pebbles tossed into the pond": What ensuing ripples would appear on the surface? Directed by the discussants involved in these conversations, additional gray literature sources were included through

Figure 5.7
Mapping the Trail Followed Through the Gray Literature



second- and third-order connections that included industry, social groups, and firm-related press releases and webpages. The main lines of search are illustrated in Figure 5.7.

Tianjin's Innovation Networks, Some Observations

Innovation networks in Tianjin, as represented in social media, seem to be government led and policy focused. This observation could simply be an idiosyncrasy of the sites we reviewed, the period and timing of review, and the inherent bias in reviewing content that is subject to public censorship even if innovation as a topic does not seem overtly contentious. In addition, viewing media discussion as a publicly available or opensource dialogue between Tianjin's innovation actors only expresses the visible networks and does not address actors that communicate in less public forums. Regardless, many of these actors seem to be linking preexisting efforts or forums to the news of the *Leading Innovative Enterprise*. They may be doing so prospectively to showcase their compatibility with the opportunities advanced in the plan. The opportunities include being designated as Tianjin's "Young Eagles" or "Gazelles," for promising and established innovative firms, respectively, and to obtain access to subsidies and research grants if existing research shows promise (Tianjin Municipality, 2019).

Because most efforts within China's partystate structure are expected to align, it is also possible that interaction between these innovation actors may represent an intentionally public dialogue between a "leader" and a "chorus." For example, the Tianjin municipality announced the innovation plan in the spring of 2019. The Tianjin CCP Party Branch then repeated amplifying guidance in the summer of 2019 in accordance with "Xi Jinping's new era of Socialism with Chinese Characteristics" (Tianjin Pioneer Network, 2019). Various CCP affiliates such as the Communist Youth League Tianjin branch and the All-China Women's Federation of Tianjin, and regional universities such as Tianjin Science and Technology University, then engaged with the government and party demonstrating how their own initiatives, some of which were private-public partnerships, help advance an innovation agenda (Tianjin Women's Network, 2019). In this example, CCP affiliates and education organizations within Tianjin demonstrate through social media with photographic evidence and press releases that they are hosting innovation competitions, forums, and field trips within the Beijing-Hebei-Tianjin economic corridor and are actively engaged with large technology firms like Alibaba, local high schools, and talent recruitment agencies, all during a period in which the Tianjin CCP party branch is exhorting the party organs to lead innovation efforts (Zhang, 2019).

Regarding Tianjin's WIC, innovation networks in public dialogue exhibit a slightly different—although still official—nature. Engagement with the annual event held in Tianjin each May since 2017 is focused on the individual firm. As with trade shows and conventions around the world, it presents an opportunity to announce business deals and debut products through eye-catching demonstrations and experiential product pavilions designed to facilitate social media sharing and posting. WIC 2019 reportedly was the venue that helped close the signing of 126 agreements with an estimated investment in Tianjin of over RMB 108 billion or USD 15.6 billion (3rd WIC Organization Committee, 2019). WIC has an explicit emphasis on AI and manufacturing, is coordinated with no less than seven major state entities, such as the National Development and Reform Commission, and attendee firms are thematically connected to Tianjin's 2020 innovation goals advanced by Tianjin Mayor, Zhang Guoqing (Shijia, 2019).[19] Social media interaction around the topics of innovation and WIC can be characterized by a gradual buildup of social media interaction by firms' official social media accounts acknowledging their participation in WIC, followed by an increase in activity focused on firms posting images and press releases during exhibition, and then a short period of business deal announcements via press release in the weeks following WIC's conclusion.

Existing platforms for promoting innovation networks, such as long-standing innovation forums, innovation and product design competitions, college graduate job fairs, and innovation field trips, may be fused onto the news and attention generated by the municipality's 2020 innovation plan as well as the publicity surrounding WIC. Firms and firm senior leadership also showed a proclivity to reference the municipality's innovative enterprise plan as well as WIC, with firms participating in these social media forums as a means to advance their candidacy for being designated as Young Eagles or Gazelles and potentially gain access to financial benefits awarded to such designees. In some cases, linking or reposting content seems to be simple opportunism to show engagement with a high-ranking official or to post photos showing physical participation at an event. Firms seem to have a human resource incentive to participate in innovation forums at the intersection of Tianjin's innovation plan and the WIC since human resource firms directly solicit talent and provide headhunting services at these events. Although the plan and WIC are primarily focused at the firm level and not at

[19] WIC is coorganized by Tianjin Municipal People's Government, National Development and Reform Commission, the Ministry of Science and Technology, the Ministry of Industry and Information Technology, National Radio and Television Administration, Cyberspace Administration of China, Chinese Academy of Sciences, Chinese Academy of Engineering, and China Association for Science and Technology.

individual employees, the cast of actors participating in these and other innovation-related events unquestionably include the supply-and-demand side of the talent market essential to staffing Tianjin's firms. Earlier Tianjin-focused studies indicated that Tianjin's networks for employment are particularly vital for its economic survival. Tianjin faces strong regional competition from Beijing to attract college graduates and technically oriented staff (Silberglitt et al., 2009).

Finally, for WIC and Tianjin's 2020 innovation plan, we found no overt questions or criticism of the events themselves or municipal policy within the gray literature. Neither had we necessarily expected to in such public forums. Nevertheless, clarifications sought on firm applications to attend the events or participate in innovation plans provide partial insight into the problems associated with executing innovation plans. Tianjin's Municipal Science and Technology Bureau provided guidance on such applications in July of 2019. In addition to clarifying how firms could engage with particular government points of contact specific to the category of AI or biotech they were applying for, the Bureau reminded firms that they must be compliant with a 2017 regulation entitled "Temporary Measures for the Administration of Untrustworthy Behaviors of Responsible Subjects in Tianjin Science and Technology Plan Project" (Tianjin Municipal Science and Technology Commission, 2017).

The guidance on untrustworthy firms was published just one year after Tianjin's innovation efforts were mentioned in domestic news. A story involving a senior researcher at a Tianjin university who overstated the ability of a recently patented process for the mass production of boron isotopes was widely circulated (Liu, 2017). The patent scandal and a related lawsuit cast Tianjin in a negative light. At the same time, a prominent CCP leader and former mayor of Tianjin, Huang Xingguo, was indicted for corruption and so may have generated additional interest in securing Tianjin's ability to implement legal safeguards (or the appearance thereof) to prevent innovation fraudsters. The guidance (*Tianjin Science Regulation 2017 number 10*) focuses on preventing irresponsible actors from exploiting the generous funding and subsidies that Tianjin's government is looking to provide qualified applicants in innovative industries. If the guidance represents more than just regulatory caution and instead reflects knowledge born of hard-learned experience after decades of incentivizing successful and unsuccessful firms, then several recurrent themes stand out:

- Patent fraud and scientific plagiarism is an ongoing concern of the city's science commission. Scientific data fabrication (as distinct from IP theft or plagiarism of an otherwise sound scientific process) also remains a major concern. The guidance forbids projects that "fabricate or tamper with scientific research data and charts, etc., in violation of scientific ethics" and perhaps points to the difficulty of having bureaucrats evaluate independent scientific claims of innovation.
- Firms that claim to have an innovative process also sometime press their need for specialized consultants not currently on staff and who cannot be directly hired into the firm. The need to pay, but not directly hire, consultants is identified as "untrustworthy behavior" and hints that project staff may have previously used city grants and subsidies to then pass on funds as income to unqualified persons. Although the guidance separately identifies bribes and kickback schemes, the expert consultant method receives detailed mention as a less obvious form of corruption with the concern that "review and evaluation expert consultants are fake, such as false reporting of professional areas, technical titles, positions, research experience and so on."

- General project management concerns are routinely mentioned in the guidance covering an array of issues to include later-than-expected project delivery times, cost overruns, high turnover of critical personnel, and a failure to adhere to inspection standards and schedules, so that a purportedly innovative process has no realistic business case at scale (Tianjin Municipal Science and Technology Commission, 2017).

Perhaps in reading these follow-up instructions and application guidance to Tianjin's innovation plans, it is possible to divine what forms public criticism would take were it permitted to circulate in social media.

Evaluation

This experiment was a success on balance. Compared with the time and resources expended, we were able to develop hypotheses on the nature of communications within networks engaged in innovation in Tianjin. Of course, we had no access to data flowing on private communications channels nor the means to engage in batch collection and evaluation methods. Nevertheless, we were able to detect messaging that was suggestive of a network for sending and receiving indicators of various actors' positioning at the very least. This included establishing the type of organization taking part in these discussions as well as suggestions of leadership roles. The discussion of permitted and sanctioned behaviors, although along the most official of channels, nevertheless provided insight into some of the issues that appear to be prevalent enough to cause official concern. This alone provides proof of principle that a more refined, purposeful, and resourced approach to listening in on these discussions could provide useful information, if only of a qualitative nature, of what might affect China's innovation propensity.

Factors in the Innovation Activity Framework

After the discussion on the nature of knowledge and innovation networks and potential measures to be employed, we turn to the third column of the Table 2.1 matrix, that of networks. Many themes related to the role of networks in innovation have appeared in prior chapters' discussions. We now collect and discuss them. As in the case of the other columns given attention in previous chapters, in the following chapter, we will present measures and candidate indicators of innovation propensity for China.

Institutions

Networks by their nature most often are typified by informal, self-assembled, and self-defined direct and indirect relationships among individuals and, to some extent, firms. Nevertheless, it is not incorrect to consider them to possess structures informal as they may be. A good deal of what transpires within an industrial or technology sector is conducted through markets and networks.

- Networks involved in the dissemination of early stage knowledge through nonmarket means, forming collaborations, and drawing on ancillary support for innovative activities are a crucial element and hallmark of innovating regions. Characteristics of a network's structure include number of "**nodes**" within the network, the **density** of connections among the nodes (i.e., how complex is the "web" linking nodes), and the network's **heterogeneity**.[20]

In a similar vein, network structure, the nature of the linkages between nodes and the communications across those linkages, may be affected by policy choices on the part of governing authorities.

- Protection of **IP rights** affects how networks form and operate. Networks are the most effective form for conveying early stage knowledge often difficult to codify. Trust among nodes leads to comfort in conveying information to others in the network. Relatedly, the "**Great Firewall**" and other means monitor and censor digital messaging. Restrictions extending to scientific and technical publications may influence the rate of innovation. The extent to which the policies to limit the transmission of messages deemed to be politically unacceptable may or may not affect how this crucial channel for network formation is able to affect innovation propensity. Although China is not unique in such policy, it may be so among the major nations vying for global S&T leadership. From the perspective of OECD nations' experience, this degree of potential or actual intrusion, even if only passive monitoring, on the part of the state would appear to run the risk of skewing the messaging across networks. Yet, it must be remembered that China's population also experienced a markedly different history from those in North America and Europe. Anecdotal information derived from Chinese citizens suggests that this degree of monitoring is not perceived as being as oppressive as might be the case elsewhere (Qian, 2019). The reasoning followed by those dismissing the risk is that the type of information deemed potentially sensitive by the censors would not appear to have great overlap with the types of technical and collaborative signals sent through innovation networks. One could take the same starting point, however, and argue that this same experience might also serve as a naturally inhibiting factor. Experience has taught that one never knows what the next turn of the wheel may bring forth (e.g., the loosening of discourse during the "Hundred Flowers" movement and its subsequent repressions) and so circumspection might introduce an unconscious narrowing of channels for communication.

Networks operate heavily in the realm of informal institutions and norms.

- Networks are conduits of information and collaboration lubricated by **attitudes toward trust**. These may prove transitory, influenced by experience, contingency, lore, and norms, and therefore cause networks to differ widely in both structure and function. This is no more the case than when considering the **role of *guanxi***, the classic informal structure affecting all aspects of Chinese society, politics, and economics (Gold, Guthrie, and Wank, 2002). The basic translation of the term is "connection," but in China it carries many subtle connotations. In a sense, the ties of *guanxi* in themselves represent a network (Lyu and Liefner, 2018). The question is whether this existing complex of bonds based on family ties, personal obligations, and other factors affect the purposefulness of

[20] The term "node" is deliberately ambiguous about whether these are individuals, firms, agencies, or other associations. Heterogeneity refers to how much different fields of knowledge, skills, actor-types, and expertise are networked or only linked to others of their kind (homogeneity).

innovation networks in China—as is sometimes claimed they do in the formal structures of markets and hierarchies to the detriment of effective operation of both. Or, could they be a factor inclining toward the generation of innovation networks?[21]

Innovation Processes

Networks are a resource for the transmission and cross-fertilization of knowledge that yields innovation. Even in the case of formal R&D by individual entities, the extraorganizational networked connections of the staff conducting such projects can provide valuable, even key, inputs of knowledge and technique.

- Some of the formal elements that arise from network relations are the creation of **scientific or technical teams** to combine assets and skills in the production of new knowledge. Indeed, the phenomena of scientific knowledge transfer along networks gave rise to the growth of what has been termed "**open science**." Open science is a consequence, in part, of the notable inability of the creators of new knowledge to fully capture for themselves its benefits due to the prevalence of spillover effects within networks, discussed below. This is true to some extent when it comes to technological innovation as well. Open science conveys a normative stance that scientific knowledge must be openly available and is becoming a growing force in several branches of knowledge creation. The cultures of Silicon Valley and other innovating regions also reflect to some extent an ethic recognizing the value to all of a mix of proprietary and nonappropriable knowledge.

  The mix of knowledge sources and types comes strongly in force at the point of invention.

- The appurtenances of some individual networks can support invention **within a sector**. The town of Solingen in Germany has been a technology leader in the production of bladed tools and weapons for centuries. But there is good reason to believe that more impactful inventions come at the **intersections of industrial sectors and technology fields**. Further, networks tie together **ecosystems of support** connecting inventing teams not only with colleagues but with funders, suppliers, and supporting services that may or may not be amenable to market transactions. **Patterns of invention** also exhibit sectoral characteristics. This may mean that institutions and incentives that work to favor invention in some sectors may prove less advantageous in others. Some branches of invention have their main driver stem from science, as in pharmaceuticals, engineering as in space or rail, a combination of science and engineering as in automobile manufacturing, or strong and consistent demand signals from a major customer, as is the case with the military, which in the United States drove invention in fields such as semiconductors and numerically controlled machine tools, or from consumer driven sectors. So, for example, one can see the importance of major basic scientific research facilities to invention in a science-driven sector but perhaps less so in one more dependent on advances in engineering.

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[21] Several young Chinese entrepreneurs, convinced of the lore surrounding the annual Burning Man festival in weaving important networks in Silicon Valley, have sought to replicate it in China. Or, properly speaking, in Mongolia, presumably to avoid problems with the Chinese authorities. The author of the article reporting on the Burning Dragon event notes that this is still under the radar of "state and market forces" but notes his surprise at the low-key and supportive press attention (Rowen, 2019).

Table 5.2
Identification of Important Factors for Innovation Across All Venues

Theme	Innovation Factors	Firms and "Laboratories"	Markets	Networks	Local Authorities	National Authorities
Institutions	**Structure**	- Balance of market/hierarchy - SOEs and POEs - State and private "laboratories"	- Market size - Industrial organization - State of competition	- Nodes, density, heterogeneity - Prof., science societies - Regional, international	- Regional govt. agencies - Stake in local POEs	- Agency responsibility - Central committee - Council of ministers
	Policy	- Degree of autonomy (S/POE) - Big firm vs. small firm - Strategy: niche, target	- Enforceability of contracts - Barriers to entry - Horiz./vert. integration	- IPR protection - Gr. Fire Wall of Ch. factor	- Results vs. other regions	- Priority setting - Campaigns - Resource allocation
	Informal	- Mgmt. attitude toward risk - Support of innovating workers - Firm/laboratory culture	- Govt. interest in outcomes	- Attitude toward trust - Role (+/–) of *quanxi*	- Influence, graft - Staffing of agencies	- Power relationships - Role of PLA - Role of ideology and debate
Process	**R&D**	- Formal R&D - "Fixing" on line, learning by doing	- Contract R&D - IPR protection - Precompetitive joint R&D	- Science teaming - Open science - Spillovers	- Regional govt. laboratories - Universities	- Spin-off and spin-on R&D - National R&D assets - Budgeting R&D support - Universities
	Invention	- General purpose; platform - Evolution vs. revolution - Drivers	- IPR protection - Research partnership, consortia - Early stage VC	- In-sector or cross-sector - Innovation ecosystem - Sectoral innov. patterns	- "Parks," incubators, accelerators	- Prizes, incentives - Patenting regulations - Demand-pull
	Diffusion	- Process vs. product - Promo activity - Response to feedback - Role of internal "champions"	- Sales - Licensing - Role of entrepreneurship	- Partnering - Demonstration effects - Role of connectors	- Selective winner promotion	- Export promotion - Visa and access policy
Precursors	**Funding**	- Own /private /state	- VC funding - Foreign DI - Stock market	- In/out-of-network source	- Region as VC, bank	- State as VC, bank - Natl. key laboratory designation
	Incentive	- Principal/agent issues - Returns to employee, mgmt. - Risk sharing	- Risk/return balance - Conflicts of profit vs. state goals	- Net benefit of teaming - Ease of teaming - Value of precomp chats	- Natl. leadership approval - Bet on "winning" firms, sectors to show results	- Consequence of social control
	Skills	- Skill retention - Skill development, training - Skill acquisition and mix	- Mobility - Diffusion - Spillovers	- Degree of homogeneity - Spillovers	- Teaching, training	- Teaching, training - Skill preferences

Networks are also powerful drivers of diffusion of useful inventions.

- Networks are the leading conduit for **demonstration effects** prompting follow-on adoptions. Early adopters influence later adopters through sharing of results and experiences. More actively, each network contains some nodes more richly and prolifically connected than the average. These **connectors** can affect the speed of diffusion by affecting many individual adoption decisions. And networks also promote **partnering** in pursuit of greater market penetration.

Innovation Precursors

Funds for innovation

- Although funding of innovation is principally a market phenomenon in the private sector, networks may also play a role in bringing funders and innovators together precontractually. Different types of networks could be more or less useful in bringing **in-network sources** to bear on the funding requirements of innovation.

Incentives

- Incentives determine the character of knowledge and innovation networks because these are informal structures in which participation is not compelled. The **net benefit of teaming** and organizing through network contacts is a paramount consideration for participation. Similarly, it would be beneficial to understand the barriers and relative **ease of teaming** to conduct or support innovative activities through networks. The calculus of risk and reward will determine how individual potential contributors regard and **value precompetitive discussion** of innovation possibilities and the sharing of technical knowledge, either formally or informally.

The development, application, and diffusion of skill bring up a key concept that helps explain why networks play so crucial a role in innovation.

- We choose to address the issue of such **spillovers** as features of networks. Market mechanisms may be involved in the actual movement of workers, but this captures only a small part of the potential for spillovers, which are usually defined as acquirable bits of knowledge that are either nonrivalrous or that are not fully appropriable by the generators or funders of the original knowledge creation. People talk. In networks, even though individuals may not be formal coworkers, they may prove to be collaborators either directly or indirectly by paying the usual price for entry into a network: providing beneficial input to other members. One useful dimension for measurement is whether network participation is among those who share similar skills, interests, and knowledge. Networks are held to be more effective generators of innovation to the degree that **homogeneity** is replaced with a mixed membership.

The completion of this cursory treatment of activities, factors, and concepts in innovation allows presentation of the full innovation activity matrix in Table 5.2. It includes those factors identified in prior chapters as well. This framework will provide the basis for the discussion of measures for key factors as well as candidate indicators for innovative propensity.

CHAPTER SIX

Measures and Indicators of China's Innovation Propensity

The previous chapters provided information drawn from the literature on innovation in general and in China (Chapters Two and Three), sectoral case studies (Chapter Four), discussion of networks with brief excursions into quantitative evaluations of bibliometric and patent data, and investigations of the gray literature found online (Chapter Five). We used this input to motivate a populated framework for factors of importance for innovation (Table 5.2). This framing represents an initial cut that may be improved by further investigation. It collects factors, trends, and activities that we would ideally examine to determine the actual and evolving state of China's innovation propensity.

Within this proposed framework, this chapter will select those factors that the prior chapters suggested might be especially crucial in generating and supporting innovative activities. Within this selected winnowing from Table 5.2, we will suggest measures that might be associated with these elements to help us better monitor conditions in China as they evolve. Finally, we will select among these measures a smaller set of candidate indicators that might serve as a dashboard for assessing China's innovative propensity over time.

Addressing the Problem of Measurement

Table 6.1 shows candidate proxies or possible information sources that could provide measures of factors contributing to innovation and innovation propensity in China. We limit further discussion to selected cells that have been highlighted within the table. The elements that populate the corresponding cells within Table 5.2 either have received frequent or broad mention in the sources we have presented, or they have been identified either in those sources or in subsequent research team evaluations as being especially pivotal in addressing the question of innovation propensity, as opposed to innovation potential, within our basic framing. They also, in many cases, represent points of difference between a view of innovation in typical OECD-country systems and how evidence portrays the Chinese innovation system.[1] Do these represent potential speedbumps to China's acceleration toward global innovation leadership? Such differences are especially worthy for later consideration when identifying a smaller group of measures that could serve as indicators of China's future innovation propensity.

Among the potential measures, some may be eminently obtainable given resources and time. Others, however, may be more aspirational while not necessarily inconceivable. At this

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[1] As an example, enforceability of contracts and recourse to courts to address legal grievances might be different in the case of China from the situation in OECD member states that would see less variance among themselves (the "Policy"/"Markets" cell in Tables 5.2 and 6.1).

Table 6.1
Candidate Measures of Factors Relevant for Innovation in China

Theme	Innovation Factors	Firm and "Laboratories" (1)	Markets (2)	Networks (3)	Local Authorities (4)	National Authorities (5)
Institutions	Structure (1)	• Companies <3-, 5-, 7-year-old density	• Density of high growth firms • Herfindahl index • Shares of SOE/POE, by sector • Proportion, 3-, 5-, 7-year-old firms	• Size, nodes, density, location, heterogeneity • Industry assoc. networks		
	Policy (2)	• Degree of POE autonomy • Role definition of SOE • Media narratives on strategy	• Reports of noncourt recourse • Shares of entrants/incumbents • Vert. int: value added/ final sales			• Priority setting • Campaigns • Resource allocation
	Informal (3)	• Media narratives on risk, entrepreneurship, culture		• Assay proxies for trust • Dealmaker network density	• Reporting on bribes, graft • Reporting on interference • Support program network	• Power relationships • Role of PLA • Role of ideology and debate
Process	R&D (4)		• Share of contract R&D • IPR protection • Media reports on precompetitive joint R&D	• Science teaming • Media narratives on partnering • Media narratives on spillovers	• Regional govt. incub/accel	
	Invention (5)		• IPR protection • Early stage VC*: #/¥/ROI	• Sectoral patent networks • Assay ecosystem array • Sectoral innov. cases		• Policies affecting incentive • Patenting, IPR regulations • PLA demand-pull
	Diffusion (6)		• Spin-off rate	• "Contagion" mapping • ID and evaluate connectors		
Precursors	Funding (7)		• Share of early stage investment • Share/amount FDI • Stock mkt new listing/turnover	• VC* deals: #/¥		
	Incentive (8)	• Innov. perf. young/old firms • Innov. perf. small/large firms • Innov. perf. SOE/POE	• Media narratives on profit vs. state goals conflict • VC* ROI	• Media narratives on partnering, teaming • Economic mobility		• Attitude, reaction to social control by state

NOTE: The highlighted cells are those evaluated as being most valuable for assessing innovation propensity. Entries have been color-coded according to potential data source: *red* = time series and quantitative data; *green* = both de jure and de facto government or CCP policies and statements; *blue* = qualitative data from the academic and gray literatures. When more than one color font is used, it connotes that there may be more than one appropriate data source type.

stage, it is important to avoid the trap of looking for the proverbial lost keys under the lamppost because that is where the light is. The initial question should not necessarily be availability of information. Although certainly an important practical consideration, we may yet be able to conceive of means for shining metaphoric illumination in less well-lit areas—once we first have an idea of where we might want to look and why.[2]

Cells have been highlighted in Table 6.1 based on judgments of the principal points in the analyses presented in the prior chapters. Their pattern suggests that some of the rows or columns appear to be important pivot points. The column representing networks stands out followed by those reflecting market phenomena and issues with the national government. Similarly, the rows representing informal institutions and incentives have highlighted cells across most of the venues represented by columns. Some rows, such as funding as a precursor of innovation, have no highlighted cells. This is not because we judged funding to be unimportant; quite the opposite, it is vital to any innovation system. It lacks highlights, however, because we did not judge funding issues to be determinative in addressing China's innovation propensity. This could change if there are reasons to believe, for example, that funding is systemically biased toward less innovative, less risk-taking firms or sectors in preference to firms or sectors with otherwise greater innovative propensity that then become comparatively constrained for resources.[3]

Consideration of funding as an important measure for innovation propensity illustrates two principles for the selection of particular cells. The Funding row cell intersecting the Market column does propose measures, although the cell containing them did not receive priority highlighting. Other measures, though perhaps more indirect, were judged to be capable of picking up any preferential effects at least preliminarily.[4] This highlights the principle of parsimony, a wish to keep the proposed dashboard indicators of innovative propensity as few as possible. However, in practice, the set of indicators might be judged insufficient to provide insight into this aspect of innovative propensity. Then the second principle comes into play: we offer a preliminary listing that almost certainly will require tuning if placed into practice.

Measures from Table 6.1 are reproduced in a roster format in Table 6.2 with more expansive labeling. It may be read in reference to the phenomena appearing in Table 5.2 to provide a guide to what information we would wish to gain through using these measures. Note that most would be more appropriately applied to individual sectors or technology branches than to China as a whole, but several could be effective at both scales. We also note in the final column of the table the expected primary data source for each prospective measure.

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[2] The notes accompanying Table 6.1 suggest for each candidate measure which among three broad sources might yield the information to be sought: time series and quantitative data, de jure and de facto government or CCP policies and statements, qualitative data from the academic and gray literatures.

[3] We have both anecdotal information and inferences from published Chinese academic work that there is concern by some about the magnitude of state funding to SOEs, which as a group appear to be less innovative than POEs (see also Wei et al., 2016). The normative narrative, however, most frequently refers either to the opportunity cost of such financing or the need for some degree of restructuring of the principles of organization for such enterprises to operate more effectively. Such critics do not necessarily imply a concomitant absence of resources for POEs.

[4] See especially the two cells under Firms/Laboratories that intersect with the Policy and Informal Institutions rows.

Table 6.2
Description of Purpose and Data Source Types for Measures Within Highlighted Cells

	Matrix Cell	Candidate Measures	Intended Purposes	Source Data Type
Institutions	Structure, market (1,2)	Density of high-growth firms	Measure of sectoral dynamism	Q
		Herfindahl index	Measure of market concentration	Q
		Shares of SOE/POE	Insight into sector differences in management and incentives	Q
		Proportion, 3-, 5-, 7-year-old firms	Tracking of ease of entry and exit	Q
	Structure, network (1,3)	Size, nodes, density, location, heterogeneity	Basic characteristics of sectoral networks, especially in the degree of heterogeneity of membership, skills, knowledge areas	Q
		Industry association networks	More formalized forms of networks; brought into being by government or membership itself	M
	Policy, firm/ laboratory (2,1)	Degree of POE autonomy	How private are the decisions of POEs, to what extent answerable to authorities other than owners?	M, P
		Role definition of SOE	Unique to China, how will the conception of SOE roles change over time, de jure and de facto?	P
		Media narratives on strategy	What are characteristic, prevalent, or unusual stories about firm/laboratory-level strategies and how discussed?	M
	Policy, market (2,2)	Reports of noncourt recourse	Can firms or teams expect to be able to enforce contracts in courts of law? What are forms of recourse?	M
		Shares of entrants/incumbents	Rates of turnover, entry, and exit	Q
		Vertical integration	Measures such as value added as share of sales. Can firms rely on supply base or do they need to integrate?	Q
	Policy, national (2,5)	Priority setting	Enunciated goals by national, local leadership; revealed goals may also be investigated	M, P
		Campaigns	Nature and effect of campaign-type policy initiatives	M, P
		Resource allocation	How have resources been assigned by priority area and to different venues along the innovation chain?	Q
	Informal, firm (3,1)	Media narratives on risk, entrepreneurship, culture	Gain insight into how managers view the value of innovation versus other strategies for thriving and survival	M
	Informal, network (3,3)	Assay proxies for trust	Use available social science tools to understand degree to which trust prevails, general and sectoral	M
		Dealmaker network density	Identify network nodes that appear to be central to brokering connections, exchanges, and deals	M

	Informal, local (3,4)	Reporting on bribes, graft	Extent to which corruption may be detected among local authorities	M
		Reporting on interference	Extent to which local authorities may exercise influence, legal or undue, on firm and team decisions	M
		Support program network	Extent to which local authorities establish programs to foster, support or guide innovation, and effect	M
	Informal, national (3,5)	Power relationships	Personal power relationships among elites and between them and lower levels that affect innovation	M, P
		Role of PLA	PLA as priority for innovation, influencer of outcomes, and source of demand-pull forces	M, P
		Role of ideology and debate	Actions, policies, attitudes, and effects that arise from ideological precepts and internal debates	M, P
Processes	R&D, market (4,2)	Share of contract R&D	How much may firms rely on external sources for R&D and other knowledge inputs by contract?	Q
		IPR protection	What is de jure/de facto status of IPR at firm level and what messages does this convey from leaders?	M, P
		Media reports on precompetitive joint R&D	Extent to which firms enter into precompetitive formal or informal collaborations through regular market channels	M
	R&D, network (4,3)	Science teaming	Participation by Chinese researcher in both global and domestic research teams and consortiums	Q
		Media narratives on partnering	Evidence of partnering and knowledge exchanges at several stages of innovation through networks	M
		Media narratives on spillovers	Evidence of transfer of nonrivalrous or not-fully-appropriable technical knowledge through networks	M
	Invention, network (5,3)	Sectoral patent networks	Inference of implicit network relationships across sectors drawn from statements of art application	Q
		Assay ecosystem array	Determine the resources that exist within networks to provide support, guidance, and other services	M, P, Q
		Sectoral innovation cases	Determine patterns of innovation by sector drivers: science, engineering, demand-pull, etc.	M
	Invention, national (5,5)	Policies affecting incentive	Assessment of how policies may affect firm/laboratory and other-level invention, directly or indirectly	P
		Patenting, IPR regulations	Evaluate regulations set on patenting and other IPR for effect on invention	P
		PLA demand-pull	Assess the role played by PLA in determining course, pattern, and subject for invention	P, Q
	Diffusion, network (6,3)	"Contagion" mapping	Sigmoid diffusion curves as well as determine specific pattern, history of firm-level "contagion"	M, Q
		Identify and evaluate connectors	Character of network nodes that are highly connected and central to network	M

Table 6.2—Continued

	Matrix Cell	Candidate Measures	Intended Purposes	Source Data Type
Precursors	Incentive, firm (8,1)	Innov. perf. young/old firms	Innovation performance characteristics of young firms and new entrants versus older incumbents	M, Q
		Innov. perf. small/large firms	Innovation performance characteristics of smaller firms compared with larger	M, Q
		Innov. perf. SOE/POE	Innovation performance characteristics of SOEs compared with POEs incumbents	M, Q
	Incentive, market (8,2)	Media narratives on profit vs. state goals conflict	Insight into balance of firm/team decisions when confronted by clash between profit interest and stated or well-understand objectives of authorities	M
		VC* ROI	Return on investment to venture/angel/private equity/state investment capital	M
	Incentive, network (8,3)	Media narratives on partnering, teaming	Report on partnering and teaming through networks to reveal what are the drivers toward and barriers to doing so	M
		Economic mobility	Individual mobility possibilities and effect on joining and behavior in knowledge/ innovation networks	Q
	Incentive, national (8,5)	Attitude, reaction to social control by state	With rise of Great Wall, enhanced monitoring, social capital, effects on marginal behavior, and revealed choices by those who would be expected to have a propensity toward innovation	M
	Skills, network (9,3)	Specialization diversity	Distribution of skills, expertise, and backgrounds through networks	Q
		Diffusion of specialized skills	Track pattern of change in access to special skills through sectors and across sectors	M, Q

NOTE: The string "VC*" is a shorthand designation for several sources of venture capital (formal venture capital, "angel" investors, POEs, local or national state sources, as well as foreign and domestic sources). Primary source data types: Q = time series and quantitative data; *P* = both de jure and de facto government or CCP policies and statements; *M* = qualitative data from the academic and gray literatures.

Candidate Indicators for China's Innovation Propensity

Which among the Table 6.2 measures might serve as a smaller set of indicators, a "dashboard" to help us better understand innovation propensity in China? Given what is known about innovative activity in general, tempered with an understanding of the specifics of China's innovation system, the indicators should be apertures for observing selected aspects of the machinery of innovation at work. The logic for selection and inclusion is inductive: If we were to observe over time the specific phenomena represented on the dashboard to the extent that we infer a pattern, we would then form hypotheses about how likely China would be to produce innovation outcomes. The temptation is to continue to add to the list of candidate indicators. The full innovation activity framework displays many important points of intersection between the venues, forces, and processes of innovation in China. A dashboard should be a parsimonious list that would capture a sense of what might be happening in China moving forward.

Beyond parsimony, indicators should have several other characteristics. The actual proxies selected should be defined with precision and include detail on data required and the population from which the sample is being drawn. As with the measures attached to the innovation activity framework in Tables 6.1 and 6.2, at this stage the issue of data feasibility should take a secondary position. The present purpose is to highlight those areas in which candidate indicators should be sought and eventually crafted. The resulting data will allow the drawing of inferences and testing of hypotheses against actual innovation performance. Only time and further effort will determine if these candidates suffice as an instrument for observing the processes that permit a nation or region to turn its innovation potential into accomplishments.

Table 6.3a shows the candidate list in four columns. The first column locates the original corresponding cell in Tables 5.2 and 6.1. The order is consistent with our discussion: first by row and then column. The second column provides the candidate indicator itself, while the third draws on the prior chapters to provide brief support for nominating the measure to the list of candidate indicators for innovative propensity. Table 6.3b simply takes the information in the first column of Table 6.3a to place the candidate indicators within the same framework of important factors for innovation used throughout this study.

The fourth column provides an illustration of the type of proxies that could be constructed to gain insight into the candidate indicators. They currently vary greatly in specificity and, indeed, even present attainability. The reliance placed on the ability to monitor several media streams and receive information suitable for coding may prove tenuous unless continuously well tuned. It would be the work of a detailed effort following on the design created by this report to flesh out and test different proxy formulations for implementation in any innovation propensity tracking effort.

Constructing and Using an Innovation Propensity Dashboard

The candidate indicators in Tables 6.3a and b are not intended to supplant more traditional spot measures of innovation performance: numbers of new products or processes, ratio of new products/processes to total sales, change in market shares, patenting and licensing performance, etc. Instead, they are intended to provide an added veneer to raise awareness of what might be generating results for more traditional measures. In the ideal, they might serve as leading indicators—benchmarks not of current performance but of the propensity toward further innovative behavior. At the least, they will paint a fuller portrait of the innovation system evolving in China and provide a firmer foundation for policy analyses.

Table 6.3a
List of Candidate Indicators of China's Innovation Propensity

Row, Column	Candidate Indicators	Intended Purposes	Example Proxy
1, 3	Size, nodes, density, location, heterogeneity of networks	-Measure changes in dimensions and growth of networks over time	M, Q: Network metrics from data assembled based on results from implied sectoral patent network indicator results (below)
2, 2	Media reports of court/noncourt recourse of legal grievances	-Determine the extent that contracts and other legal recourse are enforceable as a gauge of risk perception	M: Content analysis of media stories, collected in fixed timeframe, coded for allusion to legal processes and outcomes
3, 1	Media narratives on risk, entrepreneurship, culture	-Gain insight into how entrepreneurial culture is being valued, rewarded, held accountable	M: Content analysis of media stories, collected in fixed timeframe, coded for allusion to risk-taking and entrepreneurship
3, 3	Develop and assay various proxies for trust among potential network nodes	-Trust as an asset making it easier to convey and act on innovative ideas	M: Content analysis of media stories, collected in fixed timeframe, coded for allusion to willingness to cooperate
4, 2	IPR protection	-Degree to which innovators may feel protected -De jure and de facto policy on creative rights and processes	P: Ongoing evaluation of stated and revealed policy contained in government releases and public statements
4, 3	Scientific research teaming	-Degree to which Chinese knowledge creation gains from global knowledge networks -Gauge of government policy toward cooperation	Q: Bibliometric international and domestic network mapping and analysis of targeted scientific subfields
5, 3	Sectoral patent networks	-Infer implicit networks, especially cross-fertilization among fields -Measure of priority attached to focused innovation	Q: Cross-sectoral patent data to derive nature of and change in implicit industrial networks in targeted patenting subfields
5, 5	Policies affecting incentives	-Examine PRC/CCP de jure and de facto policies from perspective of innovation	P: Ongoing evaluation of stated and revealed policy contained in government releases and public statements, coded for innovation-related incentives
6, 3	"Contagion" mapping of diffusion patterns	-Understand secondary barriers to innovation at stage of adoption	M: Content analysis of media stories, collected in fixed timeframe, coded for allusion to enablers or barriers to invention adoption
8, 1	Innovation performance of young, small, older, and larger firms	-Measure of dynamic pace, transformation of industrial sectors and technology fields -Measure of ways in which firms compete	M, Q: Combine cross-sectional and longitudinal measures of innovation performance, by performer type, based on sector statistics, legal filings, and content analysis of media stories coded for innovation performance
8, 3	Media narratives on partnering, teaming, knowledge, and skill spillovers	-Gain insight into how well skill and knowledge spillovers are occurring	M: Content analysis of media stories, collected in fixed timeframe, coded for allusion to teaming and partnering within targeted technology sectors

Table 6.3a—Continued

Row, Column	Candidate Indicators	Intended Purposes	Example Proxy
8, 5	Attitude, reaction by innovation workers to social control by state	-Assess degree that succeeding cycles of state control intrude on innovative behavior	M: Content analysis of media stories, collected in fixed timeframe, coded for allusion to reaction, behavioral change, and obstacles stemming from change in information regime
9, 3	Diffusion of specialized skills	-Proxy net effects of chance encounters, heterogeneity, and crossdisciplinarity and teaming	M, Q: Cross-sectional and longitudinal analysis of reported statistics and content analysis of media stories coded for movement of targeted skill types across sectors and industries

NOTE: The first column positions the indicator in one cell of the framework presented in Table 5.1. Thus, "5, 3" indicates the fifth row, exclusive of the column and row titles ("Invention"), and the third column ("Network"). "Media" refers, as appropriate, to broadly available sources including academic research, case studies, and the gray literature on the internet from several sources. Primary source data types: *Q* = time series and quantitative data; *P* = both de jure and de facto government or CCP policies and statements; *M* = qualitative data from the academic and gray literature media.

As an example of this last point, China's POEs by and large have been neatly fit by foreign regulators and policymakers, in both national and international agencies, into the familiar category of private firms and treated accordingly. This convenient typing has led to confusion and policy reassessment in the United States, United Kingdom, and elsewhere in such cases as determining the appropriate penetration of "employee-owned" Huawei as a 5G network supplier. Indicators such as those being proposed would raise both the visibility and assessment of information that would help us better understand what role such entities play within the Chinese innovation system, their interactions with the other institutions and organizations that constitute that system, and what that implies for policy surrounding the international performance of such entities.

The dashboard of propensity indicators in Tables 6.3a and 6.3b are also intended to support early assessment of which quadrant in Figure 1.1 China is moving toward. Assuming continuing strength in innovation potential as measured in its assets for innovation, will the indicated innovation propensity portend greater or lesser success in realizing its potential? What is the balance of incentives for innovative behavior by individuals and organizations? How might the innovation performance of industry sectors be understood based on entrance to, growth, and exit from those sectors? What do the several indicators under the heading of networks suggest about the origin, nature, extension, and operation of industrial knowledge networks within China and in global knowledge networks writ large?

The innovation propensity indicators may also potentially address two systemic questions posed in Chapter One. Were we to witness increasing strides in Chinese innovation results as traditionally measured along with positive readings from the propensity indicators, we might reject the conjecture that China's system will not be able to overcome systemic barriers to path-breaking and frontier-defining technological innovation. If we were to see disappointing results in both, we would then tend to accept the idea that the general empirical evidence of what leads to innovation in other countries applies to China as well. On the other hand, observing contrary signals of decreasing innovation achievements coupled with high-propensity indicators would call into question the adequacy of the proposed indicators and prompt the need for revision.

A fourth pairing is possible. Were we to observe an appreciable rate and level of innovation going forward but at the same time register values for the propensity indicators that would

Table 6.3b
Candidate Indicators of China's Innovation Propensity Within Innovation Activity Framework

Theme	Innovation Factors	Firms and "Laboratories"	Markets	Networks	Local Authorities	National Authorities
Institutions	Structure			Size, nodes, density, location, heterogeneity of networks		
	Policy		Media reports of court/ noncourt recourse of legal grievances			
	Informal	Media narratives on risk, entrepreneurship, culture		Develop and assay various proxies for trust among potential network nodes		
Process	R&D		IPR protection	Scientific research teaming		
	Invention			Sectoral patent networks		Policies affecting incentives
	Diffusion			"Contagion" mapping of diffusion patterns		
Media narratives on partnering, teaming, knowledge, and skill spillovers	Funding					
	Incentive	Innovation performance of young, small, older, and larger firms				Attitude, reaction by innovation workers to social control by state
	Skills					

seem to be at odds with these results given the common understanding of how and why innovation occurs, greater scrutiny might be required: perhaps China did, indeed, succeed in creating a system of innovation with Chinese characteristics (in contrast to the currently accepted understanding of necessary precursors) that we should seek to understand more fully. Like the famous Sherlock Holmes case of the dog that did not bark in the night (Doyle, 1898), this might in itself prove illuminating in better understanding China, the nature of innovation systems, and ourselves.

CHAPTER SEVEN

Innovation Propensity: Looking Toward the Future

This study applied a systematic approach to determining what observable measures might be the early indicators or precursors that would allow us to more accurately gauge the trajectory of China's rise to innovation prominence. The dynamics of innovation in China are certain to be changing over time. Our research design identified important phenomena in China's emerging system, suggested a set of measures for those deemed important for understanding systemic propensity toward innovation, and then selected among them an initial proposal for key indicators of change. In those areas in which we could not propose currently workable measures owing to limitations on data or other practicalities, we wished at least to point out what we ideally should be looking for and at which junctures of the complex web of innovation in China. This then becomes an agenda for further research and data-gathering measures.

Such an agenda may grow in importance in the coming years. So far, innovation in China has occurred in an extraordinarily favorable macro environment. The domestic economy has enjoyed a boom unparalleled in human history in scale and rates of growth. Globalization trends in trade and a liberal attitude toward trade governance, and most particularly in the enforcement of China's adherence to the rules governing such trade, have been particularly favorable for China. Further, geopolitics have been conducive to China's rise, occurring as it did within institutions designed to admit new entrants with far less friction than had been true in earlier eras. How well might China's system perform in accelerating innovation if conditions (liquidity, government assertion of control, etc.) were to be less conducive? As an example, in 2018, the government tried to deleverage and crack down on the overhangs of debt occurring in various economic venues. This appears to have had a measurable knock-on effect on VC funding. The number of new private equity funds in the first half of 2018 was down 59.5 percent from a year earlier, equity investments down 10.7 percent, and capital raised by investment firms for seed funding showed a 53-percent drop, year-on-year (Yand, 2018). This validates our study's concept of looking for indicators and underscores the value of being cognizant of such circumstances.

With growing tension over trade and its regulation, an edgier geopolitical environment (Trump, 2017), growing internal problems over an aging work force and ethnic discord, declining growth rates, environmental degradation, and what is perceived by many both inside and outside as a rolling back of some of the freedom of choice that Chinese citizens had gradually come to expect in the prior three decades, we will need more accurate instruments of observation to understand China and where it is going with innovation.

This is all the more true because trends are not solely turning in one direction. As China grows wealthier and seeks wider influence not only in East Asia but globally, one instrument for advancing both hard and some aspects of soft power is to enhance its military capability.

Innovation is likely to prove the beneficiary of China's increasing military procurement budget in an era of modernization. This is most likely to confer an advantage similar to that enjoyed in earlier eras by France, the United Kingdom, Germany, the Soviet Union, and the United States in their turn. OECD countries such as Japan and South Korea have no aspirations to hegemony or superpower status and therefore experience a reduced demand-pull force on innovation from domestic military budgets.

A potential downside that might ensue from this driver is that the PLA and Chinese government may be sufficiently adamant and authoritative that innovation becomes constrained to conform to predetermined channels. This, too, raises a question of the value derived from general innovation compared with the priority targeting for which the government still retains ample policy instruments. The latter might appear to be more purposeful in the military as opposed to the civilian sphere and so perhaps becomes the general model. Some of the patterns in networks of cited patent art discussed in Chapter Five indeed suggest a greater focusing of potential application of innovative technology in China when compared with similar patented innovations originating from the United States. But, how does a priority-focused system incentivize that attention be paid to issues such as time-to-market and market-acceptance? Where in society does the balance of risk or reward fall in pursuing innovation? How would priority targeting affect innovation, implementation, and outcomes, as well as perceptions and allocations of risk?

Other conundrums abound. Chinese firms operate in a competitive arena. Shenzhen is perhaps the most intense hothouse for competition in the world today. The creative destruction engendered by competition, as Schumpeter pointed out and is now widely accepted, is the lifeblood of innovation. But there remain questions about what form such competition takes in China outside certain high intensity fields. Our case study of pharmaceuticals in Chapter Four (and Appendix B) suggests that although firms are competing against each other for markets and shares, there seems also to be a competition for favor and resources from regional governmental bodies. So much more is the case for SOEs, which may or may not be too big to fail but are sufficiently connected that their road toward failure may be long and drawn out. In pharmaceuticals, this form of competition may inhibit acquiring the size and resources necessary for innovation.

On the other hand, in the case of AI (Chapter Four and Appendix A), although the government has favored and seen the rise of national champions in this field, the funding for start-up innovation efforts comes not just from public sources but also from venture capitalists and these same megafirms who, in turn, invest in hundreds of smaller teams. Nothing highlights the rapidly changing environment more than this instance of what might be termed "VC with Chinese characteristics 2.0": state funding develops the industry champions who then, in turn, take on a VC role themselves toward newer ventures.

In Chapters Two, Four, and Five, we presented reasoning that drew us to the study of knowledge and innovation networks in China as a useful proxy for observing the effects stemming from the interplay of a great many of the factors of importance to innovation synthesized in the innovation activity framework (Table 5.2). What is particularly striking is how networks take on a distinct aspect of self-organization in highly innovating regions. Those connections that tend to be created through the agency of higher authorities are less effective by different measurements, as we have seen in the case study of China's pharmaceutical sector.

But this observation also deserves a note of caution. In keeping with the dichotomy, described in Chapter One, we should not say that if networks and institutions in China do not look like those in the OECD countries with whom it wishes to be compared, then China will not be able to achieve its ambitions in innovation. But, on the other hand, we should also determine whether those different arrangements might actually be able to play a similar role of encouraging innovative activity rather than spreading resources evenly, but thinly, across a geographic space.

One example of how China may seek to bolster what otherwise might be viewed as weaknesses in network formation is the Thousand Talents Plan (千人计划), one part of which seeks to recruit foreign-trained research leaders to head purpose-built laboratories and research facilities in China.[1] It remains to be seen if this proves to be an organizational solution to whatever shortcomings there may be in encouraging self-assembled networks in China. There have also been reports of considerable expenditure in priority fields and in leading companies to ensure rapid translation of foreign books and reports to remain current with the advancing state of knowledge (Zhang, 2017). (Our discussion of networks suggests that being current with the written literature is a second-best solution because only in networks can one keep abreast of the true forefront of knowledge, which at its early stages is not easily codified and is largely tacit.) Another such effort is to develop listening posts abroad in the form of research laboratories to be present in regions of high innovation activity such as Silicon Valley. In doing so, however, they will be following a well-worn path already pioneered by large MNCs interested in cutting-edge innovation. And it remains to be seen how well either of these expedients fares in China that would appear to be possibly entering a period of at least momentary disengagement from the connections to global knowledge networks that appear to have served it so well.

Going forward, attention paid to innovation networks within China and their connections to those worldwide would be attention well spent in understanding China's emerging propensity for innovation.

On April 26, 2019, Norman R. Augustine and Neal Lane, cochairs of the American Academy of Arts and Sciences study panel on "Restoring the Foundation—The Vital Role of Research in Preserving the American Dream," sent a letter to the chairmen and ranking members of both the House and Senate appropriations subcommittees on commerce, justice, science, and related agencies. As highly regarded professionals and former U.S. government officials, their open letter laid out a case for greater federal funding for R&D (Augustine and Lane, 2019). They did so by providing an extensive discussion of the competitive pressure China is placing on the United States in becoming a leading force, if not eventually *the* leading force, in global scientific and technological advances. The letter was not intended to warn about inherent danger in China's rise but rather to call attention to U.S. complacency regarding the potential fragility of its own leadership position. In doing so, two of the most prominent and respected names in U.S. S&T policy used their expertise and influence to characterize the relative difference in dedication of purpose between the two countries' governmental direction. The case that they made was well drafted and compelling.

For our purposes, it is interesting to note what evidence the two authors brought to bear. The core argument was framed with a focus on innovation through R&D and its four contributing components of human capital, knowledge capital, an ecosystem conducive to innovation, and financial capital. They presented in their exposition data on what we have termed the input side of the innovation enterprise: gross expenditures on R&D, numbers of trained

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[1] For, the official recruitment site, see Thousand Talents Plan, undated.

STEM workers with advanced degrees, etc. Data were also provided to address the output side of the ledger: bibliometric statistics on science publications, patents granted, and so forth. Except for a brief section that dealt largely with government policy and initiatives ("Innovation Ecosystem"), there was no discussion of the types of issues that have emerged from our report (except to note in one sentence that China faces domestic unrest in some regions, increasing personal constraints, population aging, environmental concerns, and an economic slowdown).[2]

By contrast, we sought to determine what measures we might use to gain a fuller understanding not only of the past and current outputs of innovation in China and not only the outcomes that may ensue from them but to understand how China, considered as a system for innovation, may transform and gain in effectiveness in the coming years. If, as illustrated in the Augustine and Lane letter, U.S. domestic discussion of policy choices refers to developments in China, it behooves us to gain insight into how such an important player, and potential source of innovation, is developing. Precisely because of the possible consequences of China becoming a peer to the United States, or even potentially its successor in the role of primary innovation leadership as the letter seems to imply, we need to recognize those indicators that might help us better understand what is occurring inside China's evolving version of the "black box" of technological innovation (Rosenberg, 1982).

The point is not to be able to take false comfort from any fissures that may open along China's path forward. As Augustine and Lane point out in their testimony, the United States, too, confronts nontrivial issues in policy and process that need addressing. And as with other countries, China's production of scientific knowledge and novel technologies is likely to provide a benefit beyond its borders and to more than just its own citizens. As we look toward the future and the prospect of traversing a path subject to greater forces of change than the world has perhaps ever seen before over such a brief time, it will serve us to be as well equipped as we can make ourselves to observe accurately, assess properly, and draw the inferences that will guide our steps.

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[2] Augustine and Lane were making a specific case. It was not their intention to provide a complete portrait of the dynamics determining China's future innovation propensity. They presented a current snapshot and inferred rates of growth to assess the degree of challenge China might present. Nothing they said was incorrect nor were their projections necessarily certain to be proven wrong. They had no purpose to deceive or misdirect.

APPENDIX A

Case Study: China and Artificial Intelligence

This appendix provides a selection from the materials gathered in support of the report's case study on AI. It is being made available in particular to those who may otherwise lack practical access to Chinese-language materials.

Introduction

AI is one of the newest fields in science with a large number of scientific subfields and technological applications ranging from autonomous vehicles to speech recognition that hold an enormous promise to revolutionize our economies and societies.[1] This appendix provides more background on the brief presentation in Chapter Three. It addresses the evolution of the AI innovation ecosystem in China across several key dimensions: government policy, data, organizational culture, software algorithms, hardware, talent, international competitiveness, and the business ecosystem. We will mostly focus on the inputs and processes that govern innovation and diffusion of AI technologies in China. The AI sector is changing across all dimensions and receives much attention in the media and research communities. However, much of this focuses on the "future of AI"—a promise yet to be fulfilled. On the other hand, the effect of AI innovation in the present is rather difficult to assess, because most current AI and machine learning applications are more prosaic, yet with important economic impact. Amazon's CEO Jeff Bezos (2017) mentioned in his letter to shareholders "much of the impact of machine learning will be of this type—quietly but meaningfully improving core operations" of individual firms. The focus, therefore, is mostly on factors relevant to innovation propensity within China's AI sector. This case study contributed to the development of the innovation propensity framework that is the core of this report.

Policy

The Chinese government has a tradition of using national science and technology programs to promote technological development by setting priorities and allocating resources for their advancement. The stated priorities are usually a final result of the combination between top-down and bottom-up priority-setting processes, because some of the priorities are purely

[1] AI has many definitions that focus both on thought process and reasoning, as well as human behavior. For an overview of the historical and current research in AI, see, for example, Russel and Norvig, 2016.

scientific while others are more politically driven (Appelbaum et al., 2018). The development of AI policies started as an attempt to incorporate the frontier technologies in China's planning documents and industrial policies and later moved into the political spotlight aided by high-profile events such as the defeat of the Go champion Lee Sedol by the DeepMind's AlphaGo algorithm as well as the development of technologies and applications with strong security and military applications such as facial recognition and autonomous systems.[2]

China's AI policy is outlined in several major national-level policies as well as regional and city-level initiatives that translate the general directions contained in the national policies into specific measures that are implemented at the local level. Coincidentally, this approach has created a national AI innovation system and several regional innovation systems, allowing for different specializations, policy models, and incentive structures for the key regional innovation hubs. Thus, the development of AI in China may be analyzed not only as an NIS, but as a collection of regional systems that are interacting with each other and, in turn, shaping the system of the nation as a whole.[3]

National-Level Policy

The first set of AI-related policy documents (2009–2015) was mainly inspired by the scientific and technological themes revolving around the development of the IOT, big data, information security, and data infrastructure. AI was primarily seen as one of the emerging technologies that was mentioned among others and did not merit dedicated national-level policy documents.[4] Over the same period, provincial governments developed over a hundred policy documents that featured AI as a keyword (CISTP, 2018).

The national policy focus started shifting around 2015, influenced by several technological and political considerations. AI technological breakthroughs included Baidu's development of AI software capable of surpassing the levels of human language recognition (Knight, 2015) and Deep Mind's defeat of the Go champion Lee Sedol, whereas the political considerations were partly influenced by the Chinese military's reactions to the American "Third Offset Strategy" (Wood, 2016), the shift from "informatized warfare" to "intelligentized warfare" (Hongliang, 2016), and the desire to develop asymmetric capabilities to counter U.S. military advantages.[5] As a result, national policy documents began talking about a national strategy for AI, culminating with the publication of the "New Generation AI Development Plan" by the State Council, which put AI at the front and center of China's technological ambitions (PRC State Council, 2017).

Released in July 2017, the New Generation Artificial Intelligence Development Plan recognized that AI is not only an engine of innovation and economic development, but more important, a strategic technology that will "lead in the future" and bring new opportunities for "social construction" to improve the precision of public services and play a key role in "effectively maintaining social stability" (PRC State Council, 2017). As with many other high-level

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[2] In his excellent book on the development of AI in China, Kai-fu Lee, 2018, describes how the match between Go champion Lee Sedol and AlphaGo drew over 280 million Chinese viewers and the defeat of the strongest Go player became an event that could be compared to the "Sputnik moment" in the United States.

[3] For an analysis of the IT sector as a multitude of regional innovation systems, see Breznitz and Murphree, 2011.

[4] For a keyword analysis of Chinese AI-related S&T policies, see CISTP, 2018.

[5] For a recent overview of Chinese military innovation in artificial intelligence, see, among others, Kania, 2019a.

documents of this kind, the Plan provided general guidelines and set ambitious goals to grow the core AI industry to 150 billion RMB and the related industries to 1 trillion RMB by 2020, and to become a world leader by 2030. Notably, the government sees its role in shaping and promoting the development of AI in the context of indigenous innovation with a focus on applied policy measured primarily at the enterprise level—the focus on the technology development and application is clear despite some symbolic reference to supporting the basic research. This focus on applied research and innovation is an essential feature of China's innovation system that has been noted by many studies.[6] The utility of this approach is being debated in the research and policy communities. Western commentators often emphasize that the relative lack of attention devoted to fundamental research may limit China's long-term ability to benefit from the AI revolution (Hao, 2019). Some Chinese scholars and entrepreneurs, however, make the point that "advances in technology disseminate so quickly throughout the industry, that Silicon Valley's head start on core technology may prove irrelevant" and that policy adaptation and deployment at scale will be the key competitive advantages that will decide the future of AI in China (Lee, 2018).

Although the Plan seemingly emphasized market-dominant and open-source AI development led by private firms that are free to make their own technology decisions and will have a leading role in the establishment of product standards, the policymakers made it clear that the benefits of AI are not to be captured by the private sector alone but shared with the military via an "all-element, multi-domain, highly efficient new pattern of civil-military integration," implicitly recognizing the military and security services as key stakeholders in AI technology development with their own technology and applications agendas, as well as competing visions about what technologies may be used by private actors and what technologies should be limited. At the same time, the authors of the document implicitly admit that firms should forge ahead in developing AI unrestricted by laws and regulations, because the Plan states that "China will have seen the initial establishment of AI laws and regulations, ethical norms and policy systems, and . . . security assessment" only by 2025.

The high level of strategic prioritization of AI development is meant to serve several essential functions. First, it provides the basis for sustained investment in the industry by national institutions and thus facilitates the supply of long-term capital—which is crucial for a system in which the overwhelming majority of new corporate loans from financial institutions are given to state firms (including local government financing vehicles) (Lardy, 2019). Second, it provides a powerful signal to the local governments to help the "right" firms, thus setting in motion the fierce internal competition between local governments driven by a mix of incentives ranging from career promotion to personal gain (Bai, Hsieh, and Song, 2019).[7] This is important because in China local governments tend to have an enormous administrative capacity and financial resources. They play a leading role in determining the amount and allocation of resources devoted to technological development. To illustrate this point, we can compare the magnitude of funds allocated by individual cities and provinces to national-level initiatives elsewhere. For example, the city of Shanghai is raising $15 billion to bolster the development of businesses related to AI (Ren, 2018) and the city of Tianjin is setting a $15.7 billion fund to fund the development of new AI technologies (Jing, 2018). For comparison,

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[6] For example, see Appelbaum et al., 2018, Chapters 2 and 3.

[7] This report provides an insightful discussion about how the local governments in China shaped the industrial development and economic competition between firms.

France has earmarked 1.5 billion euros for AI support over the next five years under its "AI for humanity" initiative (*The New Mail*, 2018). At the same time, although competition at the provincial level is encouraged and has been a largely positive force behind China's industrial development (Bai, Hsieh, and Song, 2019), the prioritization of AI and the magnitude of the national-level involvement has led to infighting between the different ministries and agencies over their roles in setting and implementing AI policy (Ding, 2018b).

Local-Level Policy

Strategic prioritization of AI at the national level has led to a flurry of provincial- and city-level policies. A recent study from Tsinghua University identified 845 provincial-level AI policy documents (CISTP, 2018). The distribution of policies is unequal. For example, Jiangsu province issued the largest number—73—whereas the northern province of Heilongjiang had only 6. Overall, the distribution of AI policies largely mirrors the disparities in technological development between different regions, with Beijing-Tianjin-Hebei, Yangtze River Delta (Shanghai-Zhejiang-Jiangsu), and Guangdong/HK/Macao emerging as the main hubs for AI development. Each regional cluster features several major AI initiatives such as "AI Development Cluster" in Shanghai and AI Town in Future Sci-Tech City in Hangzhou.

All local-level policies usually refer to a specific national-level policy and contain the priorities that are similar to those outlined in the national policies, with each leading province focusing on a slightly different set of technologies depending on their respective advantages. For example, Guangdong emphasizes smart manufacturing and robotics, whereas Fujian focuses on IOT and big data (CISTP, 2018). Local governments also set their own development targets, which may significantly exceed the national target when combined. After the publication of the New Generation Artificial Intelligence Development Plan in July 2017, local governments in 18 provinces and municipalities released their own AI plans and targets, such that the cumulative targets of only 11 local governments for the development of AI core industries by 2020 added up to almost 400 billion RMB, which significantly exceeded the national target of 150 billion RMB for the same year (Ives and Holzmann, 2018). Shanghai has set the most ambitious goal for the development of AI and is aiming to develop core AI industries in excess of 100 billion RMB, roughly two-thirds of the national target, by 2020.

Local-level policies also provide more details on the specific incentives used to attract start-up and innovative firms. For instance, Hangzhou's Future Tech City provides 3 million RMB "settlement grants" and 15 million RMB in office rent subsidies. Shanghai promises 5 million RMB in office rent subsidies or 10 million subsidies for office purchase, whereas the most ambitious AI enterprises may get up to 100 million in financial support as well as access to city's abundant data resources in areas including education, health care, and tourism (Xinhua, 2018b). Similarly, Guangzhou offers grants as high as 100 million RMB for technology leaders, tax credits, and awards for individual researchers (Xinchuang, 2019).

Interestingly, this massive planning exercise does not stop at the city level, but often migrates to even lower-level authorities, which tend to partner up with leading firms to advance their goals. For example, Shangai's Lingang Area Development Administration signed agreements with over a dozen major AI firms such as Baidu and iFlyTek in a bid to develop a regional innovation hub that could potentially rival Beijing's Zhongguancun.

Individual firms also follow suit, with a recent survey indicating that about half of early AI adopters in China are developing comprehensive, companywide AI strategies (Loucks et al., 2019). At the same time, the development of plans and strategies does not equate to having the necessary expertise and resources to implement them, since only one in nine respondents believed that their firm was a "seasoned AI adopter." In the following sections, we will briefly discuss the key capabilities of China's AI innovation ecosystem.

Inputs to AI Innovation

Data

Data, along with software algorithms and computing power, is considered as one of the critical resources for the development of AI. A recent study on the evolution of deep learning equated data to the "new oil" and learning algorithms to the refineries that extract information from new data (Sejnowski, 2018). Indeed, data can be viewed as a complement to algorithms since cheaper and more powerful algorithms are increasing the demand for data. Generally, data can be used for the creation of algorithms (training data), as an input to algorithms to generate predictions (input data), and as a benchmark to improve the performance of algorithms (feedback data) (Agrawal, Gans, and Goldfarb, 2018).

The conventional wisdom suggests that China's large population combined with the widespread use of mobile internet and a larger share of activities conducted online give China a tremendous data advantage. However, the quantity of datapoints is not the only relevant parameter to assess the data resources available to Chinese companies and how efficiently they are able to use these resources to create new products and services. A recent report analyzed the availability of data along five different dimensions—quantity, depth, quality, diversity, and access—and found that China is very well positioned in terms of quantity, depth, and access to data while lagging in quality and diversity (Sheehan, 2019b). As expected, the strengths resulted from the sheer number of people living in China, their high usage of mobile internet, and government policies that allow for access of data from public spaces through smart city projects. The weaknesses resulted from the relative ethnic homogeneity of the Chinese population (albeit somewhat mitigated by diversity in terms of income and lifestyles) as well as disadvantages in terms of data quality due to underinvestment in enterprise software and digitization of data. Overall, this means that Chinese companies that can access and effectively use the available data will have the upper hand in the Chinese market; however, the insights learned from data on the relatively homogenous domestic population may be less useful for creating products and services targeted at foreign audiences.

To address this issue, China is aiding its companies by incorporating a significant digital component into the Belt and Road Initiative ranging from laying submarine internet cables, internationalizing the Beidou navigation satellite system, and working with Huawei on promoting 5G infrastructure to pushing for Chinese companies access to e-commerce and mobile payments markets (Chan, 2019). Another important aspect of this initiative is government-sponsored foray into the development of smart cities in Asia (Shigeta, 2018). All these initiatives may allow Chinese companies to access data on consumers abroad and provide them with the necessary resources to compete with their western counterparts. For example, Alibaba was able to implement its extensive City Brain service (Alibaba Cloud, undated) in Kuala Lumpur, which gives it access to real-time traffic data in the city and allows it to train its AI algorithms on those data (Beall, 2018).

Another essential component of AI development is the availability of the labeled data—a key input element that goes into training certain types of algorithms. Here, China may have an important advantage that other countries may not be able to match. In response to the insatiable demand for labeled data for autonomous driving and facial recognition algorithms, dozens of new "data factories" are working on building the databases for AI using manual labor. These factories employ thousands of people who once worked in manufacturing and now are labeling images of anything ranging from vehicles to human faces that are later used to train the AI algorithms (Li, 2018b).

Finally, the Chinese government is actively promoting data sharing, both between government and selected private companies through public–private partnerships in a variety of domains ranging from smart cities to national security, as well as within the private sector by setting data trading platforms. The former include Alibaba's City Brain project in Hangzhou (Toh, 2019) and YITU Technology's partnerships with dozens of public security bureaus across China (Lentino, 2019). Both initiatives feature close working relationships between the private companies and local governments that provide real-time data to these firms and use their technology to make decisions in real time. Data sharing in the private sector is facilitated by local initiatives such as the creation of the Shanghai data trading platform aimed at providing a regulated space where companies can trade data such as personal credit records and consumer information, in a bid to cover at least one-third of China's national data trading volume by 2020 and thus increase its role as a major AI and data hub in China and internationally (Ren, 2017).

Algorithms

The sophistication and quality of the algorithms developed and used by Chinese companies is another critical element of China's AI innovation system. It is also one that is difficult to assess in a systematic manner due to limited information since most firms regard the information on their algorithms as proprietary.

However, limited evidence suggests that there is considerable heterogeneity in algorithm sophistication even among the most technologically sophisticated internet giants. For example, Tencent—the owner of WeChat—has long been plagued by limited innovation capabilities in advanced algorithms for user profile analysis and categorization and content distribution due to weak algorithm research departments and reliance on "low-level" development of algorithms, which, in turn, did not allow it to fully use its massive data resources (Li, 2018a).[8] In response, the company launched its AI Lab in Shenzhen in 2016 and another AI lab in Seattle, hiring top AI scientists such as Yu Dong and climbing the ranks of top industry contributors at the most prestigious AI conferences such as ICML (Doerr, 2019) and CVPR (2019).

Hardware

China's limited hardware capabilities in semiconductors may be the most significant bottleneck in its AI innovation system. The traditional market for semiconductors that are currently used for AI applications, mainly consisting of GPUs and field-programmable gate array, is dominated by a handful of U.S.-based large firms such as Intel, AMD, Nvidia, and Xilinx.

Generally, Chinese firms seem to focus more on applications of AI such as vision technologies (biometric recognition, image recognition, video recognition) and voice and natural language processing (speech recognition, machine translation) and less on basic AI-enabling hardware such as semiconductors (CISTP, 2018). Currently, China lacks the foundational

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[8] Based on Chinese-language essay by Li Guofei published in March 2018 and based on interviews with a number of Tencent insiders.

technologies in semiconductors, as illustrated by the difficulties faced by Chinese tech giants ZTE and Huawei after the U.S. government cut their access to chips produced abroad. A recent Chinese-language essay by Sai Dong[9] summarized the state of the domestic semiconductor industry, noting that the majority of China's $200 billion semiconductor imports came from "geopolitically hostile" countries. At the same time, foreign-owned firms and joint ventures accounted for three-quarters of China's domestic production of chips. The argument against foreign reliance on core technologies is prevalent within the government and expert circles and provides an additional impetus to accelerate the development of the domestic semiconductor industry.

To address this challenge, China increased its funding to hardware start-ups, such as Horizon Robotics, accounting for over 16 percent of global start-ups by company count and more than 40 percent of the global financing raised.[10] The shift in technology to workload-specific AI accelerators offers an opportunity for newcomers to compete with the established players. For example, entry into desktop central processing unit production would be very difficult for a newcomer, since Windows runs on Intel's x86 family of instruction set architectures that fundamentally protect Intel's and AMD's dominant position in this market at the instruction set level.[11] On the other hand, AI chips do not have standardized instruction sets and tend to run on open-source libraries like TensorFlow and Theano, which in principle may allow newcomers to break into this new market because no single company has captured the licenses for these technologies. At the same time, it is important to keep in mind that China has been trying to break into the semiconductor market for years and even created a dedicated fund—China National Integrated Circuit Industry Investment Fund—which so far has failed to achieve significant breakthroughs despite raising over 130 billion RMB for semiconductor financing in 2014.

Skills and Human Capital

The availability of talent is another critical component of the AI innovation system, together with data and algorithms. According to a Tsinghua University report, by the end of 2017, China had over 200,000 AI researchers,[12] mainly concentrated in large cities along the coast, with Beijing holding the first place in terms of the overall number of AI researchers as well as the average H-index, a measure of productivity and quality of citation for scholarly reports. Eighty percent of these researchers are affiliated with academic and research institutions. The Chinese Academy of Sciences has the largest number of AI researchers, whereas Tsinghua University and Shanghai Jiao Tong University employ the most international AI researchers and top-level domestic researchers (CISTP, 2018). Enterprises only employ 5.9 percent of the available talent pool. Notably, China also leads the world in the number of AI research publications and the number of cited publications in deep learning (Churchill, 2018).

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[9] Chinese language is originally available from Dong (2018). For the English version, see Ding's (2018a) excellent summary and translation link.

[10] Based on analysis of James Wang (ARK), as reported in Korus, 2019.

[11] For a legal overview of x86 architecture, see Tang, 2011.

[12] The CISTP report refers to AI researchers who published Chinese patents or papers in Chinese or English over the last ten years. A LinkedIn report published in 2017 put the number of China's AI workforce at 50,000 (LinkedIn, 2017).

Although the aggregate number of Chinese researchers and published reports indicate the presence of a large talent pool, assessing its quality is rather difficult. One way to gauge the quality of AI talent is to look at the distribution of researchers who coauthor reports at leading conferences in the field. For example, Chinese-born researchers coauthored over a quarter of upper-tier reports at the Conference on Neural Information Processing Systems—one of the most prestigious conferences in the AI field. At the same time, all the top-tier Chinese-born researchers who coauthored reports selected for oral presentations were all affiliated with U.S.-based institutions. In fact, even within the upper tier of Chinese researchers, the majority went to U.S. graduate schools and were affiliated with U.S. institutions, while only a third were affiliated with institutions in China (Sheehan, 2019a). This suggests that China has the necessary human capital for raising top-level AI talent, but is not yet able to match the educational and working opportunities of the United States since most Chinese-born upper-tier AI researchers prefer to study and work abroad.

To address this shortage, the government designed a variety of programs such as the Thousand Talents scheme to attract researchers to Chinese universities and research institutions. The government also made it easier for foreigners to gain permanent residency status and is offering incentives to companies that employ top-level talent. These efforts could be aided by a less welcoming climate in the United States for Chinese-born researchers in terms of visa restrictions and political rhetoric.

Local governments also joined the effort by providing additional funding, housing subsidies, and even access to data from government institutions.[13] For a long-term supply of talent, the Chinese Ministry of Education approved a new AI-focused major called Intelligent Science and Technology that was adopted by dozens of colleges and universities.

Institutions and Larger Structure

Organizational Structure and Management

Anecdotal evidence from the largest Chinese firms suggests that companies' internal structure and corporate practices may be a drag on the efficient use of data. For example, in an essay on Tencent's strategy and operations, Li Guofei notes that Tencent has not been able to take advantage of its enormous data resources because its customer data are scattered across different departments that do not share with each other (Li, 2018a).[14] The article attributes this failure to organizational structure, underinvestment in algorithm research, and redundant processes. This is unsurprising, given that large firms like Baidu may have as many as 14 levels of individual contributors and ten levels of management (Zhi Hu Forum, 2015). At the same time, they have to be ready to expand quickly and maintain a high level of responsiveness, flexibility, and speed, which can only be achieved by decentralization and independent decisionmaking (Hout and Michael, 2014), which, in turn, may decrease interdepartmental communication and efficient data use. On the other hand, flat organizational structures that have unified management and technical teams are less capable of maintaining control over the flow of information as exemplified by the case of Bytedance, the owner of the news aggregator

[13] For example, a foreign researcher at ShanghaiTech University suggested that the images from the university's 3,000 cameras could be used for faculty's facial-recognition research projects (Churchill, 2018).

[14] For an excellent English language summary, see *ChinaAI Newsletter* (Ding, 2018c).

Toutiao, that was criticized by the state-run Xinhua News Agency for having and "overly flat" management structure with "only three or four layers" of management between the lowest level employee and the CEO, which contributed to its inability to control the spread of "false advertising and vulgar content" (Bai and Chen, 2018). In response, the CEO of Bytedance apologized for launching a product that "collides with core socialist values" and promised to change the company's model from reliance on algorithms for filtering content to a 10,000 worker content monitoring team (Mo and Chen, 2018). Other internet giants such as Baidu, Tencent, and Alibaba have responded to government requests on controlling the flow of information by employing thousands of "content reviewers" (Huang, 2018) and placing additional demands on their employees that are already protesting against the "996" working culture (that is, working 9 a.m. to 9 p.m. six days a week). Censorship demands add costs to the operation of these companies and increase the management overload, because most decisions on removing important content or product cannot be contained at the level of the content reviewers but will likely necessitate senior management review on a case-by-case basis.

More important, the fiercely competitive environment for a share in China's domestic market pushes private firms to focus on quick rollout of underdeveloped products to gain market share, thus emphasizing marketing and sales at the expense of technological innovation. The upside of this model is that Chinese companies competing in the domestic markets became very agile at rolling out new products and then updating and tweaking them in response to consumer feedback. In turn, this leads to a heavier tilt toward product development and engineering at the expense of research. Prominent AI venture capitalist and researcher Lee Kai-Fu argues that AI is in the "age of implementation," where the ability to capture the economic rents and create better algorithms will be mainly decided by the availability of data, rather than sophisticated algorithm research by top-level engineers and computer scientists. In other words, even if one starts with somewhat suboptimal algorithms and has a huge amount of data, these algorithms can be improved to the extent that they can match and exceed the algorithms that had a superior design at the onset by solely relying on data. If this is true, the ability of Chinese firms to release new products quickly, collect huge amounts of data, and use it to improve their algorithms may help them overcome the lack of high-level fundamental research because "once computing power and engineering talent reach a certain threshold, the quantity of data becomes decisive in determining the overall power of the algorithms" (Lee, 2018). We do not know whether this is true, but the speed of technological innovation in the past suggests that fundamental changes in technology did play a crucial role in innovation and that companies that relied solely on incremental improvements based on customer feedback were unable to maintain a competitive edge in the long run (Christensen, 1997).

Another long-standing issue that is affecting the development of Chinese firms is a relative lack of IP protection. This means that companies cannot solely rely on superior technology to maintain a competitive edge in the market.[15] Instead, they have to focus on vertical integration and building ecosystems that are much harder to replicate for a potential competitor. For example, DiDi—China's largest ride-hailing service that acquired Uber's Chinese division—is focusing its efforts less on improving its algorithms but increasingly on designing, building, and operating its own fleet of "purpose-built vehicles" and providing a range of end-to-end services from car leasing, financial and insurance services, car maintenance, to even gas station

[15] As Lee points out in his book, the technology can often be stolen and the best employees poached by competitive firms.

services (Jao, 2019). In other words, the competitive pressure requires that firms increasingly invest in vertical integration in an attempt to "build walls" around their business rather than differentiate their offerings through superior technology, which, in turn, is pushing them to become large conglomerates that operate in many different industries—a model that is different from the Silicon Valley emphasis on the lean start-up culture. There appears to be little to no recourse to the courts in the world of Chinese AI tech firms.

Business Ecosystem

China's AI business ecosystem has been dominated by large internet giants due both to market forces that tend to favor economies of scale and network effects, as well as government policies that place a strong emphasis on the creation of national champions. Currently, the first group of national champions designated by China's Ministry of Science and Technology includes Baidu (autonomous driving), Alibaba (smart cities), Tencent (medical imaging), iFlytek (intelligent voice), and Sensetime (intelligent vision).[16] The first three, collectively known as BAT, are coincidentally the largest investors in AI start-ups, collectively investing in over half of China's major AI companies across dozens of industries ranging from transportation and autonomous driving to home appliances, education, and finance (Hao, 2019).

The government is experimenting with a variety of platforms that are meant to accelerate the development of the business ecosystem by promoting financial and technological linkages between large financial and tech companies and start-ups. For example, China's State Development and Investment Corporation launched the All-Nation Artificial Intelligence Venture Capital Service Alliance (全国人工智能创业投资服务联盟) in Shanghai in 2018. This platform includes large investors such as Sequoia Capital, Huaxing, and Softbank China, AI giants such as Baidu and Tencent, educational leaders such as Tsinghua University and research institutions in the Chinese Academy of Sciences, and is supported by the National Emerging Industries Enterprise Investment Guidance Fund (国家新兴产业创业投资引导基金) (SDIC, 2017).

These initiatives are meant to increase the technological and financial linkages between the different elements of the innovation system, with the large private internet companies taking the lead in determining the most promising technologies and applications, and actively participating in setting the technological standards while competing fiercely with each other. This model somewhat resembles the development of business networks in other Asian countries in the sense that it is organized around designated "national champions," but seems to be more fluid and flexible since innovations occur at multiple nodes of the network and the leading companies are actively competing with each other and with smaller start-ups across a variety of industries (Greeven, Yip, and Wei, 2019).

Exports and International Competitiveness

The international competitiveness of Chinese companies that offer products and services enabled by AI algorithms can be broadly classified into four categories: business to consumer, business to business, business to government, and government to government. The former two

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[16] This niche segmentation was not the result of the type of targeting most famously attempted by MITI in Japan in the 1950s and 1960s. Rather, this was building on existing strengths although the domains were not fixed, because Baidu, for example, also does intelligent voice, and intelligent vision, and so does Alibaba. They are not precluded from competing with each other.

categories mainly contain AI-powered products and services that are sold by private companies, whereas the latter two have a mix of private and government-owned firms.

Chinese internet companies are very competitive in the business-to-consumer export space. The success of Chinese internet companies in India is a case in point. By the end of 2018, Chinese digital apps dominated the android applications market in India by representing five out of the top-ten most popular apps in Google Play Store and 44 in the top 100. In particular, Bytedance's TikTok short videos app held the top spot in the domestic Indian market (Shaikh, 2019b). Notably, Chinese media giants found their strong suit in localization by focusing on Indian users that prefer local-language user-generated content (i.e., generally not targeting the English-language market niche, which is well served by foreign and local competitors). They also tend to localize their teams and form partnerships with local music and media companies that allow them to quickly develop and implement new products that are tailored to local consumers. With the notable exception of TikTok (which is now a global brand), other Chinese firms operating in India are generally de-emphasizing their Chinese brand origin potentially to avoid distrust or as a precautionary PR exercise (Shaikh, 2019a).

Business to business remains a relatively weak segment for the Chinese companies both in the domestic market and abroad due to a lack of a well-defined business-to-business ecosystem. Cheap labor costs reduced incentives for most companies to substitute labor with technology and thus slowed the development of the business-to-business ecosystem that is a major driver of horizontal technology diffusion. This is changing quickly because domestic labor costs are rising, and firms in different industries are increasingly seeking to lower their labor costs and increase efficiency.[17] However, as of the time of this writing (August 2019), the domestic business-to-business ecosystem in China is not yet fully developed and there are relatively few examples of Chinese firms that would provide general-purpose AI-powered products and services to businesses in foreign markets, with the notable exception of hardware and equipment manufacturers such as Huawei that may include some AI-powered analytics together with their core products and services (Liao, 2019).

Business-to-government and government-to-government segments are developing quickly and have received a great deal of attention in the West due to concerns about large-scale surveillance and civil-military cooperation in China as well as China's export of these technologies abroad.[18] Within the civilian domain, Chinese companies are currently exporting AI-powered technologies for smart cities, such as Alibaba's City Brain traffic management service in Malaysia and Huawei's high-definition internet-connected cameras and data analytics system in Bonifacio Global City in the Philippines (O'Rourke and Choy, 2019). Government-to-government exports include national security projects abroad, such as China National Electronics Import and Export Corporation's export of Integrated Monitoring and Assistance System to Venezuela and Integrated Security Service in Ecuador, both of which featured hardware for facial recognition technologies. To date, 18 countries, including Pakistan, Kenya, UAE, and Uzbekistan, received Chinese intelligent monitoring systems (Ramirez et al., 2019).

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[17] For a recent analysis of the Chinese firms competitiveness in different business segments see, among others, Henry Shi's presentation "AI Startup Ecosystems in the U.S. and China: A Comparative Perspective" given at Google on March 2019 (Shi, 2019).

[18] For an overview of the PLA's use of artificial intelligence, see Kania, 2019a.

Challenges in Chinese AI Innovation

China's ambitions to become a leading innovator and adopter of AI-enabled technologies should be taken seriously given the amount of efforts and resources that are being allocated to this goal. Although China's AI innovation system shows notable signs of progress, there are a number of constraints that might slow down the development and successful adoption of these technologies at scale.

- *Bureaucratic politics may affect China's capacity to create and adopt AI technologies, especially when adoption threatens entrenched interest groups.*

Despite the heavy policy emphasis on scientific development and the push to adopt AI-enabled technologies, China's political system may prove to be a significant obstacle in the development and adoption of AI-enabled technologies when powerful interests are affected. For example, the Chinese Academy of Sciences developed an AI-powered system to monitor and evaluate public servants in China by accessing more than 150 protected databases in central and local governments. The system, called "Zero Trust," was built to detect suspicious activity both at the personal level by monitoring unusual increases in bank savings as well as at the project level in areas such as land acquisition and infrastructure construction. Apparently, the system was particularly useful in detecting corrupt officials, because during a limited trial in 30 counties it identified over 8,000 government employees engaged in misconduct. In response, some local governments decommissioned the system to "avoid large-scale resistance among bureaucrats" who "may not feel comfortable with the new technology" (Chen, 2019). Although the limited deployment of "Zero Trust" does not provide enough basis for far-ranging conclusions, it illustrates how entrenched interest groups within Chinese bureaucracy may stall the deployment of technologies that affect their power and financial interests. This may prove to be a significant bottleneck in the development of AI and China's technological innovation system more broadly because these technologies promise to deliver a higher quality of life. If these technologies are used to monitor only the ordinary people while granting immunity to government officials and party members, this may lead to a higher concentration of power in the hands of the bureaucrats and potentially increasing the opportunities for corruption.

- *Potential vulnerability to technology shocks due to weaknesses in hardware.*

China is currently facing difficulties in mastering advanced technologies in semiconductors, which may become a significant obstacle in its development of AI. So far, China has been able to purchase the necessary technology from abroad, but U.S. government actions against ZTE and Huawei and, more important, U.S. Commerce Department's plans to put export controls on some AI-related technologies including semiconductors show that unfettered access to foreign technology may not be a given in the future (Department of Commerce, 2018). In response, China is shifting its supply chains to include more non-U.S. vendors from Japan and Taiwan and is pushing for the development of domestic chips. In July 2019, both Huawei and Alibaba unveiled their own processors. Alibaba's Xuantie 910 processor is based on open-source RISC-V design and supports some AI applications like object detection and voice recognition (Wu and Chen, 2019). Huawei also introduced two chips designed by HiSilicon Technologies, its in-house chip arm, and produced by Taiwan Semiconductor Manufacturing Co., the world's biggest contract chipmaker (Li and Cheng, 2019). Despite these developments, it is too early to conclude that Chinese firms will be successful in designing and producing the cutting-edge hardware that is necessary to enable the future development of AI, whereas imposition of export controls from the United States and their allies could potentially slow down China's AI drive.

- *Shortage of talent.*

Despite the rapid development of Chinese tech firms and the increasingly attractive compensation packages offered by the private firms and the top universities, attracting top talent remains very difficult.

- *Resistance to adoption.*

So far, it seems that China did not experience the same type of backlash against data collection and reticence to adopt technologies such as facial recognition and autonomous vehicles as seen in certain parts of the United States and European Union. A recent survey of Chinese citizens showed a high level of support for AI-powered government surveillance programs like the social credit system that rates the trustworthiness of citizens (Kostka, 2018). However, this may change in the future if these technologies are increasingly viewed with suspicion in light of developments in troubled portions of China.

Annex on National Policies Related to AI

Table A.1
Summary of National AI Policies Up Until 2019

Time	Name of Policy	Publishing Unit	Policy content
5/2015	Made in China 2025	The State Council	Accelerates the development of a new generation of IT and manufacturing technology integration, and takes intelligent manufacturing as the main focus of the integration of the two; focuses on the development of smart equipment and smart products, and promotes the intelligentization of the production process
7/2015	State Council guiding opinions concerning vigorously moving forward the "Internet Plus" plan	The State Council	AI is listed as one of its 11 key actions. The specific actions are nurturing and developing emerging industries of AI, promoting smart product innovation in key areas, and elevating the intelligentization level of terminal products. The main goal is to accelerate the breakthrough of AI core technology and promote the application of AI in smart homes, smart terminals, smart cars, robots, and other fields.
3/2016	Outline of the 13th FYP for the national economic and social development of the People's Republic of China		Accelerates the development and application of new information network technologies, focusing on breakthroughs in key technologies for big data and cloud computing, autonomous controllable operating systems, high-end industrial and large-scale management, and emerging areas of AI technologies, and includes AI in the outline of the "13th Five-Year Plan."
4/2016	Industrial Robot Development Plan (2016–2020)	Ministry of Industry and Information Technology, National Development and Reform Commission, Ministry of Finance	By 2020, the annual output of industrial robots designed and built by Chinese companies will reach 100,000 units, and the annual output of industrial robots with six or more axes will exceed 50,000 units. The sales revenue of service robots exceeds 30 billion RMB; the major technical indicators of industrial robots have reached the level of similar foreign products; major breakthroughs have been made in key components such as precision reducers, servo motors, and drives for robots.
5/2016	Three-Year Implementation Plan for "Internet Plus" and AI	National Development and Reform Commission, Ministry of Science and Technology, Ministry of Industry and Information Technology, Office of the Central Cyberspace Affairs Commission	By 2018, build foundational resources and innovation platforms for AI. The AI industry system will be established at a basic level, and there will be breakthroughs in the fundamental core technologies. The overall technology and industrial development will be synchronized with the international market, and application and system-level technologies will lead the industry.
7/2016	13th FYP for scientific and technological innovation	The State Council	Develops a new generation of information technologies, including AI, focuses on the development of AI-based methods driven by big data, and has made important breakthroughs in the direction of humanlike intelligence based on big data analysis.

9/2016	Smart Hardware Industry Innovation Development Special Action (2016–2018)	Ministry of Industry and Information Technology, National Development and Reform Commission	Focus on the development of smart wearable devices, intelligent vehicle-mounted devices, smart medical devices, intelligent service robots, industrial-grade intelligent hardware devices, etc.
11/2016	13th FYP for strategic emerging industries development	The State Council	Development of AI, fostering the AI industry ecosystem, and attitude AI technology has been integrated and penetrated into all industries. Specifically, it includes accelerating the construction of AI support systems, promoting the application of AI technologies in various fields, encouraging the integration of various industries with AI, and gradually realizing intelligent upgrades.
3/2017	2017 work report of the government		First time “AI” was written into the government work report: on the one hand, we must accelerate the development of new materials, new energy, AI, integrated circuits, biopharmacy, 5G mobile communications, and other technologies. Other emerging industries, on the other hand, must apply big data, cloud computing, and the IOT, and use new technologies, new forms of business, and new models to bring about transformation in the production, management, and marketing models of traditional industries, with the development of smart manufacturing as our focus
7/2017	State Council notice on next generation AI development plan	The State Council	Defines three strategic goals for the development of a new generation of AI, and AI rises to the level of national strategy. By 2020, AI technologies and applications will be at the world-leading level, the scale of the AI core industry will exceed 150 billion RMB, spurring the AI-related industry scale to exceed 1 trillion RMB; by 2025, major breakthroughs will be achieved in fundamental theories of AI, the scale of the core industry will exceed 400 billion RMB, spurring the AI-related industry scale to exceed 5 trillion; by 2030, AI theories, technology, and applications will all reach world-leading levels, the core industry scale will exceed 1 trillion RMB, spurring the AI-related industry scale to exceed 10 trillion RMB.
10/2017	President’s report at 19th central Congress		AI written into the 19th Party Congress report, which will promote the deep integration of the Internet, big data, AI, and the real economy
12/2017	Three-Year Action Plan for Promoting Development of a New Generation Artificial Intelligence Industry (2018–2020)	Ministry of Industry and Information Technology	The Action Plan, from the starting angle of pushing industry development, combines relevant tasks in the “Made in China 2025” with the “New Generation AI Development Plan” and refines and implements them. Taking the deep integration of IT and manufacturing technology as the main line, and taking the industrialization of new generation AI technology and integrated application as a focus; it pushes forward the deep integration of AI and the real economy.

Table A.1—Continued

Time	Name of Policy	Publishing Unit	Policy content
3/2018	2018 work report of the government		AI once again included in the government work report: strengthens the research and application of AI; advancing "Internet Plus" in many areas such as medical care, elderly care, education and culture, and sports; developing smart industries and expanding smart living.
4/2018	AI innovation action plan for colleges and universities	Ministry of Education	Faced with the opportunities of the development of a new generation of AI, universities should further strengthen the advantages of basic research, discipline development, and personnel training, further strengthen the application of basic research and common key technological breakthroughs, constantly promote the deep integration of AI and people's needs, provide new ways to improve people's livelihoods, constantly promote the deep integration of AI and education for educational reform, provide new ways to lead the innovation of science and technology, personnel training, and technology application demonstration in the field of AI in China, and promote the overall strength of AI in China.
4/2018	Robotic Industry Development Plan (2016–2020)	Ministry of Industry and Information Technology, Development and Reform Commission, Ministry of Finance	Within five years, China has formed its own relatively perfect robotic industry system. According to the work deployment of the Ministry of Industry and Information Technology, the next stage of relevant industrial promotion policies will address two key issues: "First, to promote the development of the robotic industry towards high-end; second, to standardize the market order and prevent the disorderly development of the robotic industry."
11/2018	Work plan for soliciting units to undertake key tasks of innovations in the next-generation AI industry	Ministry of Industry and Information Technology	We will deploy key tasks such as intelligent products, core foundations, intelligent manufacturing and support systems, and collect and select a number of enterprises and scientific research institutes that have mastered the key core technologies of AI, strong innovative ability, great potential for development, etc. We shall tackle key problems through "soliciting units" and strive to make breakthroughs in the symbolic technologies, products, and services.
3/2019	2019 work report of the government		We will upgrade AI to AI+, build an industrial network platform, expand AI+, and empower the transformation and upgrading of manufacturing industry. At the same time, we should accelerate the development of new industries, deepen the R&D of big data, AI, and other applications, cultivate new generation of IT, high-end equipment, biomedicine, new energy vehicles, and other emerging industrial clusters, and strengthen the digital economy.

SOURCE: Translated from AskCI (2019).

APPENDIX B

Case Study: China and Pharmaceutical Products

This appendix provides a selection from the materials gathered in support of the report's case study on pharmaceuticals. It is being made available in particular to those who may otherwise lack practical access to Chinese-language materials.

China Pharmaceutical Industry in Context

Although Chinese companies such as Tencent, Alibaba, and Lenovo have become global powerhouses in communications, media, and IT, China lacks an equivalent in the pharmaceutical industry.[1] China intends to shift its pharmaceutical industry up the value chain to become an industry based on innovation rather than low value, low-quality production. However, it has not reached the status of what might be considered an "innovator" in pharmaceutical development (Ni et al., 2017). This is due primarily to two factors: first, Chinese pharmaceuticals have not reached an innovative R&D capacity capable of developing new drugs, and second, the quality of its generics industry has yet to meet international standards more broadly. Both will require higher market concentration, stronger industry standards, and a government and regulatory environment that encourages private investment in the pharmaceutical industry.

Driven by a combination of economic development and demographic trends, China is already the world's second-largest pharmaceutical market with generics making up approximately 80 percent of the market and name-brand drugs the other 20 percent (WHO, 2017). The implementation of industrial policy at a local level is shaped by regional differences within China. Local governments are often competing and pulling industrial policy in different directions (Bernhardt and Liang, 2014).

The fragmentation of the Chinese pharmaceutical industry is well known. This stems in part from competing interests of local governments for regional development and job creation. Rapid development has ensued, but this has been carried out inefficiently, which has led to small-scale, duplicative, and low-quality production (Zhou and Lan-Juan, 2013). Small firms are problematic for China's stated high-innovation strategy because their scale prevents them from establishing sufficient profits to fund major R&D investments.

The Chinese government has recognized that consolidation of its pharmaceutical industry is important. Currently, the government requires that any new pharmaceutical manufacturer be "consistent" with national development plans for the industry. This is their response

[1] The case study from which this appendix derives was performed in early 2019, before any changes that may have been instituted as a result of the COVID-19 pandemic that first appeared late in that year in the city of Wuhan.

to the concern that too many pharmaceutical companies are established without sufficiently advanced technology, leading to a waste of resources. By introducing and enforcing international standards of good laboratory practice and good manufacturing practice (GMP), for example, China has tried to ensure that only pharmaceutical companies able to afford the technology can survive (Chitour, 2013). The industry is still predominantly focused on manufacturing active pharmaceutical ingredients (APIs), supplied to finished form manufacturers (FFMs), and nonproprietary medicines (Li, Yang, and Du, 2011). For the majority of pharmaceutical enterprises, R&D spending is less than 5 percent of sales. Much of this is spent on generics research, further limiting the amounts available for innovative drug development (IBISWorld, 2017).

In a competitive sense, Chinese firms have been able to ascend the ranks of the world's top pharmaceutical suppliers (by annual sales and revenue) through capturing both API and FFM market share, and by leveraging a unique position within TCM markets. Several mainland China firms rank among the global top 100 pharma firms in the world. As of 2018, these included (rank in parentheses) Shanghai Fosun Pharmaceutical Group (上海复星医药) (59th), Zhejiang Hisun Pharma (浙江海正药业) (65th), Sinopharm Group (国药控股股份有限公司) (71st), Humanwell Medicine (人福医药) (74th), Sino Biopharma Ltd. (中国生物制药) (87th), Shanghai Pharmaceutical (上海医药) (94th), and CSPC Pharmaceutical Group Ltd. (石药集团) (96th) (Scrip 100, 2018). These rankings may underestimate the global market influence Chinese pharma has because industry tabulations often discount TCM in global sales figures.

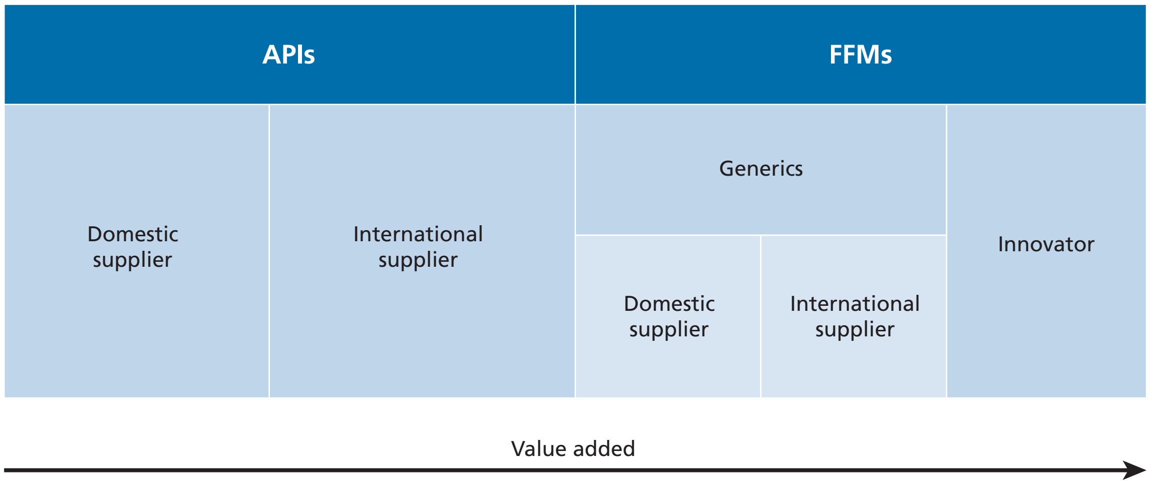
Government Support Under the Five-Year Plans

Under the 11th FYP in 2007, China's central government poured money into the biotechnology and pharmaceuticals industries. In 2008, China launched the national "New Drug Creation and Development" program, which provided 6.6 billion yuan ($960 million) to accelerate domestic drug R&D (Reviews, 2010). During the 12th FYP, the "Key Drug Innovation" project was supported with $16 billion from the central government and more than $49 million from local governments (Qiu et al., 2014). The overall goal was to improve the infrastructure of drug discovery and development. Biotechnology was also one of the seven priority industries in the 12th FYP, with the goal of having life sciences account for at least 4 percent of China's GDP (KPMG, 2011; Shobert, 2015). The pharmaceutical sector represented a portion of this larger priority area but also contains production and innovation endeavors that lie outside biotechnology as usually defined.

The 2016–2020 13th FYP provided provisions salient to the pharmaceutical industry. China's MOST issued a special target for biotechnology innovation that the biotech sector should exceed 4 percent of GDP by 2020 (China Daily, 2017). China also intended to build 10 to 20 science parks for biomedicine with a total output value surpassing 10 billion yuan ($1.45 billion) (China Daily, 2017). However, China's biologic and agricultural biologic market combined may represent just 0.1 percent of 2018 GDP, and achieving the 13th FYP ambitious biotech goals could require a historical reliance on "Chinese officials who may provide inflated numbers" (Kamierczak et al., 2019).

These strategic goals fall within a broader effort within China to reform the health care system, to include drug pricing and quality, health insurance, and physician remuneration (Sai, 2015). There is a continued push toward increasing market involvement in the determination of drug prices, a move that was initiated with the lifting of price ceilings in the summer of 2015. As outlined by the China Food and Drug Association (CFDA) and State Council docu-

Figure B.1
Value Chain for "Western" Pharmaceutical Manufacturing



SOURCE: RAND analysis.

ments early in 2015, improving drug quality would remain a priority. Plans were put in place for increasing reform and investment in the health insurance systems. This included merging the Urban Resident Basic Medical Insurance with the New Cooperative Medical Scheme, broader rollout of major disease initiatives, greater room for private health insurance, and increased government funding for public health insurance. From a provider perspective, plans included comprehensive reform of the remuneration of physicians and the medical services industry, likely a reflection of the problems created by the loss of income from a prior zero mark-up policy. There was also further encouragement for the development of capacity for primary care, electronic medical records, and telemedicine.

The government also has hoped to develop precision medicine—the customized tailoring of health care—through technologies such as telemedicine and more sophisticated uses of big data (Zhan and Qian, 2016). The push for innovation in the pharmaceuticals and medical devices industry certainly provide opportunities for domestic companies seeking to engage in R&D.

Components of the Chinese Pharmaceutical Industry

Western Pharmaceutical Production

Broadly speaking, there are two categories of manufacturing for Western pharmaceutical drug production along an innovation value chain (Figure B.1): active pharmaceutical ingredient (API) manufacturers, which produce the raw ingredients used in medicine; and FFMs, which make finished pharmaceutical products (FPPs)—the final product to be sold to market and consumed by the patient. Within APIs and FFMs, whether a firm sells primarily to a domestic or foreign market represents another indicator along the innovation value chain since exported products are generally taken as a sign of being able to meet global needs and standards. FFMs may also be categorized as "innovator" or "generic" companies. Innovator companies perform R&D to discover and bring new medicines to market. Drug discovery and clinical trials involve large R&D costs. These, as well as costs for unsuccessful trials, are recovered during a period of market exclusivity (so-called name brands). When this patent period expires, generic manufacturers may bring to market versions of the original brand drug that contain the same active molecules, produce the same therapeutic effect, and are manufactured to the same quality as the original product (IMS Institute for Healthcare Informatics, 2014).

China has been the world leader in the production and export of APIs, the easiest and furthest upstream product class (Chitour, 2013). For most of the decade since 2010, revenue from this raw material manufacturing industry has had an average annual growth rate of 15.9 percent (IBISWorld, 2017). The majority of revenue comes from exports, a demonstration of international competitiveness. Because the pharmaceutical raw materials industry does not require high technological capacity, industry profitability is relatively low (IBISWorld, 2017). China produces over 2,000 API drug products, with annual production capacity exceeding 2 million tons (WHO, 2017). Profit margins have been limited by factors such as the appreciation of the yuan renminbi, rising labor costs, and increased regulatory costs, but profits remain strong overall (IBISWorld, 2017).

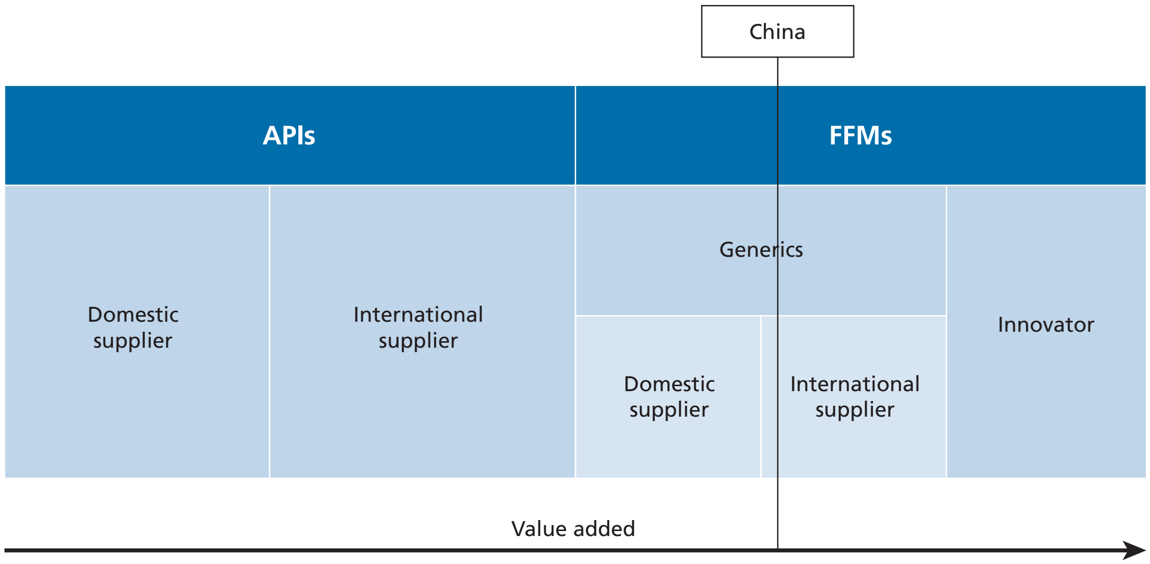
The scale of China's industrial ambitions means that it will naturally seek to diversify from exporting APIs into production of FPPs. Recent data indicate that Chinese manufactures are shifting to FPPs. These are sold primarily in the domestic market, however, with very few breaking into foreign markets (WHO, 2017). There are no Chinese companies within the top-ten largest generic pharmaceutical companies in the world, for example, Pharmaceutical Technology (2019). Chinese FFP companies struggle to sell products in foreign markets because of the rigorous registration and approval process in the United States, Europe, and Japan, for example, WHO (2017). In addition, the language barrier, in contrast to the success of Indian FFP firms in developed countries, remains an issue for Chinese FFPs (WHO, 2017).

Furthermore, the large majority of FFMs in China produce generic drugs (Bernhardt and Liang, 2014). Low-technology generic producers, which compete mostly on price, dominate the Chinese pharmaceutical market. Consequently, margins are low at around 5–10 percent (IBISWorld, 2017). Chinese companies dominate sales in the local generic market, whereas the local innovative drug market is dominated by imports by multinational corporations (Bernhardt and Liang, 2014). SOEs also tend to focus on the generics market. Their R&D expenditure has been low by international standards, at less than 5 percent of total revenue (Wang, Chen, and Tsai, 2012). Exports by domestic firms are only 0.5 percent of total revenues, highlighting their weakness in terms of international competitiveness.

This industry summary notwithstanding, China has succeeded in winning international accolades. China's pharmaceutical research community can rightly point to globally recognized successes in pharmaceutical innovation to include Tu Youyou's 2015 Nobel Prize in medicine. Her TCM application technique against a chloroquine-resistant form of Malaria demonstrated distinctively Chinese pharmaceutical innovation and that the reconciliation of Western and Eastern pharma practices could yield novel—if perhaps episodic—successful application against disease (Youyou, 2015).

Based on these attributes, we assess China's innovation position in the Western pharmaceutical value chain as reaching "medium-level" status, falling in the middle of the "generics" subcategory within FFMs (Figure B.2). This conclusion is based on the fact that the majority of Chinese manufacturers are involved in the export of APIs, whereas the remaining minority of FFMs sell domestically. China has no companies that have made proprietary drug discoveries (with the exception of TCMs, to be addressed later) that have achieved success on the international market. Therefore, they are not considered "innovators" within FFMs.

Figure B.2
China's Position Within Western Pharmaceutical Drug Manufacturing Innovation Value Chain



SOURCE: RAND analysis.

It is no surprise, therefore, that these higher-value segments in China face a number of challenges and are generally less developed compared with multinational pharmaceutical corporations. Manufacturing capacity is not well standardized, which leads to excess capacity in times of low demand (Ni et al., 2017). A generally weak regulatory and inspection environment can have serious consequences when it comes to drug quality. This hinders attempts for China to break out of low-value API exports into the more lucrative generic export market.

Biologics

Another major focus of investment, both in terms of R&D and production, is in the biological drugs segment. These are pharmaceutical products manufactured, at least in part, through the use of biological systems, most often single-celled organisms in large reaction vessels. "Biosimilars" is the counterpart of the term "generics," which applies to the manufacture of relatively small molecular weight pharmaceuticals principally through chemical means. In the case of biologics, manufacture of newly off-patent pharmaceutical products may not yield molecules that are precisely the same as those produced by the original innovator but are tested for similarity of clinical outcome to that of the original innovator's product. The Chinese government views the emerging biosimilars market, both domestically and internationally, as a major opportunity. From a public health standpoint, cancer is a major cause of morbidity and mortality in China and an increasing problem (Chen et al., 2016). Foreign investors are participating actively in R&D and production in the biologics sector through joint ventures and direct investment. This includes investments by most of the world's leading biopharmaceutical companies.

There are more than 500 biological product/biopharmaceutical companies in China. Most of those involved in R&D were established by returnees from abroad or by Western/joint venture companies (WHO, 2017). Although estimates vary, analysts believe that the Chinese government spends more than $600 million annually on biotech R&D through its funding initiatives (WHO, 2017). China's national and local governments also pour money into quasi-VC companies that invest in technology enterprises. The revenues of China's biopharmaceutical sector in 2014 were 275 billion yuan ($40 billion) (WHO, 2017).

Traditional Chinese Medicine

TCM is one of the most important contributions China has made to the global biotechnology industry. China has a long history of innovation in the natural medicine industry, especially the commoditization of medicinal herbs and traditional medical practice. TCMs play an important role in China's health care system and are expected to play a large role in the future. The public in China has confidence in these products and practices that are used to treat minor ailments such as colds and headaches but also major medical conditions such as autoimmune disorders and cancer (Jiang et al., 2018).

In recent years, China has sought to promote R&D on the active ingredients used in TCM, such as natural plant materials, to determine their clinical efficacy for potential application to a broader array of medical conditions (Jiang et al., 2018). China produces the largest amount of domestic and international patents related to TCM (Jiang et al., 2018). The Chinese government clearly sees new clinical discoveries of TCM as one of China's unique contributions to the global pharmaceutical industry. The sales growth rate of Chinese formulated product in the TCM market consistently outperformed Western medical sales from 2008 to 2015, accounting for 44 percent of the pharmaceutical retail market in China (WHO, 2017).

Jiangzhong Pharmaceutical group Co. (江中制药), one of the largest TCM pharmaceutical firms selling over-the-counter products in China, has adopted a strategy similar to other Chinese pharmaceutical enterprises by leveraging Chinese government subsidies and state-backed investment vehicles to develop. It is a subsidiary of CR Pharma—one of China's largest pharmaceutical companies (CR Pharmaceutical, undated). When CR Pharma bought Jiangzhong Pharma in 2018, it was one of the largest mergers and acquisitions in China (*South China Morning Post*, 2018). The company has built an array of public–private partnerships with Chinese medical universities and private health care groups. It has funded and built China's largest TCM university, for example, Liu and Li (2013). Its "China National Engineering Research Center for Protein and Drug Technology" (中国蛋白质药物技术国家工程研 究中心) has received financial support from major national projects, including being designed as a "national key laboratory," which affords it special status for preferential government loans and research grants (Liu and Li, 2013). China had roughly 220 national key laboratories as of 2018, and the China central government planned to increase to 700 by 2020 (Xinhua, 2018a). Jiangzhong and CR Pharma are involved in several health care equity funds, which leverage state backing to invest in SME pharmaceutical firms in China (*South China Morning Post*, 2017). Such tight networks involving the national and local governments, state-backed equity funds, universities, and private industry are not uncommon in China.

Pharmacy Industry Fragmentation and Regulation

There are different ways of classifying how many drug manufacturing firms there are in China. Based on the 2014 National Bureau of Statistics of China, there were 6,839 enterprises involved in the manufacture of medicines (National Bureau of Statistics of China, 2014), whereas the 2014 National Statistics Handbook estimated there were 4,629 enterprises in 2013. On average, it is estimated that there are around 5,000 firms in China, the vast majority of which are SMEs.

Market fragmentation is a well-recognized problem in China's pharmaceutical environment. There is insufficient regulatory capacity to adequately inspect and monitor such a large number of manufacturers. This allows low-cost manufacturers to compete by circumventing already low-quality standards, thus compromising safety. The sheer number of companies also creates a burden for regulators, which delays their other activities such as approving needed medications for patients. The China Center for Drug Evaluation has historically struggled with insufficient manpower, which has itself discouraged pharmaceutical R&D. The average waiting time for standard reviews was 12.3 months, roughly comparable to that for the U.S. Food and Drug Administration (12.9 months), but this could be prolonged much further to a point of having an uncertain time for obtaining final approval (Ni et al., 2017).

Until recently, regulatory standards in China were not consistent with international practices either. China did not join the International Council on Harmonization of Technical Requirements for Registration of Pharmaceuticals for Human Use, forcing innovative drugs that were already marketed in other countries to undergo new drug registration through China's Drug Registration Regulation. Consequently, the entry of import drugs to the local market was delayed seven years on average compared with the date the drug was first marketed in other countries (Ni et al., 2017). For example, Gardasil (a human papilloma virus vaccine) was first marketed by a multinational drug company in 2006 and approved in over 130 countries in the world. However, it had yet to be approved by the CFDA ten years later. Furthermore, for registration purposes, it was necessary to repeat the clinical trials of import drugs as China's good clinical practice was different from the good clinical practice according to the International Council on Harmonization of Technical Requirements for Registration of Pharmaceuticals for Human Use. In addition, preapproval by the CFDA was needed before clinical trials could be conducted, which meant another several months or more of waiting (Ni et al., 2017). The reasons for the delay may have less to do with health concerns or an intrinsic lack of harmonization but may possibly be a manifestation of a technical barrier to trade designed to limit the penetration of imports to serve other policy objectives.

Promoting Market Concentration

Increasing market concentration is a crucial aspect of improving the R&D capacity of Chinese firms as well as the quality of generic drug production. Concentration is increasing, albeit slowly: the market share of the top-100 firms has shown remarkably little growth until recently.

Investors in Chinese firms have traditionally struggled to withdraw their capital gains because of an underdeveloped mergers and acquisition market and strict initial public offering regulations (Qiu et al., 2014). There are signs that this is changing with the value of deals in the health care sector increasing substantially in the most recent years. Moreover, the average size of deals had grown significantly, increasing by five times between 2008 and 2013 (Niu, 2015).

One of the most significant challenges in achieving greater market concentration has been that local governments sometimes interfere with the closure of poorly performing local enterprises for political reasons. Local protectionism has been a major barrier to further market consolidation. Many companies provide significant tax revenues for local governments and employment for many workers, so closing them can be challenging not only because it decreases local government tax revenues but because closures could increase unemployment rates that reflect negatively during local government audits by the central government.

Chinese cultural practices can also have implications for the mergers and acquisitions market. *Guanxi* (a personalized network) is commonplace and means that in practice companies have obligations to other parties because of past relationships that are not shown on financial statements (Coyne, Haverty, and Lin, 2012). SOEs have been known to disguise their "debts" through the invention of transactions between themselves that they have no intention of ever settling (Coyne, Haverty, and Lin, 2012).

The government can encourage market consolidation through a number of mechanisms. General policies for encouraging merger and acquisition activity include making financing more easily available for companies seeking to engage in acquisitions and creating a tax environment favorable for mergers and acquisitions. More specific to the pharmaceutical sector, the CFDA has sought to use regulations for good laboratory practice and GMP both to raise the quality of drugs produced in China and to increase market concentration by weeding out weak firms. GMP certification also offers the advantage of exports being able to compete better internationally (Macintyre, 2011). The cost of compliance with new standards is likely to have a greater impact on small- and medium-sized enterprises (Niu, 2015). From a drug-procurement perspective, open tendering carried out across provinces to avoid favoring the companies of any particular region can also help to drive weak manufacturers out of the market.

Research and Development

The history of drug R&D in China may be divided into four distinct periods. Initially, Chinese companies simply imitated the synthetic methods and technologies of foreign companies. Over time this progressed to a more innovative form of drug development. Drug innovation came to mean modifying delivery methods and preparation formulae of existing drugs (the "excipients" or nonactive ingredients) without altering their underlying molecular structure of the active ingredients. Eventually, China progressed to "imitative innovation." Chemical modifications of existing drugs, such as changing acid or base groups, meant that China was developing "me-too" drugs. The final step of this process, which the Chinese government is keen to encourage, is the discovery of new chemical entities using advanced technologies (Ding et al., 2011; Qiu et al., 2014). At each stage, the development of the Chinese pharmaceutical industry was shepherded by relevant regulation, usually from new patent laws. For example, patent law began to give full protection to drugs in 1992, effectively requiring that competitors modify molecular structures, which gave rise to "me-too" drugs. This shows the influence government can have on shaping the industry through its choice of regulation (Qiu et al., 2014).

Overall, R&D is key to the innovative pharmaceutical industry that China wishes to encourage. Despite China having one of the fastest-growing rates of industry R&D investment in the world, R&D investment as a share of GDP remains low and only accounts for 2 percent of sales. This compares with the 14–18 percent seen at the same time in leading global pharmaceutical companies (Zhou and Lan-Juan, 2013). In 2015, China contributed only 1.8 percent of the global total toward medical research despite its market size (Moses et al., 2015). Granted, pharmaceuticals are not necessarily the same thing as medical research, but the low level of R&D suggests an overall lack of prioritization for the medical field as a whole.

China also faces challenges from an underdeveloped VC system, poor links between research and industry, and underperforming IP output (Zhang, Cooke, and Wu, 2011; Zhang and Zhou, 2017).[2] In more developed markets, start-ups contribute considerable innovation to the pharmaceutical value chain, but in China they play a smaller role, partly because of the lack of VC investment. The money may not necessarily be lacking, but the incentives to entice investors may well be. The overall pharmaceutical milieu contributes to low returns on R&D. A relatively slow approvals process means new drugs take a long time to come to market. When drugs do come to market, pricing policies have been in such flux that pricing is challenging. This, combined with a general lack of attention to drug quality, means that innovative products can potentially be undercut by low-quality products. From a reimbursement perspective, the depth of coverage is low and China's National Reimbursement Drug List is updated infrequently, at times five years or more. As a result, even if innovative drugs do come to market, many Chinese will not have access to them (Ni et al., 2017). However, the number of new drug applications to the CFDA still expanded to 388 new drug applications submitted in 2014 (up from about 50 in 2009).

Public–Private Mix of Investment and Geographic Variation

Different areas of the pharmaceutical sector tend to benefit from public and private R&D funding. Public funding is more concentrated in less-developed provinces with substantial natural herbal resources. The TCM and biopharmaceutical subsectors receive more public money than the chemical medicines subsector (Qiu et al., 2014).

Private investment had been estimated to provide 75 percent of total pharmaceutical R&D in China (Moses et al., 2015). However, it is unclear how far this R&D money is used to produce genuinely new drugs. Many of the so-called innovative drugs produced are really copy-cat drugs from a clinical perspective (Y. Huang, 2015). VC activity and investment levels in the pharmaceutical sector have been substantially lower in China than in other developed counties. China derives little export revenue from truly innovative products, which is a clear challenge for the pharmaceutical industry in future (Huang, 2015).

Bibliometric Assessment of Pharmaceutical Research in China

Publications indexed in the Scopus database reflect that among 28 disciplines, pharmacology, toxicology, and pharmaceuticals publications increased by 35 percent from 2008 to 2017, but they represented less than 1 percent of all China's publications in 2017, dropping from 1.7 percent in 2007. The citation capacity of China's work, a measure of report quality, peaked in 2013 and dropped in 2017. Of the work being cited, those reports published with foreign partners were cited at the world average of citation intensity, but work with a China-only address was cited less than the world average over the decade studied.

Table B.1 shows the number of projects represented in publications attributed to Chinese authors publishing in pharmacology, toxicology, and pharmaceuticals and immunology in 2007 and 2017. A small increase can be seen in the number of projects overall, from 1,438 to 1,539 in 2017. The number of addresses listed on reports doubled during that time, suggesting that many more entities participated in R&D by 2017; this finding is supported by the

[2] For example, Chinese pharma executives pointed out as recently as 2017 the following issues regarding poor links between research and industry: Chinese universities and private research institutes lack the infrastructure to effectively manage and transfer research from the lab to downstream. Finally, there's the absence of an effective intermediary (or enabling system), such as a dedicated technology-transfer or patent office, to facilitate the leap from upstream to downstream. Many top universities are starting to build tech-transfer offices, but they are in no way as common as in Western universities. See Zhang and Zhou, 2017.

Table B.1
Chinese Contributions to Scholarly Literature in Pharmacology, Toxicology, and Pharmaceutical Research, 2007 and 2017

	2007	2017
All Chinese pharm/immune projects	1,438	1,539
All unique addresses	351	726
University participation by address (China and int'l)	100	462
Corporate collaborative projects-all	86	157
Corporate collaborative, just int'l partners	38	31
University partnership (int'l)	30	661
Cities	144	556
Countries	26	51

SOURCE: Scopus publications database.

fact that many more Chinese cities were seen in the address lines of reports, rising from 144 to 556 cities in 2017. Moreover, university participation quadrupled from 100 to 462, perhaps in response to government calls to break down barriers among sectors. Moreover, corporate collaboration in pharma research projects doubled. International corporate partners dropped slightly from 38 to 31 in 2017, but international university partnerships saw the largest jump of any category, from 30 to 661 in 2017, suggesting a growing attractiveness of Chinese research centers to international partners.

Patents

China has made substantial progress in indicators such as patent applications. In 1991, China filed 1 percent of global life science patent applications, but in 2011 it filed 30 percent (Moses et al., 2015). The number of reports published by Chinese scholars in peer-review journals related to pharmaceuticals has leapt to the second position in the world (Ni et al., 2017). However, China incentivizes scholars through Science Citation Index-based promotions, which creates pressure for quantity over quality. The citation rate of academic reports remains in level or even dipped and in general the lives of patents are short. Between 2002 and 2013, the proportion of patents actually licensed to total patents granted gradually declined despite the rapid increase in the number of granted patents during the past decade (Ni et al., 2017). The statistics on the relevant literature suggest that research in pursuit of drug patents increased year by year (in China), reaching a peak in 2010, but yielded only 344 patents, which accounted for only 1 percent of the total of such patents worldwide (Ni et al., 2017). Overall, 95 percent of the patent market is dominated by non-Chinese pharmaceutical companies, and there is a gap between China and developed countries such as the United States (Ni et al., 2017).

Foreign R&D in China

Drugs developed abroad have a more problematic licensing pathway than those developed in China. Following approval abroad, drugs developed overseas are still required to provide local

Chinese clinical trial data (Su, 2013). This provides a powerful incentive for international firms to conduct R&D in China initially. In 2008, a new tax law offered preferential income tax rates and turnover tax exemptions to R&D centers providing research services to overseas companies (Deloitte, 2017).

China has certainly been successful at moving clinical trials onto its soil. In 2001, only four clinical trials were registered in China, but by 2010 that figure had risen to 497 (Bernhardt and Liang, 2014). China's R&D activities experienced rapid growth with revenues from the top-ten firms involved in such operations rising from 25 billion yuan in 2006 to 63 billion yuan in 2011 (Hvistendahl, 2013). The 20 largest international pharmaceutical companies in the world have all established manufacturing or R&D operations in China (IBISWorld, 2017).

Contract manufacturing and research, specifically CROs for preclinical research and clinical trials, have become a major industry in China. In 2014, there were approximately 300 CROs in China. Big pharmaceutical firms are seeking ways to reduce what they say it costs on average to research, develop, and bring to market a new drug in the United States (Tremblay, 2008). Although salaries have risen in recent years in China and India, the cost of outsourcing work to those countries remains lower than in developed countries.

Many CROs in China are founded by Chinese scientists returning from overseas (WHO, 2017). Their success was likely driven by market factors as well as the incentives provided by the Chinese government. China has a large patient population that has been willing to be involved in clinical trials. The inclusion of Chinese patients can also be beneficial as word-of-mouth referral is popular for Chinese consumers (Bernhardt and Liang, 2014). Estimates indicate that clinical trials in China can be conducted between four and ten times faster than in many other industrialized countries, clearly attractive for companies looking to market quickly (McTiernan, 2015).

Some multinational pharmaceutical companies have come to look to China for more innovative collaborations, built on the CRO structure. According to a senior director at the German pharmaceutical company, Roche Pharmaceutical, "We realized that a lot of the international CROs were in China, so there was no need to continue in that direction. So, we started to focus on collaborating with the emerging [Chinese] biotech companies, as well as with academic researchers, resulting in highly innovative projects in virology and in oncology within two years" (Reviews, 2010).

There are, however, concerns about the reliability and quality of trials conducted in China. GlaxoSmithKline fired its head of R&D in 2013 for misrepresenting data in a clinical trial of an experimental drug for multiple sclerosis (Hvistendahl, 2013). Other drug trials, such as that for the anticoagulant Eliquis (apixaban), have had problems that have on occasion led to delays in U.S. FDA approval (McTiernan, 2015). If the perception develops that Chinese trials are more likely to be invalid or unacceptable, this could be a significant concern for the research-contracting companies who carry out clinical trials.

Furthermore, there is evidence that higher-level R&D activities are not being moved to China. There seems to be a low level of knowledge diffusion when multinational corporations attract talent at the expense of local firms because of the higher salaries they can offer (Wang, Chen, and Tsai, 2012).

High-Technology Parks and Clusters of Excellence

China's central and local government organs offer a variety of incentives to spur biotechnological innovation in China. In fact, compared with most other developing and developed nations, the variable of government support has arguably been one of the more notable attributes of pharmaceutical and biotechnology development in China (Wang et al., 2009).

China's pharmaceutical industry is strongly present in Beijing, Shanghai, Shenzhen but also increasingly in other major cities. There has been rapid growth in the number of R&D centers around China, which have more than quadrupled since the mid-2000s (Bernhardt and Liang, 2014). These science parks were intended to imitate the Californian Silicon Valley example and build local innovation systems that would coordinate universities, R&D institutes, and production units (Wang, Chen, and Tsai, 2012). Entering the 13th FYP, there were approximately 20 relatively mature pharmaceutical clusters in China; 10 to 20 more were slated for construction to the year 2020. Local governments typically offer subsidies in the form of tax breaks or low interest rate leases on land to foreign investment. These parks allow international companies to take advantage of China's many low-wage scientists and smooth the entry of medications into China's market. They are also set up to encourage the creation of knowledge relationships between multinational corporations, local firms, academic institutions, and local private and public investment banks. Bioparks such as Zhangjiang Park in Shanghai and Zhongguancun Park in Beijing have attracted major international companies such as Eli Lily and Novo Nordisk to establish their local R&D headquarters. Early evidence suggested that these parks improved research commercialization prospects (Zhang, Cooke, and Wu, 2011).

Although the existence of these bioparks and clusters is a sign of significant investment in pharmaceutical capacity, it remains to be seen whether this number of clusters can be viable in the long term. The danger seen early on was that central or local government would be unable to discourage superfluous clusters (Macintyre, 2011). There is criticism that the R&D clusters encouraged by state and local governments have resulted in a boom of new science firms that are isolated from domestic SOEs. Instead, these innovative smaller firms became more closely associated with large multinational corporations (Wang, Chen, and Tsai, 2012). It is not clear that they did not choose wisely. Nevertheless, ensuring that China is able to effectively transfer foreign R&D and knowledge to domestic firms still remains a challenge.

Human Resources for R&D

The strategic priority for pharmaceutical R&D places substantial demands on China's science workforce. Shortage of talented Chinese employees is one of the greatest challenges to China's pharmaceutical industry (Bernhardt and Liang, 2014). Although China leads the world in terms of the overall size of its science and technology workforce, as late as 2015 it still had only 1.9 science and technology workers per 10,000 equivalents, less than a quarter of that in the United States (Moses et al., 2015). As with other aspects of R&D, human resources are concentrated in a few key provinces (National Bureau of Statistics of China, 2014). Nevertheless, an estimated 25 percent of Chinese students who study abroad return to China, which provides a large foreign-trained workforce (Rezaie et al., 2012).

The Chinese government has focused on increasing the number of graduates with advanced scientific training using tempting incentives such as increased pay. Whether these students will stay for the longer term is unclear, and there is evidence to suggest that China is not attracting the most highly trained and accomplished group of students or researchers to return, at least from the United States (Cao et al., 2020).

Corruption

Corruption has long plagued the Chinese health care system and until recently had been largely tolerated by the Chinese authorities. Hospital reliance on drug sales and low doctor salaries offer powerful incentives to accept bribes and under-the-table payments are difficult to turn down. The substantial backlog of regulatory drug approvals also creates a potential market for corruption to streamline a drug's review. Corruption and bribery may also be contributing to the local protectionism that makes increasing market concentration difficult to achieve. More recently, however, China has taken decisive, if perhaps uneven, action.

In December 2013, the National Health and Family Planning Commission issued a prohibition of nine unethical conducts within the health care industry. The prohibition focused on public health care staff taking or accepting money outside their legitimate income but also included prohibitions on participating in marketing exercises and procuring drugs not in accordance with legal standards. The anticorruption policy has been placed into key performance indicators for public health care staff, which are vital to their career and promotion prospects (DBS Group Research, 2015).

The GlaxoSmithKline scandal also highlighted that the authorities are increasingly willing to act on cases of perceived corruption and that there is a growing trend toward increased government enforcement. GlaxoSmithKline was hit with the largest bribery fine ever imposed on a foreign company in China, and the company's British head in China received a two-year prison sentence (Barboza, 2016). Although these actions generated headlines, they were seen in many quarters as a symbolic crackdown on dubious practices with the true motive of reducing drug prices rather than driving out international pharmaceutical makers. GlaxoSmithKline is unlikely to be the only company engaging in these practices given the substantial profits to be made.

These actions in the health care sector formed part of President Xi Jinping's wider campaign against corruption in the CCP (NPR, 2017). It remains to be seen the extent to which this affects location decisions by foreign companies in view of the burgeoning Chinese market. There may be scope for increased pressure to be placed on multinational corporations without driving them away. The fact that these corrupt practices are likely to be widespread could also give Chinese authorities leverage over such multinational corporations.

Conclusion

Although there is a tension between the desire for an innovative pharmaceutical sector that can develop new medications and strengthening the domestic generic sector so that cheap medications can be made broadly available, China has many advantages it can leverage. It has a huge market that is very attractive to domestic and international firms alike, a population that is able to spend more on drugs and an increasing number of foreign-trained graduates returning home with science backgrounds. A coherent national pharmaceutical strategy that incorporates industrial policy will help to promote overall health care goals, particularly because industrial policy is intimately linked with other aspects of policy such as drug regulation and approvals, pricing, and reimbursement.

Overall, the findings of the case study suggest that China has made strides in allocating inputs with the potential to put China at the cutting edge of pharmaceutical innovation, yet significant barriers remain. China is putting in place the building blocks for a successful pharmaceutical ecosystem based in China, although not necessarily carried out by Chinese companies. Rapid increases in R&D funding form the bedrock of their strategy and have led to increasing numbers of patients and publications. Capital investments in biotechnology parks are increasing as a way to create knowledge networks to spur innovation. IPRs have been modernized to close to those in Western countries, although further progress will be needed to foster true innovation. Efforts to eliminate corruption in health care are another important component of rationalizing all aspects of the pharmaceutical environment.

However, after decades of prioritization, China has yet to pass key thresholds of pharmaceutical innovation that would place it near the frontier of pharmaceutical development.

The pharmaceutical industry in China is heavily fragmented, leading to significant quality shortcomings. Furthermore, market fragmentation has meant that China predominantly exports upstream active pharmaceutical ingredients (APIs) and has largely failed to break out of low-value production into innovative drugs. China has not reaped the returns to R&D investment it has hoped.

Balanced against that will be the interests of local government and party leaders who may have a desire to retain some aspect of pharmaceutical production within their region with hopes of moving up the manufacturing and trading value chain. At the same time, given the long timelines and capital intensity of drug R&D and the trial and approval processes, the same authorities will likely be more interested in shifting the marginal investment toward shorter-payoff industrial sectors to improve performance indicators for their region. The resolution of these different interests and tension among incentives will likely determine the degree to which China realizes its aspirations in this sector of innovation.

APPENDIX C

Bibliometric Measurement of Scientific Knowledge Networks

In this appendix, we provide a more detailed discussion of the use of bibliometrics in understanding national and global knowledge networks.

Network analysis is increasingly used to study knowledge systems. This is due to the rise in collaborative exchange and teaming of R&D activities, which have their own dynamics (Milojević, 2014). Taylor (2016) found that innovative nations are ones that create and exploit networks to exchange knowledge, stay abreast of developments, and attract top talent to visit or settle. Wagner (2018) has shown that elite scientists and institutions are more likely to connect to others at the same level in global collaborations. These features suggest that international connections can be competitive—meaning that gaining the attention of other top researchers for the purposes of forming a collaboration becomes a mark of prestige that can enhance the reputation of individuals, institutions, and nations, and thus is sought after on a competitive basis.

Specific measures of network structure and dynamics can be analyzed to better understand the activities and advantages of national actors. Measures include "betweenness centrality," degree, density, and k-core relationships, each of which is used to show where and how knowledge is being shared across communities (Monge and Contractor, 2003), with an emphasis on flow opportunities that pass along strategic information. "Betweenness centrality" shows which players (called "nodes") exert power or influence over knowledge exchange: more central players have more power to control flows of knowledge and to facilitate relationships among network members. The measure of "degree" shows which members are more connected to others within a knowledge network with a higher degree conveying a propitious vantage point to stay on top of developments wherever they occur. "Density" shows the range and scale of the ability of any node to reach other actors in the network—often these connections are used to search for knowledge or identify new partners. "K-core relationships" shows which players are more intensively connected to one another, suggesting the formation of a group or intensifying development activities.

The collection of nodes and interactions ("links") determines the structure of what some scholars call the "typology" of the network—sparse and dense landscapes, and connected and disconnected populations. Barzel and Barabási (2013) have pointed out that networks observed in nature and society share structural commonalities—rules that can be discerned, observed, and measured. The Worldwide Web network of linked webpages has features in common with, say, a network of film actor collaborations. Networks whose nodes do not seem to have anything in common can show nonrandom similarities, such as metabolic and transportation networks studied by Amaral and Uzzi (2007). This striking commonality of network structures suggests to many scholars that some laws of connectivity and principles of exchange underlie all complex communications networks and that these principles and laws are knowable. Once known, opportunities exist for using networks to reach specific goals.

Considerable attention has been paid to the quality as well as the quantity of Chinese publications, patents, and STEM degrees. "There are two primary features of the innovation produced by China's new [National Innovation System]: rapid nominal output growth and lower than average quality of these [patent and journal] outputs" (Schmid and Wang, 2017). Although it appears that Chinese scholarly output is improving (Xie and Freeman, 2019), notwithstanding programs intended to expand education (e.g., by increasing the number of universities), some analysts believe that improving the quality of STEM and other education (outside a small number of elite universities) has taken a back seat to the research and production aspects of innovation (Liu et al., 2017) and to the focus on increasing educational capacity and degree production.

Within any R&D community, the process of communication networking begins during the education of STEM professionals, in laboratories and through conferences. Within China, the operation of the government-based funding system and the concentration of rewards on a first author can inhibit cooperation among researchers and associated network development (Liu et al., 2017). Further, there is less collaboration among companies and between companies and universities in China than in the United States, in part because funding mechanisms and differences in reward and legal structures reduce the incentives to partner (Liu et al., 2017), although industry-university collaboration is growing.

Innovation networks are local—within an institution or a locale, notably in the SEZs in China. They can also span a nation, especially for government-funded projects that aim to create connection. Increasingly, scientific knowledge networks and to some extent innovation networks are international (Dong et al., 2017). In some cases, R&D and innovation networks seem to transcend all manner of boundaries such as the collection of individuals who, with or without the support of their employers,[1] contribute to the development of the internet through the Internet Engineering Task Force[2] or the development of Linux and other open source software.[3] Although those examples may represent extremes, STEM professionals commonly identify with professional communities that transcend the boundaries of their institutions and nations (Saxenian, 2002).

The steady growth in international collaboration may be modulating the evolution of NISs. It also increases the potential for borrowing or otherwise appropriating ideas originating outside one's organization, locality, or country. "[M]any historical cases support the view that learning by imitation is a very promising way to catch up to advanced foreign industries" (Richter and Streb, 2011). Extramural sources for ideas have been a factor throughout the history of innovation (Arora, Cohen, and Walsh, 2016), but the broadening and densification of networking increase the likelihood that ideas will be found outside one's institution. In China, some collaborative potential has been chilled, however, by the continuing emphasis on indigenous approaches and outputs (Liu et al., 2017).

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1 Although much has been written about the altruism and group orientation of such contributors, there is also evidence of attending to self-, employer, and national interest.

2 IETF, undated.

3 See, for example, The Linux Foundation, undated. See also The Cathedral and the Bazar, undated.

International collaboration may also facilitate the maintenance of productive connections between Chinese living overseas and those in China. There has been a trend of transnational entrepreneurs who take advantage of a mix of ethnic, economic, and social networks—as one scholar has put it, a shift from brain drain to brain circulation (Saxenian, 2002). Meanwhile, this century has seen a trend of repatriation of Chinese who have been STEM students abroad (Zhou, 2018). China has also been encouraging the return of expatriates who have built STEM careers overseas along with recruiting a variety of experts broadly, notably through the Thousand Talents Plan,[4] which provides incentives for living and working in China. The early years of that program, at least, also saw fraud and mismanagement that diverted resources from their objective (Suttmeier, Yao, and Tan, 2006). Recently, scholars are returning to China in increasing numbers, although more so from the European Union than from the United States (Cao et al., 2020).

Through its systematic process of sending students and scholars abroad over the past four decades, and of investing in research projects in many parts of the world, Chinese scholars have joined existing networks and helped create their own distinct connections within China and at the global level. The increased governmental investments in R&D have led to exponential increases in production of scientific and technological publications and patents. Many of these products have been produced and shared at the international level, in journals and at conferences with peers from around the world.

China's S&T Publication Record

China has shown remarkable capacity to grow its S&T base by increasing publications in academic journals. Yet, counting S&T reports can be a tricky business. The Chinese Academy of Sciences reports more than 8,000 academic journals, of which about 4,600 are scientific. Most of these journals are published in Chinese and often address local issues and regional problems. A small percentage of Chinese journals are published in English. When Chinese scholars want to reach a broad audience, or when they coauthor with others from abroad, reports are published in English.

The U.S. National Science Foundation relies on the Scopus database to provide information on scientific publication trends. We drew from the same database for this study. Scopus indexes reports from a select set of high-impact journals chosen because they adhere to accepted standards of practice including rigorous peer review. Scopus data on China show a rapidly increasing number of reports with at least one Chinese author from 2008 to 2017. The numbers of publications are shown in Table C.1. Of worldwide publications totaling 1.9 million in 2008, 262,000 reports had a Chinese author; in 2013, this number grew to 447,000 reports; by 2017, the number had doubled from 2008 to reach 521,000 reports with at least one author from China. In 2017, China's output recorded in Scopus was second in the world, just slightly smaller than the leading country, the U.S. China's share of the world totals recorded by Scopus grew from 13.5 percent of the records in 2008 to 19.4 percent by 2017.

When we examine China's publication output by discipline, we find that engineering is the most frequently represented subject. Engineering is followed by materials science, physics and astronomy, computer science, medicine, chemistry, biochemistry, and others. Figure C.1 shows the breakdown by discipline for China's publications for 2008, 2013, and 2017.

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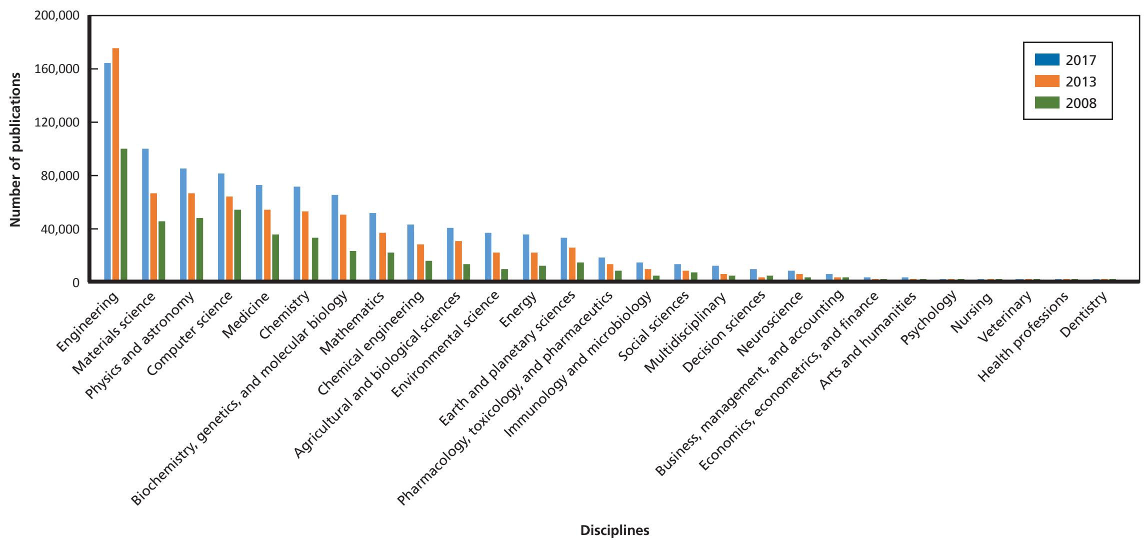
[4] See Thousand Talents Plan, undated.

Table C.1
China Publications in Comparison to Total in Scopus Database

	2008	2013	2017
World total, publications and percent	1,933,008 (100)	2,458,954 (100)	2,682,037 (100)
China total, and as a percent of all world output	262,024 (13.5)	446,557 (18.2)	520,928 (19.4)
China internationally coauthored reports, and as percent of all China's output	37,033 (14)	73,333 (16.4)	115,267 (22)

SOURCE: Scopus database.

Figure C.1
China's Publications by Discipline



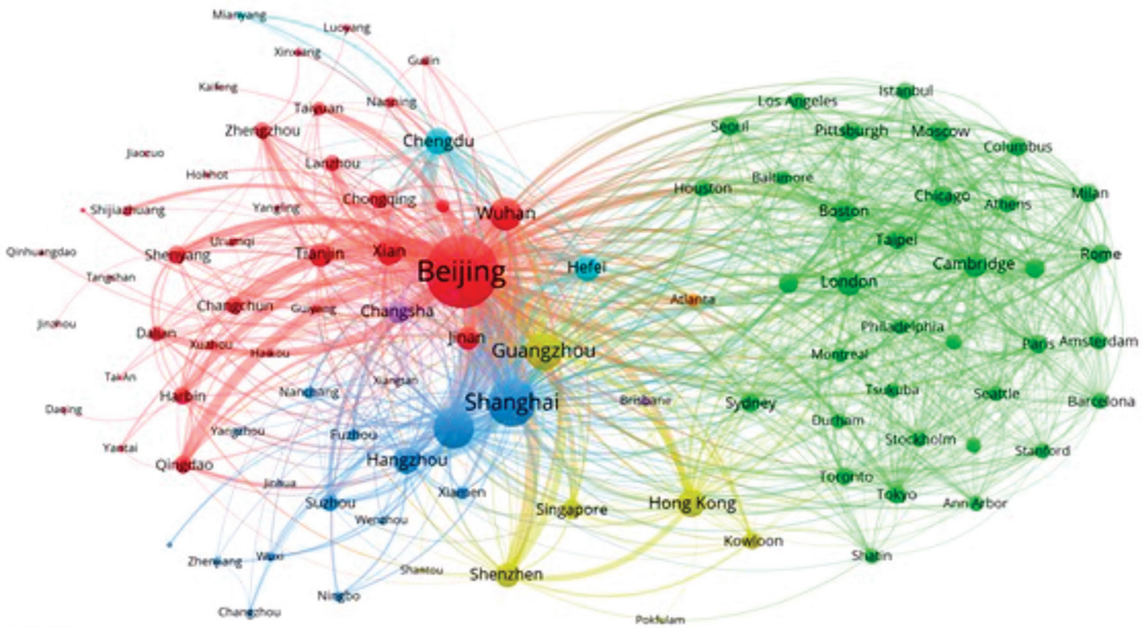
SOURCE: Scopus database.

The growth rates of disciplines vary. Although small in number, psychology, economics, and health reports were growing the fastest over the decade studied, possibly reflecting demand growth for this knowledge because the economy expands and industry differentiates its demand for knowledge inputs.

Of the total reports published with at least one Chinese address, a subset is coauthored with someone from a foreign country.[5] (These records also allow us to examine networks, discussed below.) Table C.1 shows the numbers and percentages of China's reports internationally coauthored. They grew more quickly than the number of reports overall: international coauthorships tripled over the same time period. China published 37,000 internationally coauthored reports in 2008, 73,000 in 2013, and 115,000 in 2017. China's share of international

[5] The foreign partner could be a Chinese national who worked overseas. The counts were made by address and country or record rather than the actual nationality of the coauthor.

Figure C.2
Collaboration Pattern of Chinese Cities, 2017



SOURCE: Scopus.

NOTE: Network color is the result of clustering calculations not discussed in this report.

coauthorships is smaller than that of other scientifically advanced countries, but China has been participating in the S&T system for only a brief time.

Networks of Cities in China

Using Scopus data of China's networks, we examined the extent of connections among cities in China. In 2007, Beijing dominated the network that other cities are difficult to see. Moreover, most international collaborations emanated from Beijing. By 2012 the participation of Hangzhou, Shanghai, and Nanjing as well as Guangzhou had grown along with greater dispersal of connections between Chinese cities and other large global cities.

Figure C.2 shows the connections among cities in 2017, revealing a great deal more connection among Chinese cities—even smaller cities such as Zhengzhou and Qingtao. Wuhan and Chengdu have grown into major scientific cities. The average clustering coefficient has dropped as Beijing has reduced its centrality and greater dispersal of power has spread across the network. Many more pathlengths exist to create connections among Chinese cities, as well as between Chinese cities and international cities. Shanghai has overtaken Beijing as the primary international collaborator.

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In this report, the authors examine the propensity within China's innovation system to realize its potential as an innovating nation: what is the balance of systemic forces that incline toward seeing that the innovation assets China possesses lead to innovation outcomes? They lay out a conceptual framework for capturing the major activities, interactions, and flows that give rise to technological innovations. They use this framework to place within one matrix salient elements that appear in the global literature on innovation, the literature on innovation in China and on its political, economic, and social systems, the results from three case studies prepared for this report (pharmaceuticals, artificial intelligence, and distributed ledger technology), and three different inquiries into the nature and measurement of network organization. They then provide a determination of which cells in the matrix that results from placing these elements into the innovation framework might be most useful as windows into those aspects of China's innovation system dynamics that might be expected to affect innovation propensity and observed innovation outcomes.

Measures are developed for these elements with an emphasis more on what the authors would like to know as opposed to what information might be most readily available presently. Thirteen of these indicators are then selected to form a preliminary "dashboard" of candidate indicators for China's propensity toward future innovation. These are offered not as final findings but rather as a first set of candidates to be assessed and refined in later empirical analyses. The authors also offer sample proxies for these draft indicators.

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