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Diffusion, innovation and the tech-politics underlying power transitions

Review article based on Technology and the Rise of Great Powers: How Diffusion Shapes Economic Competition by Jeffrey Ding

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Klaus Schwab, founder of the World Economic Forum, first popularised the term 'Fourth Industrial Revolution' (Schwab 2015). Schwab identified artificial intelligence (AI), robotics and biotechnology as some of the key emerging technologies of the unfolding Fourth Industrial Revolution (4IR). Recent developments have elevated one technology over all others as being the defining feature of the Fourth Industrial Revolution — AI.

The great power rivals of the twenty-first century — the United States and China — have both intensified their efforts to become the global leader in AI. Previous industrial revolutions have been associated with great power transitions. Will the geopolitical winners and losers of this century be decided by who leads the battle for AI supremacy? Will China eclipse the US as the preeminent global power?

Technology and the Rise of Great Powers: How Diffusion Shapes Economic Competition (Princeton University Press, 2024) by Jeffrey Ding attempts to answer the above questions. Challenging alarmist accounts that have highlighted China's lead in various AI innovation indicators, Ding argues that diffusion of general-purpose technologies (GPTs)[i] such as AI matters more than just innovation. Highlighting the uphill challenges China faces in unseating the US, he argues that the US is ahead of China as far as GPT diffusion metrics related to AI are concerned.

In this book, Ding applies the GPT diffusion theory to provide a fresh retelling of historical industrial revolutions. His argument has relevance beyond the great power rivalry between the US and China; it has lessons for rising powers such as India.

Unpacking Ding's GPT and leading-sector theories

The central theme that motivates Ding's scholarly inquiry is one that has inspired a lot of international relations scholarship (Kennedy 1987; Yang 2013; Brooks and Wohlforth 2015; Chen

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and Evers 2023) — what *causes* the rise and fall of great powers? More specifically, what role do technological revolutions play in power transitions?

In answering this, Ding challenges the dominant idea of a leading-sector (LS) mechanism that 'stresses a country's ability to dominate innovation in leading sectors' (p.15). Building on decades-long scholarship on GPTs (Bresnahan and Trajtenberg 1995; Petralia, 2020), Ding argues that it is the diffusion of GPTs, as opposed to the LS model, that best explains the historical winners and losers during power transitions.

Demonstrating the analytical rigour that is present in the entire volume, Ding describes the contrasting causal chain for the LS and GPT mechanisms. In the case of LS, the domination of one great power in certain leading sectors leads to monopoly profits (following classic first-mover advantage), thereby catapulting the great power to economic pre-eminence. In case of GPT, however, 'some great powers sustain economic growth at higher levels than their rivals do because, during a gradual process spanning decades, they more intensively adopt GPTs across a broad range of industries' (p.16). While not discounting the significance of innovation in cutting-edge sectors, Ding favours the diffusion of GPTs over LS mechanism because the former leads to economy-wide productivity growth. For instance, according to Ding, while Japan achieved 2.4 per cent annual total factor productivity (TFP) growth from 1983–1991 through leadership in high-tech sectors like semiconductors, its reliance on LS mechanisms led to stagnation (0.2 per cent TFP growth in the 1990s) and a widening GDP gap with the US, which prioritized GPT diffusion. Similarly, during the second Industrial Revolution, the US surged ahead of Britain by diffusing electricity broadly: the US GDP grew 5.3 times (1870–1913) versus Britain's 2.2 times. By 1912, US per capita electricity production was double of Germany's and five times that of Britain. This diffusion enabled the US to establish a per capita GDP lead over Britain by 1900, despite comparable starting points.

The three industrial revolutions

Ding analyses in a very nuanced manner the First, Second, and Third Industrial Revolutions, that were defined by Britain's rise, the US's ascent, and Japan's challenge, respectively. He compares and assesses LS and GPT theories to find out which one of these provides a compelling understanding of how technological leadership and transformation helps states achieve economic leadership. In Ding's view, all three case studies provide support for the GPT theory.

Britain became the world's most advanced economic power during the (first) Industrial Revolution (1780–1840) not through breakthrough innovations, as claimed by the LS theory, but because it was able to spread mechanical skills across industries, which aligns with the GPT theory. Using different technological candidates for both the theories, Ding shows that it was Britain's unique institutional strengths that helped mechanisation diffuse across sectors, which in turn contributed to Britain's economic leadership.

For instance, France produced elite engineers, but failed in disseminating technical knowledge widely. Unlike France, Britain developed a flexible apprenticeship system and created institutes which helped spread mechanical expertise. Mechanics in Britain had superior access to technical publications and training opportunities. The GPT skills infrastructure contributed immensely to Britain's success.

Similarly, during the second Industrial Revolution (1870–1914), the US emerged as the technological and economic leader, again not so much through technological innovations as through systematic technological diffusion. The candidate leading sectors for this IR were steel, electrical equipment, chemicals, and automobiles; while the candidate GPTs were interchangeable manufacturing, electrification, chemicalisation, and internal combustion engines.

The US created comprehensive engineering education systems which emphasised practical, experience-based learning. Some institutional innovations like land-grant schools, technical institutes, and strong university-industry linkages helped the spread of technological knowledge. In chemical engineering, the US pioneered the 'unit operations' concept, breaking down complex processes into standardized, transferable components that could be applied across multiple industries. Therefore, while Germany led in chemical breakthroughs, and the US actually trailed in initial innovations, what helped the US was systematising, standardising, and creating institutional mechanisms for spread of technological understanding. Per Ding, this approach proved far more economically transformative.

Unlike the first and second IR historical case studies, the third Industrial Revolution — or the Information Revolution — serves a different purpose. In the case of IR-3, Japan and the US were engaged in a close economic competition, spurred by the developments in information and communications technologies (ICT) during the period 1960–2000. During the 1970s and (especially) 1980s, scholars and policymakers in the US anticipated Japan eclipsing the US as an economic powerhouse. However, such fears were not realised as Japan's growth story stalled in the 1990s (often referred to as Japan's 'lost decade'), and its economy has struggled ever since. That is to say: '*[t]he feared economic power transition [...] never occurred*' (p.133).

Ding uses the IR-3 case study to make the case that while conditions for LS mechanism existed for Japan — which dominated innovation in key technology sectors such as semiconductors, consumer electronics and computers — the economic transition did not take place, as the US was ahead in diffusing ICTs during the same period. More specifically, Ding establishes that the US led in diffusing computerisation (the chosen candidate GPT for IR-3). In particular, '*institutional adaptations that widened the base of computer engineering skills and knowledge proved crucial to the enduring technological leadership of the United States in the IR-3*' (p.148).

Therefore, the IR-3 case study, according to Ding, disconfirms the LS mechanism. It does not undermine the GPT theory, because Japan trailed the US with regard to diffusion of GPTs.

Shortcoming: Inadequacy in threat-based explanations

In addition to the GPT and LS theories, Ding also uses two other theories — varieties of capitalism (VoC) and threat-based explanations — to explain developments during the industrial revolutions. The VoC explanation 'highlights differences among developed democracies in labour markets, industrial organization, and interfirm relations and separates them into coordinated market economies (CMEs) and liberal market economies (LMEs)' (p.39). Threat-based explanations, on the other hand, 'assert that external threats are necessary to incentivize states to innovate and diffuse new technologies' (p.82).

Like in IR-1 and IR-2, the author is able to convincingly demonstrate that the VoC approach does not provide a sound explanation of the failure of Japan to eclipse the US in IR-3. However, he does not provide sufficient grounds to discard threat-based explanations in the case of IR-3. Ding notes that 'tensions in East Asia and the oil crises of the 1970s' and 'dangers of the Cold War' created a 'threatening international environment' for Japan and the US, respectively (p.154). He argues that '*General threat-based explanations therefore cannot explain differences in technological outcomes between the United States and Japan, namely, why the United States was more successful in ICTs than Japan.*' (p.154)

The book fails to acknowledge that Japan and the US did not face threats on a similar scale. The US was embroiled in an ideologically-fuelled great power rivalry with the Soviet Union at the global level, and was directly engaged in multiple proxy wars during the IR-3 period. Japan's threat environment, in contrast, was a regional one. There is therefore scope to strengthen the threat-based explanations approach (especially for the IR-3 period), and clarify the significance of the differences in the nature and scale of threats.

GPT and LS are not either-or

There is a risk of policymakers misinterpreting argument of the book to mean that it is necessarily and always an either-or choice between the LS and GPT theories. States can focus on both trying to gain a first-mover advantage in critical sectors, and in building up GPT skill infrastructure[ii] to help diffuse knowledge and technological expertise from research to various application sectors. In the highly charged geopolitical environment of the present, gaining expertise and knowledge of critical sectors is essential, and research in academic institutions and laboratories could yield significant benefits.

Application of Ding's framework to India

While the book is primarily concerned with the rise and fall of great powers, it has lessons for rising powers such as India. India did not feature as a power of global significance during any of the previous industrial revolutions. During IR-1 and IR-2, India was one of the many colonies of the British empire. For most of IR-3, India was a newly-independent state with extreme poverty and sluggish economic growth. It was only towards the end of the IR-3 period — the 1990s — that India's economy started to grow at a faster rate. This period also saw the spread of computers, telecom, and internet in India.

India undertook some diffusion of the GPT of IR-3—computerisation—beginning in the 1980s, and accelerating through the 1990s and 2000s (Rajaraman 2015).

- In 1990, the size of India's IT and IT-enabled services (ITeS) sector was about USD 100 million (Gopalakrishnan 2016). In the financial year 2024, '*India's IT-BPM [Business Process Management] industry (excluding e-commerce) is expected to reach USD 254 billion*' (MEITY n.d.).
- In 1997, 160,000 people were employed in the software industry (Arora and Athreye 2002). In 2024, the IT-ITeS industry employs more than five million people in India (MEITY n.d.).
- In 1993, there were about 100 engineering colleges in India that offered a bachelor's degree in computer science; about 3000 students graduated with computer science degrees (Rajaraman 1993). There were 2,461 All India Council for Technical Education (AICTE-approved) institutions offering computer science education at the undergraduate level in India in 2022-23; while 3,76,048 students were enrolled in these colleges for computer science engineering (Shrangi 2024).

While not strictly comparable (being gathered from different sources and with different methodologies), these numbers still give a rough idea of India's success with diffusion of computerisation. In the IR-4 phase, given that AI has all the characteristics of GPTs, going by Ding's GPT Diffusion Theory, it follows that AI's diffusion across different sectors of the economy is necessary to contribute towards economic growth. IR-4 offers India an opportunity to increase its relative power in the international system, and the country could do this by focusing on GPT diffusion mechanism outlined by Ding: expanding AI engineering and knowledge so as to create the necessary skill infrastructure.

AI diffusion would also require significant financial resources. The trade-offs would be potential risks of lack of enough focus on other important technologies given India's resource constraints, increased job displacement and managing computational resource constraints. These, however, have to be weighed against productivity gains that are possible because of AI diffusion, and also against the opportunity costs of not doing so.

Notwithstanding the focus on diffusing GPT such as AI during IR-4, it is of paramount importance that India also works on pioneering, breakthrough AI innovation. Trade wars, supply chain issues and national security concerns have made global value chains very unstable, making the sourcing of high-tech innovation products/services difficult. In such an environment, India cannot afford to just build GPT skill infrastructure.

A GPT skill infrastructure can lead to better diffusion and eventually economic development when global trade is relatively open, and knowledge and expertise flow with less hindrance. The world is in a constant state of flux, where till recently globalisation was a phenomenon, but after the COVID-19 pandemic and due to the trade wars, trade barriers are rapidly going up. The concept of comparative advantage still holds, but it is increasingly being sacrificed at the altar of national security. In such an environment, India cannot afford to continue with the status quo on research and development (R&D) spending. R&D is a component of both LS and GPT theories.

- For the LS theory, doing R&D for staying at the cutting-edge in leading sectors is the most important endeavour.
- As per the GPT theory, R&D can happen anywhere as long as the underlying technology can be sourced and diffused across different sectors. Diffusion is the key.
- With AI, R&D can also be in models (such as foundational open-source models) that are more suited for diffusion as opposed to cutting-edge proprietary models. India should also therefore focus on the development and deployment of open-source AI models as a GPT diffusion mechanism.

Further, the relative resource crunch in India (as compared to China and the US) means that deployment of public funds will have to be optimised for short-to-medium term impact. This is because it takes decades for the GPT diffusion to become significantly impactful. As Ding has argued, 'if the lessons of past industrial revolutions hold, the key driver of a possible US-China economic power transition will be the relative success of these nations in diffusing AI throughout their economies over many decades' (p.189). Therefore, in the current geopolitical environment, rising powers such as India should focus on both LS (for short-to-medium term returns) and GPT mechanisms (for long-term returns).

Why the book matters

The work featured in this book started out as Ding's dissertation at the University of Oxford, and continued to take shape during Ding's stints at Stanford University and George Washington University. A dense academic treatise, the book presents new ideas regarding technological innovation, economic development, and global power dynamics. It provides a framework that can help scholars and policymakers examine ongoing technological transformations, and understand how technologies actually transform economies.

Where the book really challenges readers is in thinking beyond individual inventions. and considering the broader institutional and other skill-related systems that truly drive technological and economic progress. While the book might seem a bit repetitive at times, the repetition does drive home the point being made — diffusion of GPTs (as opposed to innovation in some leading sectors) during industrial revolutions decides the winners and losers of power transition.

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Notes

[i] Note that this is different from the 'GPT' in ChatGPT.
[ii] Ding defines GPT skill infrastructure as '*education and training systems that widen the pool of engineering skills and knowledge linked to a GPT*' (p.8).