Review of International Political Economy

ISSN: (Print) (Online) Journal homepage: https://www.tandfonline.com/loi/rrip20

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To cite this article: Jeffrey Ding (2023): The diffusion deficit in scientific and technological power: re-assessing China’s rise, Review of International Political Economy, DOI: 10.1080/09692290.2023.2173633

To link to this article: https://doi.org/10.1080/09692290.2023.2173633

Published online: 13 Mar 2023.

REVIEW OF INTERNATIONAL POLITICAL ECONOMY
https://doi.org/10.1080/09692290.2023.2173633

The diffusion deficit in scientific and technological power: re-assessing China's rise

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ABSTRACT

Virtually all scholars recognize that scientific and technological capabilities are becoming increasingly important factors in a nation's overall power. Unsurprisingly, debates over a possible U.S.–China power transition highlight China's rise as a science and technology superpower. These discussions overwhelmingly center on national innovation capabilities, reflective of the bias in assessments of scientific and technological capabilities toward the generation of novel advances. This paper argues that these assessments should, instead, place greater weight on a state's capacity to diffuse, or widely adopt, innovations. Specifically, when there is a significant gap between a rising power's innovation capacity and its diffusion capacity, relying solely on the former results in misleading appraisals of its potential to sustain economic growth in the long run. I demonstrate this with two historical cases: the U.S. in the Second Industrial Revolution and the Soviet Union in the early postwar period. Lastly, I show that, in contrast to assessments based on innovation capacity, a diffusion-centric approach reveals that China is far from being a science and technology superpower.

KEYWORDS

diffusion; innovation; China; United States; technology; economic governance

Introduction

The genius inventor experiences a Eureka moment. An awesome engineering marvel reaches completion. A new theorem changes everything. These are the images that come to mind when most people picture scientific and technological advance. Neglected in the collective imagination is the toil of *diffusion*: an invention becomes a standardized product, an engineering marvel is re-constructed in another context, a theory spreads from one institution to another.

Likewise, most writing on the history of science and technology is primarily concerned with the emergence of new technologies (Edgerton, 1999). In contrast, as one economic historian points out, 'Much less attention … if any at all, has been

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Supplemental data for this article can be accessed online at https://doi.org/10.1080/09692290.2023.2173633.

accorded to the rate at which new technologies have been adopted and embedded in the productive process. Indeed the diffusion process has often been assumed out of existence' (Rosenberg, 1982, p. 19).

The same blind spot is evident in assessments of national scientific and technological (S&T) capabilities. Scholars and policymakers gravitate toward measures of a nation's capacity to generate new innovations, largely neglecting what happens after their initial introduction (Breznitz & Murphree, 2011, p. 2). Emphasizing a country's ability to monopolize innovation in leading sectors, influential theories of historical power transitions argue that dominating cycles of innovation in key technologies propels a rising power to global leadership (Kennedy, 1987; Modelski & Thompson, 1996). Predictably, debates over China's S&T capabilities also center on whether China can produce novel technologies.

Yet, without diffusion, even the most extraordinary innovations will not have an impact. Achieving great heights requires nightly toil, not just moments of sudden flight. Of course, in many cases, being the first to introduce new technologies makes it easier to adopt these technologies quickly and effectively. However, this advantage can be offset by other factors that affect the rate at which a country adopts new innovations at scale, such as the strength of communication channels that update small and medium-sized enterprises about new technological advances and the density of linkages that connect research institutes and firms. Therefore, a country's innovation capacity can diverge significantly from its diffusion capacity.[1]

When such a gap exists, innovation-centric assessments of national S&T capabilities will be misleading because they underweight a state's capacity to incorporate new advances into productive processes. In cases when the emerging power has a strong innovation capacity but weak diffusion capacity (*diffusion deficit*), it is less likely to sustain its rise than innovation-centric assessments depict. Conversely, when the emerging power possesses a strong diffusion capacity but weak innovation capacity (*diffusion surplus*), it is more likely to sustain its rise than innovation-centric assessments portray. Historical cases of both scenarios bear out these expectations. The U.S. in the late 19th century, a case of diffusion surplus, became the preeminent economic power, and the Soviet Union in the early decades of the postwar period, a case of diffusion deficit, suffered an economic collapse. In both cases, appreciation of diffusion capacity provided a more balanced assessment of S&T power.

Applied to present-day debates about China as a rising power, a diffusion-centric perspective provides new insights into China's S&T capabilities. China's perceived rise as a 'science and technology superpower' has occupied a substantial share of the debate over a possible U.S.–China power transition (Lan & Forbes, 2006; Suttmeier, 2008). These discussions overwhelmingly center on China's capacity to generate new S&T innovations, captured by indicators such as R&D expenditures and patent outputs (Kennedy, 2016; Rapkin & Thompson, 2003). However, an evaluation of China's ability to adopt new technologies across productive processes reveals a diffusion deficit, which rebuts claims that China is poised to become a science and technology superpower.

This article makes several contributions. First, by demonstrating that assessments of S&T capabilities should be rebalanced toward diffusion capacity, it suggests modifications to theories of global economic leadership that emphasize a country's ability to monopolize innovation in key sectors (Gilpin, 1981; Kennedy, 1987; Modelski & Thompson, 1996). This intervention directly bears on the broader questions related to the political economy of power, a core issue that connects international political economy and security studies.

In this vein, the article's main contention has major implications for assessments of national power, especially as scholars deem S&T capabilities as core power resources on the same level as economic and military capacity (Brooks & Wohlforth, 2016, p. 16; Nye, 1990, p. 34; Paarlberg, 2004). A diffusion-centric orientation is especially salient for assessments of a rising power's ability to exploit technological changes and maintain higher economic growth rates than its rivals, which has been historically connected to the rise and fall of great powers (Kennedy, 1987, p. xx). The article's findings have less bearing on other channels by which states can leverage S&T capabilities for influence. Innovation-centric assessments may be rightly prioritized in such contexts, including the effect of states' S&T capabilities on their prestige, structural power over global supply chains, and ability to field advanced military systems (Gilady, 2017, pp. 55–89; Malkin, 2020; Paarlberg, 2004). Still, appropriate attention to diffusion capacity can better inform other S&T dimensions of state power. For instance, there can be a large disparity between a military's ability to first develop or obtain new technology systems and its ability to adopt such systems throughout its branches and subunits.

Second, this study intervenes in debates over China's rise as a S&T power. While some scholars believe that China will inevitably overtake the U.S. as the preeminent technological power (Allison 2017; Layne, 2018), others argue that the U.S.'s lead in technology is durable (Beckley, 2012; Brooks & Wohlforth, 2016). These studies suffer from a common limitation: they only compare the U.S. and China's ability to produce new innovations, neglecting their ability to effectively use and adopt emerging technologies.[2] By revealing the gap between China's innovation capacity and diffusion capacity, this paper argues that innovation-centric assessments mistakenly inflate China's S&T power.

This analysis also engages with scholarship on China's industrial policy. Recent literature has paid more attention to technological developments located downstream of R&D and new-to-the-world innovation, such as China's ability to commercialize novel products and scale-up mass manufacturing capabilities in certain sectors (Breznitz & Murphree, 2011; Nahm and Steinfeld 2014). This paper further extends the scope of analysis to include not just China's production of emerging technologies but also the mechanism by which they are embedded in productive processes across a range of other industries.

Finally, a spotlight on diffusion suggests modifications to how policymakers approach technology policy and strategy, which are often affected by innovation-centrism. Political scientists and economists have traditionally emphasized the need for governments to aggressively protect intellectual property rights and the monopoly profits that come from innovation (McCarthy, 2015, p. 138). Recent work on the benefits of more open technological systems, which are characterized by more fluid distribution of new advances, has challenged the prevailing view that innovations must be protected at all costs (Weber 2004). This paper lends credence to the latter approach.

The rest of the article proceeds as follows. Building on an extensive body of econometric and historical evidence, the next section compares the relative importance of diffusion capacity and innovation capacity in power assessment. When there is a significant gap between these two dimensions, this section defends the former as a preferred barometer for whether rising powers can sustain economic growth at the technology frontier. Based on the process outcomes model, I clarify how various indicators map onto diffusion capacity and innovation capacity, showing that national S&T indicators are biased toward the latter. Section three leverages historical cases of rising powers, revealing that the failure to account for diffusion capacity resulted in misleading assessments of their S&T power. Next, I apply a diffusion-centered framework to assess China's S&T power, decomposing two influential indexes of national S&T capabilities to separately measure China's diffusion capacity and innovation capacity. Section five concludes.

The significance of diffusion capacity for assessments of national S&T capabilities

Assessments of national S&T capabilities should give greater consideration to a nation's diffusion capacity. Traditionally, these assessments center on a nation's potential to introduce new innovations, neglecting the often long and tortuous phase when new advances permeate across productive processes. Yet, leaders in innovation capacity can be laggards in diffusion capacity, and laggards in innovation capacity can be leaders in diffusion capacity. When there is a substantial disparity between these two facets of a nation's S&T capabilities, innovation-centric assessments of its power to leverage S&T advances for sustained economic growth will prove misleading.

Disentangling diffusion

Central to assessments of national S&T capabilities is a basic distinction between innovation and diffusion.[3] The former is defined as the first introduction of a new product or process, whereas the latter is defined as the spread of an innovation through a system or population (Schumpeter 1934, pp. 223–233). Thus, a state's ability to introduce novel S&T advances ('innovation capacity') is different from its ability to spread new innovations throughout its domestic ecosystem ('diffusion capacity').

Of course, it is difficult to completely disentangle innovation and diffusion. To derive power from scientific and technological advances, states must both introduce and spread these advances. The two processes can overlap and interact, as evidenced by the fact that additional innovations often occur in the process of diffusion (Taylor, 2016, p. 231). Oftentimes, a state's innovation capacity strongly correlates with its diffusion capacity.[4] The state that introduces a new method can benefit from first-mover advantages, thereby also leading in the widespread adoption of that method. When the source of the technological advance is international, absorbing such innovations require tacit knowledge that is difficult to extract from its original context (Fadly & Fontes, 2019; Keller, 2004). China's 'indigenous innovation' policies, for example, have boosted the capabilities of Chinese technology giants in key global production networks, which has aided the commercialization and adoption of emerging technologies by small and medium-sized firms (Malkin, 2020).

In theory and practice, however, a country's innovation capacity and diffusion capacity can widely diverge. A country's adoption rate of new technologies depends not just on its innovation capacity but also on many other factors, such as institutions for technology transfer, human capital, and openness to trade (Comin & Hobijn, 2010). Sometimes, the 'advantages of backwardness' allow latecomers to diffuse new technologies faster than the states that pioneer such advances (Gerschenkron, 1962). Cross-national studies on diffusion rates over multiple technologies have linked faster rates of intra-country diffusion with a later date of first adoption (Perkins & Neumayer, 2005; Pulkki-Brännström, 2009; Ray et al., 1969). To be clear, latecomer advantages do not determine a country's diffusion capacity. Without sufficient supporting infrastructure and human capital, latecomer countries cannot absorb key technologies. Nevertheless, I highlight the 'advantages of backwardness' thesis because it captures the tension between innovation capacity and diffusion capacity.

Substantial differences between a country's diffusion capacity and innovation capacity are not limited to developing countries. For example, while they both boast high living standards and highly developed economies, Sweden and Denmark have very different S&T systems, with the former investing heavily in frontier R&D and the latter concentrating on integrating new technologies into its production system (Edquist and Lundvall 1993). To compete in a world of globalized science and technology flows, the most advanced economies must also absorb and exploit innovations more effectively than the country in which it was first incubated. Per one estimate derived from data on the OECD countries over 135 years, 93 percent of total factor productivity increases in these high-income countries comes from knowledge that originated abroad (Madsen, 2007).

Additionally, leaders in the innovation of new technologies can also be laggards in the overall extent to which such advances penetrate a population of users. While the 'advantages of backwardness' argument primarily focuses on the speed of adoption, or the time from first use to saturation, innovation latecomers can also achieve a higher intensity of adoption (Comin & Mestieri, 2014, pp. 570–571). Take, for example, continuous casting, which is widely regarded as one of the most important process innovations in the history of the steel industry (Perkins & Neumayer, 2005, p. 795). The Soviet Union was one of the first countries to introduce continuous casting in the mid-1950s, but the diffusion of continuous casting throughout the country was very slow. In 1980 continuous casting produced only 10.7 percent of steel in the Soviet Union. This diffusion rate compared unfavorably with those of many countries that lagged in the initial innovation of continuous casting, such as Japan, which produced 59 percent of its steel with continuous casting in 1980, despite introducing the technology five years later than the Soviet Union (Poznanski, 1983, pp. 310–311).

Differential effects of diffusion and innovation capacity on growth outcomes

Careful work on the relationship between differential adoption of technology and growth trajectories further supports the need for independent analysis of diffusion capacity in assessments of national S&T capabilities. Using data on the diffusion of 15 technologies over 166 countries to study how technology adoption patterns affect cross-country income gaps, Comin and Mestieri distinguish between two different 'margins of adoption' (Comin & Mestieri, 2018). The *initial adoption lag*, closely linked to differences in innovation capacity, refers to the time between a pioneer's introduction of a new technology and the first implementation of this advance in other countries. The *intensive margin of adoption*, more tied to diffusion capacity, captures cross-national differences in the technology's intensity of use.

Measuring both margins of adoption is essential to comprehending how new technologies differentially advantage certain nations. In their analysis of the impact of these two margins on cross-country growth dynamics, Comin and Mestieri find that they contributed equally to the income differentials between Western and non-Western countries during the 19th century (Comin & Mestieri, 2018, pp. 168–169). Again, these two margins do not always converge. In some cases, leaders in the initial adoption of a technology can fall behind on the intensive margin of adoption. As demonstrated by the earlier example of continuous casting, compared to the Soviet Union, Japan faced an initial adoption lag but eventually led in the intensive margin of adoption because of its superior diffusion capacity (Figure 1).

Related work has shown that indicators of diffusion capacity can be more predictive of long-term growth outcomes than indicators of innovation capacity, which can be unreliable due to the long and uncertain lag between the initial introduction of a new technological advance and its impact on productivity growth. One analysis of technological shocks in the U.S. economy in the postwar period finds that two standard proxies of innovative activity, R&D intensity and patenting rates, have limited ability to predict fluctuations in total factor productivity. By contrast, activities related to broadly disseminating information about new products and processes track better with subsequent changes in productivity (Alexopoulos, 2011). Moreover, a study on the effect of human capital investments on long-term growth trajectories also favors measures of diffusion capacity. Leveraging U.S. county-level data, Maloney and Caicedo (2017) trace enduring income differences back to two

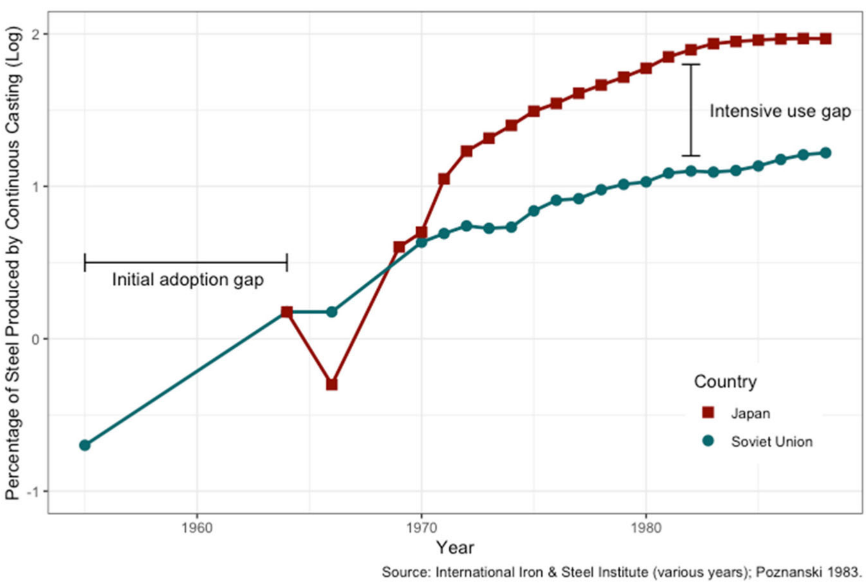

Figure 1. Diffusion curves for continuous casting.

different types of human capital in 1880: one that captures more inventive activities, proxied by patenting density, and one capturing more adoptive activities, proxied by the density of engineers in a county. While both types had a positive effect on long-term growth trajectories, the effect of engineering density was stronger than the effect of patenting density.

The salience of diffusion capacity is only enhanced for rising powers close to the technological frontier, which boast leading firms that can quickly copy or license innovations. For advanced economies with a certain degree of absorptive capacity and access to these global networks, divergences in long-term economic growth are shaped more by imitation than innovation (Alnuaimi et al., 2012; Gries et al., 2017, pp. 320–321).

Indicators of innovation capacity and diffusion capacity

Incorporating both diffusion and innovation capacity into assessments of national S&T capabilities is only meaningful if reliable metrics for both dimensions exist. To further unpack differences between measures of innovation capacity and measures of diffusion capacity, I draw on the process-outcomes model (Geisler, 2000). By separating the flow of S&T from initial inputs to ultimate absorption in the economy into identifiable stages, each with distinct measurable activities, the model clarifies which metrics attest to innovation capacity and which attest to diffusion capacity (Figure 2). Under indicators of innovation capacity, I include measures of R&D inputs (e.g. funding, personnel), direct outputs of R&D (e.g. patents, publications), and the effectiveness by which R&D inputs translate into direct outputs (e.g. R&D efficiency). Under indicators of diffusion capacity, I include measures of intermediate outputs, such as the usage rates of new methods, and measures of the strength of the linkages between direct outputs and intermediate outputs, such as the robustness of industry-research institution collaborations (Geisler, 2000, pp. 243–266).

Although innovation inputs and outputs represent only a portion of the S&T development process, they dominate assessments of national S&T capabilities in international relations scholarship. In fact, in one of the few articles dedicated to benchmarking S&T power resources, Robert Paarlberg states that S&T capabilities 'can be measured in terms of either final scientific output or R&D input' (Paarlberg, 2004, p. 126). Accordingly, Paarlberg's measures of scientific and

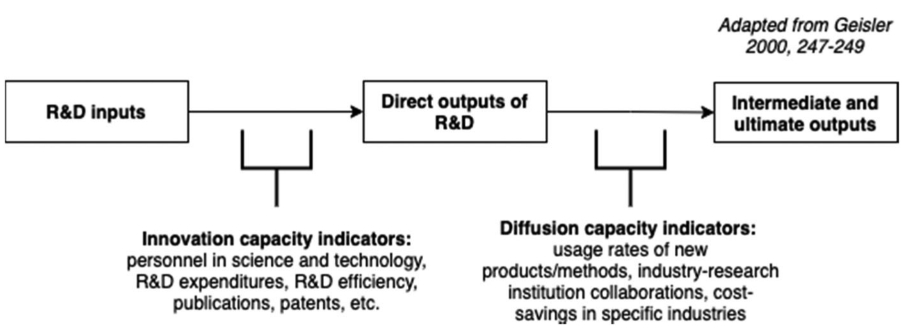

Figure 2. Innovation and diffusion capacity metrics, ordered by process outcomes model.

technological leadership include scientific papers published, patents registered, prizes won, innovation hubs, and R&D spending (Paarlberg, 2004, p. 126–133). Similarly, other work that benchmarks international S&T performance privileges innovation capacity indicators, such as patenting rates (Taylor, 2012, p. 119; Taylor, 2016, pp. 37–38) and Nobel Prizes (Gilpin, 1968, p. 29).

Among indicators of innovation capacity, R&D spending has become a magic number of sorts. Paarlberg writes that 'perhaps the best way to measure the U.S. lead in science and technology' is with R&D inputs (Paarlberg, 2004, p. 129). The U.S. National Science Board (NSB), one of the pioneers of national S&T indicators, also prioritizes data collection and analysis of R&D inputs and direct outputs. The NSB's 1993 *Science & Engineering Indicators* claims, 'The long term importance of R&D expenditures to technological preeminence, military security, and knowledge growth is axiomatic' (National Science Board, 1993, p. 89).

This bias toward indicators of innovation capacity is reflected in power formulas used to calculate the power of states. Combing through an encyclopedia of all power formulas published from 1714–2010 (Höhn, 2011), I found 25 power formulas that incorporate scientific or technological capabilities as a separate element of national power.[5] I could identify indicators of diffusion or innovation capacity for 14 of these formulas. This remaining sample strongly favored indicators of innovation capacity. Nine of the power formulas employ a mix of both innovation capacity indicators and diffusion capacity indicators, with six favoring the former and none favoring the latter.

The other five formulas exclusively relied on innovation capacity indicators. For instance, the Indian National Security Index, developed by India's National Security Council Secretariat in 2002 to assess comprehensive national power, calculates S&T power using three innovation capacity indicators: patents granted to residents per mission, R&D expenditures as a percentage of GNP, and scientists and engineers as a proportion of R&D spending (Hwang, 2010). By contrast, none of the power formulas solely relied on diffusion capacity indicators.

S&T development is a complicated, messy process, so neatly sorting S&T metrics by associations with innovation capacity and diffusion capacity is a tough endeavor. Fortunately, the process-outcomes model functions as a helpful guide for identifying innovation capacity metrics and diffusion capacity metrics. These metrics reveal that the existing literature on power assessment is biased toward innovation capacity. A clear basis for differentiating between these two types of metrics will serve useful for the historical case studies of S&T assessments of rising powers, as well as the application to present-day assessments of China's S&T capabilities.

Historical cases of diffusion deficits and surpluses

I have presented a range of evidence to argue that assessments of national S&T capabilities should pay more heed to diffusion capacity. In this section, I employ two historical case studies to illustrate that the general reasoning from the previous section extends to assessments about rising powers' S&T capabilities.

To tease out the independent significance of diffusion capacity, I focus on cases of rising powers with substantial disparities between their diffusion capacity and innovation capacity. Accordingly, I study the U.S. in the late 19th century as a case when a rising power has a weak innovation capacity but strong diffusion capacity (*diffusion surplus*). I also study the Soviet Union in the early postwar period as a case when a rising power has a strong innovation capacity but weak diffusion capacity (*diffusion deficit*). In both cases, there is general agreement that adaptability to S&T advances played an outsized role in determining the rising power's long-term growth trajectory. This alleviates concerns that innovation-centric assessments were only misleading in these cases because the effects of other factors, such as imperial overstretch or demographic changes, overwhelmed the impact of innovation capacity.[6]

The two cases bear out the expected outcomes tied to diffusion deficits and surpluses. Innovation-centric assessments of the U.S., a case of diffusion surplus, underestimated its potential for S&T leadership; conversely, innovation-centric assessments of the Soviet Union, a case of diffusion deficit, overestimated its potential for S&T leadership. The U.S. sustained higher levels of productivity growth than its rivals and cemented its claim to economic preeminence in the early 20th century. In contrast, the Soviet Union's productivity growth stagnated in the 1980s and its economy collapsed shortly after.

The U.S. in the second industrial revolution (1860–1890)

The rise of the U.S. as an economic power took place amidst an era of remarkable technical breakthroughs, sometimes dubbed the 'Second Industrial Revolution' (Mokyr, 1998). If judging technological leadership in this period based on a country's ability to generate novel S&T advances, few would have picked the U.S. as the leading candidate. The U.S. trailed Germany and other advanced economies on this front, leading many prominent American scientists to underrate the U.S.'s prospects for S&T leadership. Assessments based on diffusion capacity, however, tell a different story, as Americans excelled at the widespread adoption of innovations first introduced by other countries.

In the decades before World War I, the staying power of the U.S. S&T base confirmed the diffusion-centric view. Across various measures of industrial output and efficiency, the U.S. emerged as the preeminent economic power. Most notably, the U.S. surpassed Britain in per capita GDP and labor productivity around 1900 (Bolt & Luiten van Zanden, 2020; Broadberry, 2006, pp. 108–109). Did a failure to account for diffusion capacity contribute to flawed assessments of U.S. S&T capabilities? If theoretical expectations of a diffusion surplus hold, the case study evidence should reveal that innovation capacity indicators depicted the U.S. as a relatively weak S&T power. By contrast, the historical data on U.S. diffusion capacity should point toward the strength of U.S. S&T power in this period.

Indeed, the U.S. was far from an innovation leader during the second half of the 19th century. Scholarly and media reports criticized the U.S.'s failing in basic research during this period (Shryock, 1966, p. 73; The New York Times, 1860; Taylor, 2016, p. 9). American researchers lacked the financial support to compete with their European counterparts. By one estimate, in 1891 the entire U.S. research ecosystem supported only twenty-six 'adequately endowed post-graduate fellowships in science' (Cohen, 1976, p. 383).

European centers of excellence were advancing the technological frontier.[7] Carl Snyder, in an influential article for the *North American Review* published in 1902, attributed European leadership in the great discoveries of the 19th century to their elite research institutions. The U.S. lacked institutions comparable to the German university system, the Royal Institution of London, or the College de France (Snyder, 1902, pp. 67–72; Dupree, 1964, p. 300). Nor were American cities competitive with London, Paris, and Berlin as innovative research clusters (Shryock, 1966, pp. 72–73). It is no surprise, then, that the best and brightest American researchers furthered their training at European institutions. This brain drain was an 'almost wholly one-way direction of movement of graduate and postdoctoral students' (Cohen, 1976, p. 359).

International comparisons of developments in chemicals, a key emerging technology in this period, provide more detailed indicators of the U.S.'s comparatively weak innovation capacity. From the inception of the Nobel Prize in 1901 to 1930, German and Britain researchers won almost three-fourths of the Nobel Prizes awards in chemistry, whereas just one American attained the top honor in that span (Thackray et al., 1985, p. 161). In 1899, German publications accounted for half of all citations in American chemical journals, essentially double the share attributed to American publications (Thackray et al., 1985, pp. 405–407). At the same time, American articles barely registered in the chemical journals of Europe, where the best research was published. According to one analysis of references in *Annual Reports on the Progress of Chemistry*, an authoritative British review journal, American publications accounted for only 7 percent of the citations in 1904 (Thackray et al., 1985, p. 157, 402; see also Macleod, 1971, p. 207).

In some cases, prominent critics of American science exaggerated U.S. deficiencies to press their case for additional R&D support (Kevles et al., 1980). The U.S. performed well on some indicators of innovation capacity, including patent counts and government R&D expenditures (The New York Times, 1860; Kevles et al., 1980, p. 32). Overall, though, the majority opinion was that the U.S. lacked the means to produce original breakthroughs. Across rankings of nations in terms of 'productive scholarship' during this period, America's 'most favorable classification' was fourth place, after Germany, Great Britain, and France (Slichter, 1902, p. 12).

Judgements based on diffusion capacity, by contrast, paint the U.S.'s S&T capabilities in better light. Even though the U.S. lagged behind industrial rivals in scientists and researchers, the U.S. cultivated a broad-based system that trained more engineers and cultivated strong linkages that transferred knowledge between academic and industrial research institutions. Compared to arrangements at European peers, research and teaching in American universities were more closely tied to commercial opportunities, which 'aided the diffusion and utilization of advanced scientific and engineering knowledge' (Mowery & Rosenberg, 1993, p. 36). As a result, in many emerging technologies, the U.S. lagged in generating new breakthroughs but led in adapting them across many useful domains.[8]

Revisiting international comparisons in chemicals, despite lagging behind Germany in terms of chemical innovations and top chemists, the U.S. was the first to institutionalize the discipline of chemical engineering. This was necessary for the widespread diffusion of chemical processing, which came to transform a wide range of industries such as ceramics, food-processing, glass, metallurgy, petroleum refining, etc. A crucial step in this process was the emergence of unit operations, which broke down chemical processes into a sequence of basic operations (e.g. condensing, crystallizing, electrolyzing, etc.) that were common in chemical processing across a number of industries. Enabled by unit operations, the development of chemical engineering broke down the siloed divisions of industrial chemistry, which had been primarily oriented around the production of a very large variety of chemical products with little concern for the unifying principles between the manufacture of different products (Little, 1933, p. 7; Rosenberg, 1998, p. 176).

Though Germany dominated industrial chemistry, the U.S. led in cultivating a chemical engineering discipline that facilitated the gradual chemicalization of many industries. By 1913, the U.S. led the world in the production of chemicals (Murmann 2003), an indicator of the U.S. advantage in the intensive margin of adoption. American institutions of higher education, most notably MIT, were early adopters of the unit operations model and helped cultivate a common language and professional community of chemical engineering (Guédon, 1980, pp. 45–76; Rosenberg, 1998, p. 171). Rosenberg and Steinmueller conclude, 'American leadership in introducing a new engineering discipline into the university curriculum, even at a time when the country was far from the frontier of scientific research, was nowhere more conspicuous than in the discipline of chemical engineering early in the 20th century' (Rosenberg & Steinmueller, 2013, p. 1145).

Fittingly, one of the most colorful denunciations of America's innovation capacity simultaneously underscored its strong diffusion capacity. In an 1883 address to the American Association for the Advancement of Science (AAAS), Henry A. Rowland, the vice president of the AAAS, denigrated the state of American science for its skew toward the commercialization of new S&T advances. Rowland expressed his disgust for media representations that upheld the 'obscure American who steals the ideas of some great mind of the past, and enriches himself by the application of the same to domestic uses', over 'the great originator of the idea, who might have worked out hundreds of such applications, had his mind possessed the necessary element of vulgarity' (Rowland, 1883, p. 242; Taylor, 2016, p. 9). Yet, it was America's diffusion capacity – in all its obscurity and vulgarity – that sustained its growth to economic preeminence.

The Soviet Union in the early postwar period (1950–1970)

In the early postwar period, the Soviet Union shocked the world by launching the first satellite. Sputnik was just one of the many prominent Soviet scientific and technological achievements in the early decades of the Cold War. During this time, 'the USSR appeared to all as a rising technological juggernaut (Taylor, 2016, p. 75)'.[9] Ultimately, the Soviet Union's total factor productivity growth slowed significantly in the 1970s; some studies, in fact, estimated a decline in factor productivity over the decade (Trachtenberg, 2018, pp. 86–87). The Soviet Union's collapse in 1991 laid bare the inefficiencies of its productive engine.

Did neglect of the diffusion process contribute to misleading views of the Soviet Union's S&T power? In cases of diffusion deficit, when a rising power's innovation capacity substantially outpaces its diffusion capacity, innovation-centric assessments will overestimate its ability to sustain its rise. If theoretical expectations hold, evidence from this case should show that innovation-centric measures corresponded to a view of the Soviet Union as a S&T superpower. Additionally, diffusion-centric measures should expose the fundamental weaknesses of the Soviet Union's S&T capabilities in this period.

An innovation-centered lens shaped views of the Soviet Union as a S&T superpower. The Soviet Union became a world leader in two key indicators of innovation capacity, R&D spending and the employment of scientists and engineers (Beckley, 2018, p. 35). A 1962 OECD report, one of the first efforts to systematically compare national S&T capabilities, found that the Soviet Union was near parity to the U.S. in these two indicators (Freeman & Young, 1965). By 1970 the Soviet Union led the world in R&D spending as a percent of gross national product (3.28 percent), exceeding the comparable U.S. figure of 2.57 percent (National Science Board, 1987, p. 236).

The notion of a 'scientific manpower gap' – specifically, that the Soviet Union was graduating two to three times as many scientists and engineers than the U.S. – took hold in U.S. discourse (Teitelbaum, 2014, pp. 32–36). Throughout the 1950s, this figure was 'repeated ad infinitum' by analysts and politicians, including the Central Intelligence Agency (CIA) director, the Atomic Energy Commission chair, the Assistant Secretary of Defense, and key members of Congress (Kaiser, 2006, pp. 1231–1234). In a 1955 speech, M.H. Trytten, a key director at the National Research Council highlighted the 'startling fact' that the Soviet Union was producing around twice as many science PhD graduates as the U.S. (Krige, 2000, p. 87).[10]

Detailed studies and compilations of national S&T indicators, though careful to note the differences between the two countries in counting science and engineering graduates, confirmed the Soviet's strength in innovation capacity throughout the period. [11] Per 1985 figures, reported in the NSF's Science and Engineering Indicators, the Soviet Union graduated the most 'first university degrees' in natural sciences and engineering, which was more than double the U.S. figure.[12]

Assessments of Soviet diffusion capacity presented a different picture. One particularly prescient CIA report, published in 1969, concluded that 'the technological gap between the Soviet Union and the developed West is large and is probably widening' (Central Intelligence Agency, 1969, p. 1). The crucial difference, to which the report devoted a full section, was the U.S.'s superior mechanisms to spread technologies, described as a 'fast-acting, seemingly almost biological process', compared to the Soviet Union's mechanisms, which were 'much more balky' (Central Intelligence Agency, 1969, p. 24, 2). Limitations to the Soviet economy's diffusion capacity included lack of competitive pressures, disincentives for firm-level technology planners to adopt new technologies out of fear that they would be forced to meet higher production targets as a result, and separation between the R&D system and the broader economy (Central Intelligence Agency, 1969; Cocka, 1980, pp. 220–240; Kontorovich, 1990, p. 255).

While the Soviet Union was at the forefront of introducing new technologies in many areas, it lagged in adopting technical improvements across a broad range of production processes. A 1977 assessment of Soviet progress in nine technology areas concluded that the Soviets were most successful in the initial research and pioneering of innovations and least successful in the diffusion of innovations across the economy (Amann et al., 1977).[13] The Soviet Union was the innovation leader in extra-high-voltage transmission of electricity, for instance, but the U.S. and Great Britain were the diffusion leaders by 1970 (Amann et al., 1977). A similar story played out in machine tools and the oxygen converter process for steel, which only diffused to 12 percent of Soviet steel production (Berliner, 1973; Central Intelligence Agency, 1969, p. 47). As the CIA's 1969 assessment concluded, 'In no major branch of industry is the average level of Soviet technology in use on a par with that in the United States or Western Europe' (Central Intelligence Agency, 1969, p. 5).

Similarly, the Soviet Union's impressive success in a narrow set of mission-oriented technological feats – most dramatically captured by the launch of Sputnik – did not translate into broader technological trajectories. In domains relatively insulated from the economic system, such as rocket engines and advanced weapons systems, the Soviet Union performed exceptionally by investing high amounts of resources and talented personnel. Soviet scientists and engineers also made impressive contributions to the development of computers and semiconductors, and the Soviet Union successfully exploited military applications in these two domains. However, as these technologies spread to affect the entire economy, like with the advance of computerization in the 1960s and 1970s, the Soviet Union could not keep pace (Graham, 2013, p. 78).

Over time, the Soviet leadership recognized that diffusion capacity was the weak link. General Secretary Breznhnev commented in 1971, 'If one examines all the links of the complex chain uniting science with production, it is not too difficult to see that the links connected with the practical realization of scientific achievements and their adoption in mass production are the weakest' (Quoted in Cocka, 1980, p. 197)˙ In the 1970s Soviet policymakers tried to set up institutions tasked with 'the implementation and diffusion of new technology' (Cocka, 1980, p. 219). Indeed, these reactions perhaps best capture the Soviet Union's diffusion deficit.

The China case

Will China become a science and technology superpower? This question has loomed large since at least 2006, when China outlined its ambition to become a 'science and technology power' (*keji qiangguo*) by the middle of the century (Suttmeier, 2008). For some, China's rapid progress in emerging technologies make its ascent to S&T leadership is inevitable (Allison 2017; Layne, 2018). Others express more skepticism about China's S&T capabilities, arguing that U.S. S&T leadership is durable (Beckley, 2018; Brooks & Wohlforth, 2016, pp. 35–40).

This article intervenes in assessments of China's S&T capabilities by disentangling diffusion and innovation capacity. Existing assessments typically focus on China's aptitude in generating novel breakthroughs, with many depicting China as a leading S&T power based on its impressive performance on indicators of innovation capacity. Such judgments would overestimate China's S&T capabilities, however, if there is a significant gap between China's innovation and diffusion capacity. Indeed, I find that China's diffusion capacity lags far behind its innovation capacity, which undermines claims that China is poised to become a S&T superpower.

Innovation-centrism in analysis of China's S&T power

In debates over China's S&T power, complex dynamics get reduced down to a magic word: innovation.[14] Drawing on theories that identify innovation in leading sectors as the key mechanism behind historical power transitions, scholars frame the U.S.–China technological competition around which state dominates the creation of new technologies (Kennedy & Lim, 2018; Rapkin & Thompson, 2003).[15] For instance, in their analysis of how and when a U.S.–China power transition could occur, Rapkin and Thompson (2003, p. 333) concentrate on 'China's capacity to innovate'.

An evaluation of the international relations scholarship on China's S&T capabilities provides some systematic evidence of a bias toward innovation capacity. I reviewed sixty articles across the following three journals: *International Affairs*, *International Security*, and *Review of International Political Economy*. From each journal, I selected the twenty articles that ranked highest in a Google Scholar search for 'China' and 'technology'. Of the twelve articles that assessed China's S&T capabilities in relation to a rising power's ability to sustain its economic rise, over 80 percent of the articles' assessments favored innovation capacity indicators.[16]

As was the case with overestimates of the Soviet Union's S&T power in the 1970s, present-day assessments of China's S&T power also heavily rely on indicators of innovation capacity, often citing China's impressive performance in R&D expenditures, scientific publications, and patents.[17] No indicator garners more attention than R&D expenditures. Accordingly, the expectation that China will soon surpass the U.S. in R&D spending has renewed fears of China's growing S&T power. Citing China's heavy investments in R&D, reports by influential commissions have warned that the U.S. faces a 'tipping point in R&D' (American Academy of Arts & Sciences, 2020, p. 11) and an 'innovation deficit' (MIT Committee to Evaluate the Innovation Deficit, 2015). Under the Global Power Index (GPI), a model developed by the Pardee Center at the University of Denver, a country's share of global R&D expenditures accounts for half of its technological power.[18] Frequently used by the National Intelligence Council, which leads the U.S. intelligence community's strategic forecasting efforts, the GPI predicts that China's national power will equal that of the U.S. in 2030 (National Intelligence Council, 2012, p. 16).

To be clear, some assessments of China's innovation capacity do conclude that U.S. technological preeminence is durable. Beckley's comparison of U.S. and Chinese innovative capabilities, published in 2011, finds that over the past twenty years the U.S. had increased its lead over China in many indicators, including a variety of patent and R&D metrics (Beckley, 2012, pp. 63–73). Likewise, Brooks and Wohlforth's argument for sustained U.S. technological leadership primarily employs innovation capacity indicators, including triadic patent families and top-cited articles in science and engineering (Brooks & Wohlforth, 2016, p. 24).

Still, when the innovation capacity indicators from these previous studies are updated, nearly all the figures portray a narrowing U.S.–China gap in S&T capabilities, with China emerging as a near-peer competitor. I found the most recent figures for 20 S&T indicators employed in Beckley's article.[19] Apart from the number of universities ranked in the top 20 of the Academic Ranking of World Universities, China has substantially closed the gap with the U.S. across 14 of the 15 indicators of innovation capacity. Per one indicator, in 2009, foreign firms accounted for the majority of invention patents granted by China's patent office. Now, according to updated 2019 figures, domestic Chinese firms account for 80 percent of invention patents granted. These preliminary results suggest that more detailed analysis of China's diffusion capacity is necessary.

Decomposing diffusion and innovation capacity reveals china's diffusion deficit

Does China's diffusion capacity diverge significantly from its innovation capacity? In order to separately assess these two dimensions, I consult two influential and reliable indexes of national S&T capabilities: the Global Innovation Index (GII) and the Global Competitiveness Index (GCI). Among the dozen or so cross-national indexes that evaluate countries' ability to develop and use new technologies, these two stand out for their objectivity and influence (Kennedy, 2017, p. 11). Experts on China's science and technology ecosystems regularly cite the GII to judge China's standing relative to the U.S. in global technology leadership (Chen et al., 2021, p. 4). Chinese scholars pay particular attention to the GCI. Since the index was established in 2004, they have published 253 articles that include the exact terms 'comprehensive national power' [*zonghe guoli*] and 'Global Competitiveness Index' [*quanqiu jingzhengli zhishu*] (author's search of China National Knowledge Infrastructure database, conducted on May, 2, 2021; Pillsbury, 2000, p. 226, 373).[20]

For each of the indexes, I sorted S&T indicators by their association with diffusion capacity and innovation capacity, according to the process-outcomes model introduced earlier. I focus on indicators for which it was relatively straightforward to determine whether they measured innovation capacity or diffusion capacity. For instance, the GII tracks the R&D expenditures of a country's top three firms and the quality of a country's top three universities – two obvious indicators of innovation capacity. The index also includes many indicators that clearly evaluate a country's ability to disseminate new advances, such as the extent of research collaboration between universities and businesses. I excluded S&T indicators that could credibly measure both diffusion capacity and innovation capacity, such as school life expectancy and enrollment in tertiary education.[21]

This decomposition of the GII and GCI demonstrates that China's diffusion capacity significantly lags behind its innovation capacity (Table 1). If judged solely by the 2020 GII's indicators for the latter, China rates as a top-tier S&T power, boasting an average global ranking of 13.8. For reference, the 13th ranked country in the overall GII is Israel, widely recognized as a global leader in S&T. The gap between China and the U.S. on this innovation capacity subindex is very small: the U.S's average ranking is 11.9 (Figure 3).

However, if evaluated on GII indicators of diffusion capacity, China's average ranking drops by 34 spots. The closest comparator based on the overall 2020 GII is the 47th ranked country, the Russian Federation, which few judge to be a prospective S&T superpower. When measured based on this diffusion capacity subindex, the gap between China and the U.S. is very wide: the U.S.'s average ranking is 26.9.[22] The decomposition of the GCI produces similar results. China's average global ranking in GCI indicators of innovation capacity is around 15; it falls to about 44 in terms of GCI indicators of diffusion capacity (Supplementary Appendix C).

This gap between China's innovation capacity and diffusion capacity holds when raw scores are used instead of ranks. For some indicators, the shape of distributions could greatly deviate from the linear one imposed by ranks.[23] As an additional check, I compared China's raw scores across diffusion and innovation capacity indicators with those of the U.S., France, and Israel – the latter two countries ranked just ahead of China in the overall 2020 GII. Relative to all three

Table 1. China's S&T power: an innovation-diffusion decomposition of the GII.

Innovation Capacity Subindex		*Diffusion Capacity Subindex*	
Indicator	China's global ranking	Indicator	China's global ranking
Researchers, full-time equiv./mn pop.	48	ICT access	71
Gross expenditures on R&D	13	ICT use	53
Global R&D companies	3	University/industry research collaboration	29
QS university rankings	3	State of cluster development	25
R&D performed by business	12	GERD financed by abroad	81
R&D financed by business	4	JV strategic alliance deals/bn	76
Patents by origin*	1	Patent families 2+ offices/bn PPP%GDP	27
Patent Cooperation Treaty patents by origin*	15	Intellectual property receipts, % total trade	44
Utility models by origin/bn PPP$ GDP'	1	High-tech net exports, % total trade	5
Scientific & technical articles*	39	ICT services exports, % total trade	61
Citable documents H-index	13		
Average ranking	**13.8**	**Average ranking**	**47.2**

Source: Global Innovation Index 2020, World Intellectual Property Organization (2020). per billion PPP$ GDP.

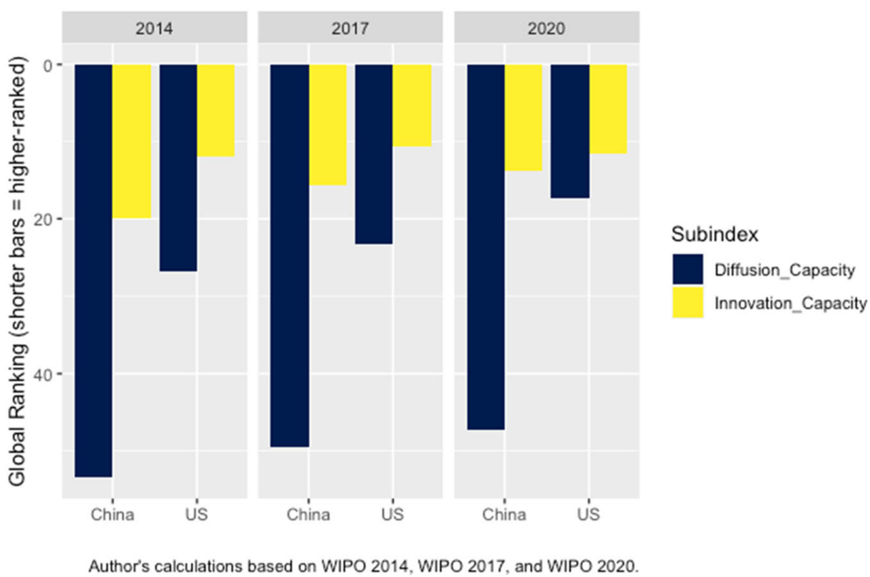

Figure 3. China's diffusion deficit over time.

countries, China's average score in the innovation capacity subindex was higher while its average score in the diffusion capacity subindex was lower.

China's diffusion deficit extends beyond a single-year snapshot. Using the same procedures as the decomposition of the 2020 GII, I calculated the average rankings of the U.S. and China on the innovation and diffusion capacity subindexes for the GII in 2014 and 2017. In all three years, China's average rank in diffusion-oriented indicators trailed its rank in innovation-oriented indicators by over 30 spots (Figure 3). While China has improved its average rank in the diffusion capacity subindex by about 5 places since 2014, the gap between China and the U.S. on this measure has only widened, as the U.S. improved its own diffusion capacity ranking by almost 10 places over the same period.

Notably, these results run counter to claims that China's rising S&T prowess comes from its strategic advantage in deploying innovations at scale.[24] For instance, influential reports play up China's capacity to adopt AI advances because it graduates more computer science students than competitors.[25] These analyses draw from a few examples of Chinese success at large-scale deployment in domains such as high-speed rail and mobile payments. Alongside the analysis that follows, the decomposition of these indicators cautions against overestimating China's diffusion capacity.

China's lethargic diffusion capacity is further confirmed by a detailed evaluation of its adoption of information and communications technologies (ICTs), generally considered the key drivers of future productivity growth.[26] While China has achieved a few noteworthy successes in ICT diffusion in consumer-facing applications – such as the spread of mobile payments and e-commerce – Chinese businesses have been slow to embrace digital transformation. China lags behind the U.S. in penetration rates of many digital technologies across industrial applications, including digital factories, industrial robots, smart sensors, key industrial software, and cloud computing (Alibaba Research Institute, 2019; Synced, 2020; Techxcope, 2020).

Furthermore, composite measures reveal a large gap between the U.S. and China in terms of the countries' readiness to effectively spread and utilize ICT advances. China ranks 83rd in the world, 67 places behind the U.S., on the International Telecommunication Union's ICT Development Index, which combines the level of networked infrastructure and access to ICTs and the level of use of ICTs in the society (International Telecommunications Union, 2017, p. 31).[27] China also significantly trails the U.S. in an influential index for adoption of cloud computing, which is essential to implementing AI applications and many other emerging technologies (Supplementary Appendix D). In 2018, U.S. firms averaged a cloud adoption rate of over 85 percent, more than double the comparable rate for Chinese firms (Wang and Chen 2020).

In sum, China faces a diffusion deficit. Therefore, most assessments of China's S&T capabilities overestimate China's capacity to convert technological breakthroughs into national productivity improvements because they privilege indicators of innovation capacity. A rebalanced evaluation of China's potential for S&T leadership requires looking beyond multinational corporations like Huawei, first-tier cities like Beijing, and flashy R&D numbers to the humble undertaking of diffusion. This perspective brings a different cast of characters into the spotlight: smaller firms, fourth-tier cities that rarely feature in English-language coverage, and technology transfer mechanisms.

Conclusion

In President Joe Biden's first speech to Congress, he emphasized the need for the U.S. to develop breakthroughs in and dominate the technologies of the future. According to Biden, the U.S. was 'falling behind in that competition … China and other countries are closing in fast' (Biden, 2021). Biden's remarks reflected two common themes in discussion about national S&T capabilities: the overwhelming preoccupation with which state first generates novel advances (innovation capacity), as well as the belief that China is close to overtaking the U.S. in S&T preeminence. In this article, I have shown how the first point influences the second, and in the process have challenged both assumptions.

This article has argued that appraisals of S&T capabilities should give greater weight to a state's diffusion capacity, or its ability to spread and adopt innovations, after their initial inception, across productive processes. Diffusion capacity is central to a rising power's ability to translate technological advances into higher productivity growth than its rivals – a process that has been historically connected to the rise and fall of great powers. Crucially, a state's diffusion capacity can significantly deviate from its innovation capacity: innovation laggards can be diffusion leaders (diffusion surplus), and innovation leaders can be diffusion laggards (diffusion deficit). When a substantial gap between these two dimensions exists, traditional assessments of S&T capabilities that focus on innovation capacity will be misleading.

A variety of evidence supports these arguments. To reveal the innovation-centrism in conventional assessments of national S&T capabilities, I reviewed all published power formulas and the international relations scholarship on China's S&T power resources. I tested these claims with two historical cases of rising powers that faced substantial gaps between their diffusion capacity and innovation capacity. In line with theoretical expectations, the U.S. in the late 19th century, a case of diffusion surplus, rose to economic preeminence, and the Soviet Union in the early decades of the postwar period, a case of diffusion deficit, eventually experienced an economic collapse.

Applying a diffusion-centric perspective to gauging China's S&T capabilities, this article improves assessments of an increasingly significant aspect of the U.S.–China power balance. Preoccupied with China's growing prowess in developing new-to-the-world breakthroughs, many existing assessments warn that China is primed to overtake the U.S. in S&T leadership. However, these studies neglect China's deficiencies in adopting and spreading novel advances throughout its economy. My assessment of China's S&T capabilities reveals a diffusion deficit, which suggests that China is far from becoming a S&T superpower and is less likely to sustain its rise than innovation-centric assessments predict.

This article's arguments engage with other studies that scrutinize the nature of power in the global political economy. Enduring debates over the decline of American economic power have emphasized innovation capacity in key industries (Kennedy, 1987) and profit-shares of multinational corporations that produce the most advanced technologies (Starrs, 2013). Recent scholarship on China's productive power also focuses on the growing capacity of Chinese multinational corporations like Huawei to set global standards and extract monopoly rents (Malkin, 2020). By highlighting the importance of diffusion capacity, this article suggests that power in the global economy resides in a broader set of actors. Analyzing this alternative conceptualization of power requires looking beyond top firms and strategic industries to how new advances spread from these frontier domains across the entire economy.

Judgements of S&T power also have high and immediate stakes for U.S.–China technological rivalry. Overestimates of China's S&T capabilities could intensify U.S.

efforts to contain China's rise or spur escalatory arms races, much like the illusory 'missile gap' of the late 1950s (Beckley, 2012, pp. 77–78; Crawford, 1993, p. 228). In recent years, fear of China's rise has solidified a rare bipartisan consensus among U.S. policymakers on the need to compete with China in emerging technologies. However, recent legislative actions, which represent the boldest efforts to bolster U.S. investments in science and technology since the Cold War, primarily aim to secure U.S. leadership in the innovation of new technologies. If these policies also undervalue diffusion capacity, a more optimal strategy would rebalance investments toward institutions and mechanisms that facilitate the widespread adoption of emerging technologies (Shapira & Youtie, 2017).

Future research should develop better cross-national measures of diffusion capacity based on the intensive adoption of new technologies, which could help clarify other cases of diffusion surpluses and deficits. Cross-country studies indicate that while new technologies are spreading between countries faster than ever, they are spreading to all firms within a country at increasingly slower rates (Andrews et al. 2015). This further enhances the significance of measuring the time between a country's initial adoption of new technologies to intensive penetration throughout the entire country. Additionally, more research on why China struggles with diffusion capacity is needed. Talent shortages and other bottlenecks might be resolved by market adaptations or policy adjustments, but other conditions may be difficult to change absent a fundamental reorientation of China's political economy (Synced, 2020). For instance, China's favoritism toward state-owned enterprises and centralized approach to picking and supporting winners sometimes props up technology solutions that diffuse slower than technologies chosen by market-based mechanisms (Kennedy, 2017).[28] Addressing these gaps in our knowledge will be crucial for determining whether China will improve its diffusion capacity in the future.

Notes

1. International relations scholars are primed to associate diffusion with international diffusion. In this paper, diffusion refers to the internal spread of new S&T advances throughout a country. Thus, diffusion capacity captures a state's effectiveness in adopting new advances across domestic systems. The source of these new advances can be domestic or international.
2. Beckley (2012) recognizes that 'the ability to *produce and use* commercially viable and military relevant innovations' (p. 67, emphasis mine) is key to technological superiority, and Brooks and Wohlforth (2016) make a distinction between 'technological inputs' and 'technological outputs' (pp. 22–26). However, nearly all of Beckley's S&T indicators relate to the ability to produce innovations. While Brooks and Wohlforth note the need to track how R&D inputs translate into outputs, which they measure by article publications and patent filings, I am interested in how these outputs diffuse.
3. Related work on the S&T power of nations makes the same distinction but focuses on the innovation phase. Kennedy (2018, p. 16) and Taylor (2016, p. 28) literature on military innovation tends to employ a broad definition of 'innovation' that subsumes the diffusion process. Evangelista (1988, p. 52).
4. Other factors that could boost both innovation and diffusion capacity include relatively open economies, democratic governance, and political decentralization. Even for these variables, it is important to make careful distinctions between effects on innovation and diffusion. For instance, recent scholarship has questioned the

connection between decentralization and national innovation rates, arguing that previous work had misidentified decentralization's boost to diffusion as innovation (Taylor, 2016, p. 137).

5. See accompanying dataset.
6. For the U.S. case, alternative factors include trade barriers that protected domestic industries, rapid population growth, and a favorable security environment. Possibly, the U.S. achieved sustained growth because these factors outweighed the influence of the U.S.'s weak innovation capacity. This scenario is unlikely because, as historians have argued, S&T advance was central to U.S. productivity improvements in this period (Mowery & Rosenberg, 1993, pp. 31–32). For a summary of alternative factors in the Soviet Union case, including excessive military spending, see Trachtenberg (2018, pp. 84–92).
7. For an analysis of how Britain's innovation capacity outdistanced its diffusion capacity in this period, see Supplementary Appendix A.
8. See Supplementary Appendix A for more evidence of the U.S.'s relative advantage in diffusion capacity in other technological domains.
9. While some assessments of overall Soviet Union power, especially from the U.S. intelligence community, emphasized Soviet military power, my focus is on Soviet S&T capabilities in the civilian economy.
10. Throughout this paper, especially in the U.S. case study, I employ engineering human capital as an indicator of diffusion capacity. To resolve some of the tension with citing statistics that encompass engineering graduates as indicators of innovation capacity in the Soviet case, I show that this "scientific manpower gap" was mostly framed as a Soviet advantage in scientists and elite researchers. I thank an anonymous reviewer for raising this point.
11. For other indicators of innovation capacity, such as patents, it was difficult to compare the two countries. The Soviet Union developed a distinct system of intellectual property, which awarded inventors with dachas and prizes instead of patents. Gordin, 2014.
12. National Science Board (1987, p. 233).
13. The nine areas were automobiles, chemicals, computers, high-voltage electric-power transmission, industrial-process control, iron- and steelmaking, machine tools, military technologies, and rocketry and manned space capsules. Evangelista (1988, pp. 38–62) describes this study as 'the most careful comparison of the relative levels of Soviet and Western technology.'
14. This section focuses on China's ability to generate and adopt commercially viable innovations. For analyses of China's military innovation system, see Cheung (2013) and Walsh (2014).
15. One notable exception is Breznitz and Murphree (2011). They note that 'policy makers and academics put too much faith in the notion that states and societies must create novel technologies in order to secure long-term growth and enhance national welfare' (p. 2).
16. An accompanying dataset includes all the articles reviewed. For coding details, see Supplementary Appendix B.
17. Kennedy (2015, p. 284).
18. Moyer and Markle (2017, p. 8). In fact, for periods before 2005, share of global R&D expenditures was the sole indicator of the GPI's technological dimension of power. Now, a country's share of global ICT capital stock makes up the other half of its technological power.
19. An accompanying dataset lists the initial and updated versions of the 20 indicators.
20. Because global rankings convey reputational effects, states sometimes try to game these indexes (Kelley & Simmons, 2019). This issue is not as relevant for the decomposition exercise because states would not predict the choice of subindexes, and any attempt to game the indicators would apply equally across the subindexes.
21. Supplementary Appendix C contains a detailed explanation of how I sorted the indicators for both the GII and GCI. Possibly, China's diffusion capacity could benefit from its large population of students in tertiary education. As an additional check, I

re-ran the analysis with the tertiary enrollment indicator included in the diffusion capacity subindex. This did not meaningfully affect the main results. Supplementary Appendix C provides further details.
22. This decomposition exercise was undertaken for twelve other countries: Denmark, France, Germany, India, Israel, Japan, Russia, Singapore, South Korea, Sweden, Switzerland, and the United Kingdom. China had the largest difference between its diffusion capacity subindex and innovation capacity subindex. This result holds for the GII in 2014, 2017, and 2020. See Supplementary Figure S1 in Appendix C.
23. I am grateful to an anonymous reviewer for pointing this out. Supplementary Appendix C reports the detailed figures cited in this section.
24. See, for example, Breznitz and Murphree (2011) and de La Bruyère and Picarsic (2020).
25. Allison and Schmidt (2020, p. 10).
26. While this article's theoretical framework does not focus on variation among technological developments, these ICT-specific measures address one concern about whether the GII decomposition captures a country's capacity to diffuse the disruptive innovations that are likely to transform the entire economy.
27. In some areas, including measures of ICT access, China's ranking has declined over the past decade. This is based on figures reported in the 2011 and 2021 GII.
28. Some of these tendencies echo the Soviet Union's struggles, although China's diffusion capacity benefits from extensive international linkages, entrepreneurial environment and venture capital sector, and a higher degree of decentralization in the actual implementation of industrial policies.

Acknowledgements

I am very grateful to Felipe Forero for invaluable research assistance. For helpful comments and input, I thank: Markus Anderljung, Alexis Carlier, Allan Dafoe, Max Daniel, Hiski Haukkala, Yutao Huang, Stephen Kaplan, Alex Lintz, Morgan MacInnes, Karolina Milewicz, Adam Salisbury, Toby Shevlane, Duncan Snidal, participants at the DPhil Workshop at Oxford University, and especially Ben Garfinkel and Remco Zwetsloot.

Disclosure statement

No potential conflict of interest was reported by the author(s).

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