Innovation Policy in China

YANFEI LI
Economic Research for ASEAN and East Asia

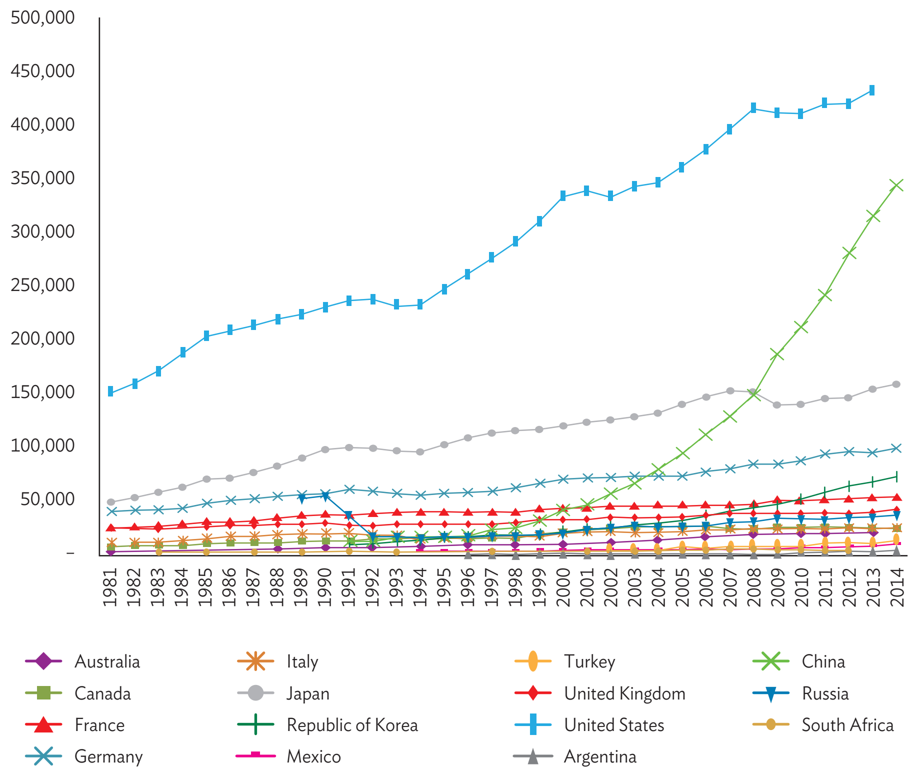
DAYONG ZHANG
Research Institute of Economics and Management,
Southwestern University of Finance and Economics

3.1 | Introduction

China has recently emerged as a key power driving research and development (R&D) and innovation in the world. According to the World Bank's World Development Index database, the country contributed more than 400,000 science and technology (S&T) journal articles in 2013, slightly fewer than the United States (US) and almost four times as many as Japan. The country also now has the largest number of full-time researchers in the world. Accordingly, China registered 1.1 million patent applications in 2015, 87% more than the US and about 2.5 times more than Japan (World Intellectual Property Organization [WIPO], 2016). These figures seem to be driven by the country's total annual spending on R&D, which was 2.05% of gross domestic product (GDP) during 2005–2015, compared to 2.73% of the US and 3.58% of Japan during the same period. Figure 3.1 shows the total domestic spending on R&D of 15 countries, including China.

The government plays a key role in R&D initiatives and funding in China. In 2014, about one-third of China's R&D expenditure was funded by the government (Krasodomskyte, 2015). The goals of the government's R&D policies include to (i) advance China's comprehensive innovation capability ranking from 18th to 15th by 2020; (ii) increase the rate of contribution from technological progress to economic growth to above 60%; (iii) extend the share of knowledge-intensive services in GDP to 20%; and (iv) reduce the import of technologies to 30% of the country's total needs by 2020, and have Chinese R&D achievements ranked among the top five in the world in terms of the number of patents and citations. To reach these goals, the government has announced the 13th Five-Year Plan for Economic and Social Development, the National Strategic Program for Innovation-driven Development, and the 13th Five-year National Science and Technology Innovation Plan. These plans represent a continuation of the previously announced National Medium- and Long-term Program for Science and Technology Development (2006–2020) and the 12th Five-year Plan (2011–2015). Correspondingly, R&D expenditure will reach 2.8% of GDP by 2020 (Xinhua Net, 2016a, 2016b).

Figure 3.1: Gross Domestic Spending on Research and Development, 1981–2014 (US$ million)



Source: Authors' compilation based on World Bank data.

The Wall Street Journal (2014) frames this development in terms of the critical mass argument, stating: 'China's technology sector is reaching a critical mass of expertise, talent and financial firepower that could realign the power structure of the global technology industry in the years ahead', and so that '[t]raditionally Chinese companies were fast followers, but we are starting to see true innovation'.

However, the evidence shows that China is still significantly lagging in technology and innovation. According to the World Bank's World Development Indicators, payments for intellectual property made by China in 2015 were 22 times higher than its receipts from the rest of the world. Meanwhile, what the rest of the world paid to China for intellectual property use was less than 1% of what the world paid to the US. These data are puzzling if indeed China has accomplished its transition from an imitative latecomer in technology to an innovation-driven knowledge economy. Moreover, the question is whether China has become or will soon become a technological innovation superpower.

It is hard to give a definite answer. This is partly because knowledge is limited regarding (i) how technological catching up works, especially the impact of various industry policies; (ii) how technology advances or how innovations happen at both the macroeconomic and microeconomic levels; (iii) what the key factors, components, and design of national and regional innovation systems should be to ensure effective catching up and innovation; and (iv) what business and industrial strategies and industry policies should be applied at different stages of technological development to ensure competitive advantage. Another issue is the difficulty in measuring technological progress and innovation performance, and thus the lack of data.

This chapter will contribute to the literature in three ways. First, it gives a detailed and in-depth review of the characteristics of several selected industrial sectors in China and examines what factors have been driving the successful cases and what factors may have worked to China's disadvantage. Second, a quantitative method is applied to test whether the influence of these factors is statistically significant and to what extent they determine success or failure. Third, two case studies shed some light on how these factors work at the firm level and identify additional findings at this level.

The rest of the chapter is organised as follows. Section 3.2 reviews China's policies for technological catching up and innovation. The first part of Section 3.3 discusses the theoretical basis of effective policies and presents quantitative evidence from the Chinese economy. The second part of Section 3.3 presents case study evidence, since it is well understood that many aspects and factors that relate or contribute to technological progress and innovation are not quantifiable. Section 3.4 derives the implications for the country's future innovation policies. Section 3.5 concludes.

3.2 | The Innovation Situation in China

For developing countries, catching up in technology is equivalent to innovation. This chapter adopts the broad definition of innovation by Zanello et al. (2016). It includes not only the adoption of new products or processes, or new organisational and marketing practices (where 'new' means new to the world, new to the country, or new to the firm) but, in line with the Schumpeter tradition, also new business models and new sources of supply. This means that innovation could either be ground-breakingly novel, incremental, or imitative. Creation, adoption, adaptation, assimilation, and the diversification of technologies are all part of the innovation process. It also means that innovation can take many forms, such as product innovations, process innovations, marketing innovations, and managerial and organisational innovations. In this sense we can account for the different innovation modes to isolate their diffusion patterns and their impact on firm performance.

In the catching-up stage, the following mechanisms could be applied to absorb imported or transferred technologies: (i) licensing, technical consulting, technical services, and co-production; (ii) movement of goods through international trade; (iii) movement of capital goods through foreign direct investment (FDI), purchase, or leasing; (iv) movement of people with specialised knowledge, expertise, and skills through migration, travel, and overseas education and training; (v) international research collaboration; (vi) diffusion through public media and the Internet, especially of codified and digitised knowledge; and (vii) transfer and spillover through participating in the global value chain (Fu et al., 2016).

While there are many means of catching up in technology, whether or not an economy succeeds in acquiring and then absorbing the technology depends on many factors (Zanello et al., 2016). The theory of innovation diffusion distinguishes two types of factor: external and internal. The four external factor are as follows. First, the nature of the technology, which strongly influences the speed of diffusion. Basic technologies or technologies that are standardised or modularised spread faster. Second, the adaptability of the technology. This refers to the skills, knowledge, tools, and complementary conditions required to perform the modification or customisation for local needs. Third, the communication channels, including both the transmission of information and the transportation infrastructure. Communication is not only between the entities of the advanced economy and those of the recipient economy (thus common culture, language, and social characteristics matter) but also between firms, intermediaries, public research institutes, and the government within the recipient economy. Fourth, incomplete, outdated, or underdeveloped institutions may become barriers to diffusion. Internal factors are mainly related to the firms of the recipient economy, such as the availability of financial resources, skills, knowledge, capacities, entrepreneurship, and management; and the organisational structure, size, location, degree of competition, the role of clusters, regulations, and policies.

There appear to be different models in reality. Wong and Goh (2015) conducted case studies to examine the S&T policy models and trajectories of S&T development in mainland China, the Republic of Korea (henceforth, Korea), Malaysia, Singapore, and Taiwan. Korea and Taiwan implemented a 'new start-ups for product technology pioneering' model in which the governments set national goals and offered incentives and support to firms to build their capacities and competencies in conducting R&D to achieve technological progress in line with national goals. At the same time, the governments allocated resources to advance scientific activities that would later fuel technology development and co-evolve with it. Importantly, the governments focused on selected areas where certain firms are perceived as capable in achieving the goals. Interestingly, both economies applied the reverse product life cycle strategy, which builds up process capability using imported foreign technology in the initial stages and is followed by the mastering of sophisticated products through imitative R&D.

In Taiwan's case, this strategy was reflected in the transition from original equipment manufacturing (a kind of contract assembly operation) towards original design manufacturing (indigenous product development and process technologies). In the Korean case, the strategy was implemented mainly through *chaebols* (large domestic firms), which focused on both heavy industries and consumer electric and electronic products. Taiwan, on the other hand, chose to support small and medium-sized enterprises (SMEs) and focus on niche areas along the global value chain.

Malaysia and Singapore mainly followed the FDI leveraging model, which relies on the introduction by multinational companies (MNCs) of new and advanced technologies or the upgrading of their production processes and capabilities in the host country. The spillover of know-how from the MNCs is expected to spawn local supporting industries and eventually foster local enterprises in the main businesses to compete with the MNCs. This model focuses on the provision of basic infrastructure, including general education and training and non-specific incentives for in-firm training and technology diffusion, to provide complementary local human resources as well as maintain political stability and security to support export-intensive manufacturing activities.

In the case of mainland China, the economy appears to have implemented both models with its own modifications and characteristics. It implemented the FDI leveraging model through joint ventures with local firms. This model has dominated China's high value-added and high-tech exports so far. However, since 2009, the modified product technology pioneering model, which has been implemented through large state-owned firms in selected industries, has emerged as a strong force in driving technological catching up in strategic industries, such as high-speed rail, space and aviation, electronic chips, infrastructure engineering and construction, energy,[1] and advanced computing.

Since the reform and opening-up in 1978, China has established a comprehensive and modern national innovation system (NIS) complemented by regional innovation systems. The current stage of China's NIS is firm-centred or business-driven, with the government, universities, and public labs playing supportive roles (OECD, 2008). Table 3.1 lists the main policies and institutional set-up from the 1950s to 2016.

Figure 3.2 sets out the implementation of the NIS in China. In summary, the State Council Steering Committee of Science and Technology and Education is the top policymaker in China's NIS. Various ministries and ministry-level agencies carry out different functions under the direction of the steering committee. The Ministry of Science and Technology is the key ministry for implementation. Its main tasks include (i) formulating strategies, priority areas, policies, laws, and regulations for S&T; (ii) promoting the building of the NIS; (iii) guiding reform of the NIS; (iv) designing and implementing programmes to fund basic and applied research; (v) creating science parks and incubators and inducing firms to innovate; (vi) developing measures to promote investment in S&T and allocating and encouraging the development of human resources and specialised talents; and (vii) promoting international cooperation and exchanges in S&T. It provides innovation funds for small high-tech firms in collaboration with the Ministry of Finance; supports university-related R&D, science parks, and human resources development in collaboration with the Ministry of Education; and works with other ministries to define and implement sector R&D policies and programmes.

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1 This especially includes unconventional and offshore oil and gas, renewable, (smart) power grid, and nuclear energy.

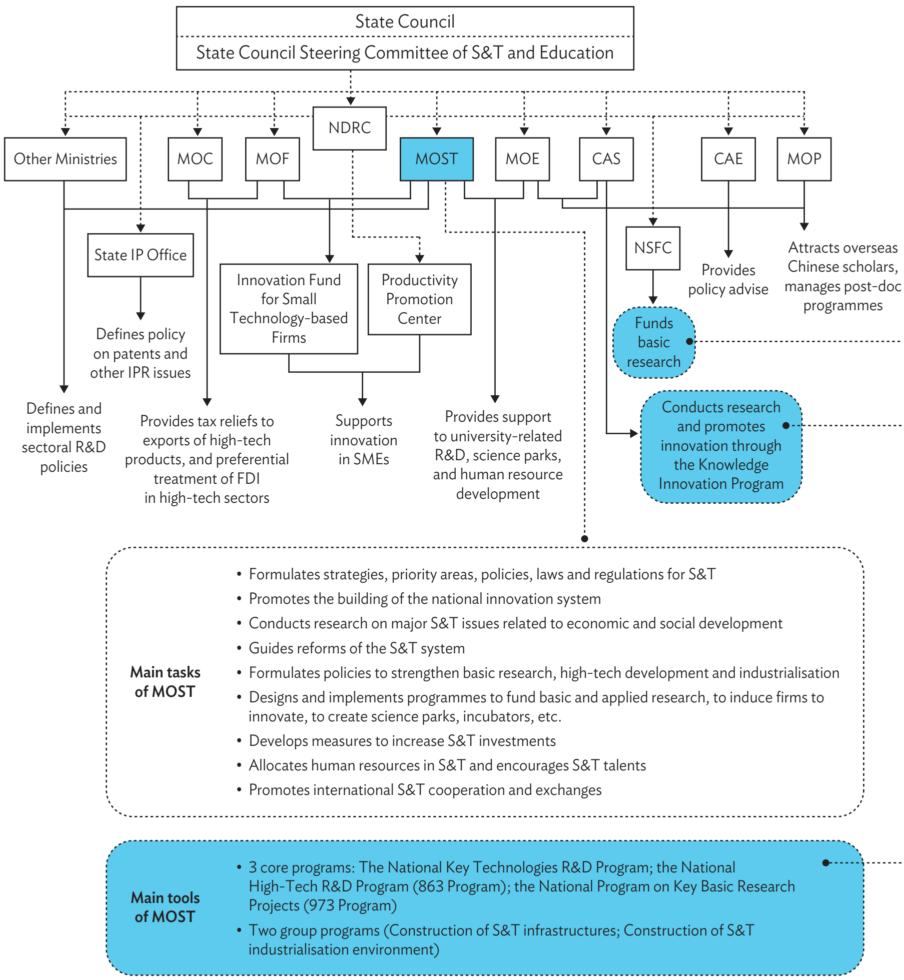
Table 3.1: Brief History of Policies and Institutions for Scientific and Technological Development and Innovation in China, 1950–2016

Period	Policy or Institution
1950–1977	Formation phase of the national innovation system
1978–1994	National plans for science and technology (S&T): – High-tech Research and Development Program ('863 Program') – Torch Program – Spark Program The National Program for Key Basic Research Projects – National Natural Science Foundation – Climbing Program – Other policies: reform of the funding system, development of the technology market, and commercialisation of S&T achievements
1995–1997	• Enterprise-centric reform: innovation by enterprises and property rights reforms • Strategy of Invigorating the Country through Science and Technology and Education • Establishment of national engineering centres and productivity promotion centres • Technology Innovation Project (for enhancing the innovation capacity of enterprises) • Other policies to accelerate the commercialisation of S&T achievements
1998–2005	Chinese Academy of Sciences approved to implement the knowledge innovation project and the construction of the national innovation system
2006–2015	National Medium- and Long-term Plan for Science and Technology Development (2006–2020): – To enhance indigenous and self-dominant innovation – To leapfrog in priority fields – To enable development and lead the future
2016	The 13th Five-year National Science and Technology Innovation Plan

Source: Authors' summary based on Song (2013).

The Ministry of Commerce and the Ministry of Finance also work together to provide tax relief to exporters of high-tech products and preferential treatment to FDI in the high-tech sectors. The Chinese Academy of Sciences not only conducts research directly and through programmes such as the Knowledge Innovation Program but also works with the Ministry of Education and the Ministry of Personnel to attract overseas Chinese scholars and manage postdoctoral programmes. The Chinese Academy of Engineering is another academic body that provides advice on S&T-related policies. Importantly, the National Development and Reform Commission – the powerful national economic policymaker – is also involved in the NIS as it sets up productivity promotion centres and works with the National Natural Science Foundation of China in funding basic research.

Figure 3.2: Institutional Profile of Public Governance of Science, Technology, and Innovation in China



CAE = Chinese Academy of Engineering, CAS = Chinese Academy of Sciences, IP = intellectual property, IPR = intellectual property rights, MOC = Ministry of Commerce, MOE = Ministry of Education, MOF = Ministry of Finance, MOP = Ministry of Personnel, MOST = Ministry of Science and Technology, NDRC = National Development and Reform Commission, NSFC = National Natural Science Foundation of China.

Source: Organisation for Economic Co-operation and Development, based on data from the MOST and other sources.

3.3 | Analysis of Innovation Policies Undertaken in China

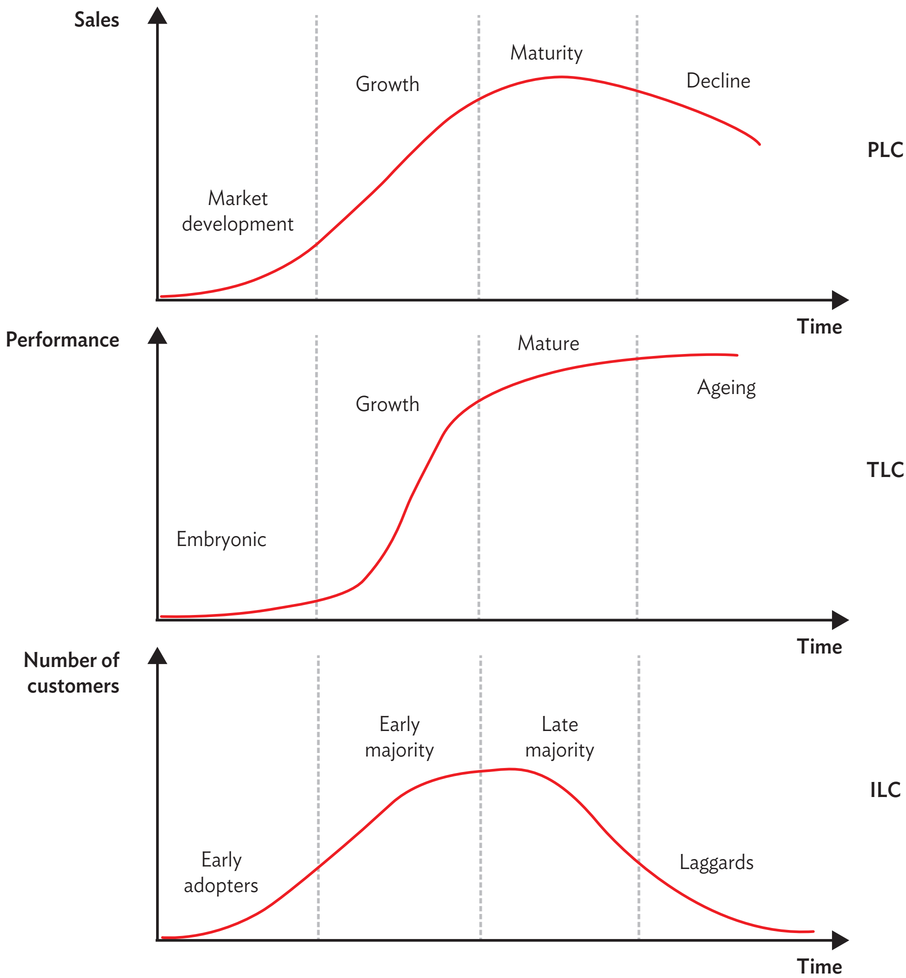
3.3.1 Theory and quantitative analysis

Theories in the literature

Since the characteristics of technology appear to be important factors in determining the strategy for catching up, it is necessary to look into theories that explain the evolution of technology as well as the role of firms, industry, and clusters in this process. The product life cycle theory, proposed by Levitt (1965) and Vernon (1966), divides the evolution of a technology into four subsequent stages: introduction, growth, maturity, and decline. At the maturity stage, an extension strategy may be applicable through measures such as rebranding, price discounting, seeking new markets, and creating new uses of the product. The theory was initially developed to explain the marketing of new products and subsequently was used to explain international trade, industrial organisation (e.g. entry, exit, market power, and market structure), firm theory (e.g. firm size, investment decisions, and competition strategy), and, eventually, innovation and the evolution of technology (Segerstrom et al., 1990; Klepper, 1996). The product life cycle is further elaborated as the technology life cycle (Taylor and Taylor, 2012) and the industry life cycle (McAuliffe, 2015). The technology life cycle focuses on the pattern of changes in performance over time. The focus of the industry life cycle is the pattern of the number and types of customers over time along the product life cycle. In principle, all three can be divided into four stages (Figure 3.3).

However, these theories do not explain why some countries have managed to catch up in certain technologies while others have not. In other words, the dynamics about learning are not reflected in these models. The product life cycle theory can easily be extended to the international product life cycle model (Ayal, 1981). As Figure 3.4 shows, the innovating economy starts and dominates exports from the beginning until the product reaches maturity. Other advanced economies are initially importers but subsequently start production themselves so as to also become exporters. Eventually, as the product becomes mature and affordable, low-income economies start to import it. Subsequently, with standardised design and production processes, low-income economies take over production and eventually become exporters of the product. Empirical evidence from electronics and electrical product manufacturing seems to follow such a pattern. Nonetheless, this theory does not explain technological catching up and spillover in all industries. Some technologies, such as precision instruments, machinery tools, core computer chips, and aviation

Figure 3.3: Product, Technology, and Industry Life Cycle Theories



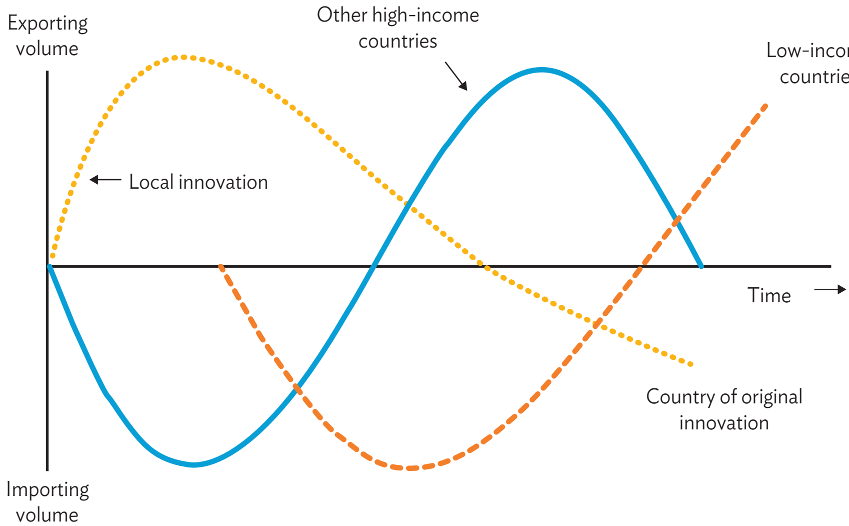
ILC = industry life cycle, PLC = product life cycle, TLC = technology life cycle.

Source: Authors.

and space technology, have several successful cases of catching up. These exceptions should motivate further innovations in economic theories to explain the dynamics of catching up and the barriers in this process.

As will be further explored and developed in the next section, the S-curve theory, in other words, the S-curve of the evolution of a single piece of technology, provides some insights into the standing theoretical issue mentioned above.

Figure 3.4: International Product Life Cycle

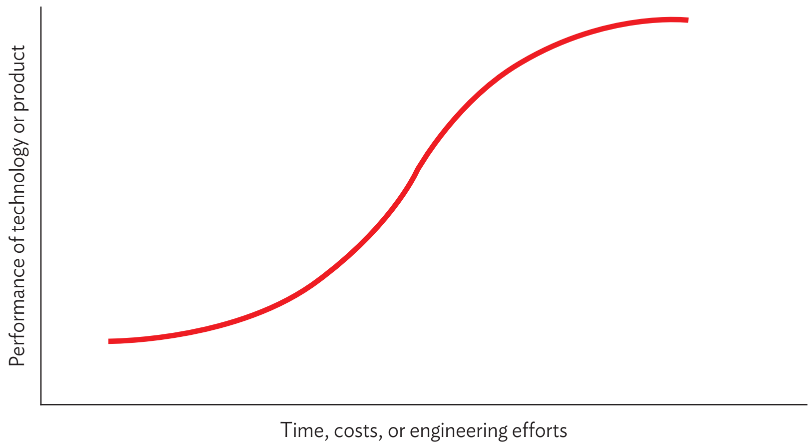


Source: Authors.

This theory considers the relation between the performance of a technology and the cost (in terms of time or engineering efforts) of reaching the level of performance. This typically appears as an S-shape curve (Figure 3.5). As Christensen (1992a, 1992b) states: '[In] a technology's early stages, the rate of progress in performance is relatively slow. As the technology becomes better understood, controlled, and diffused, the rate of technological improvement increases. But the theory posits that in its mature stages, the technology will asymptotically approach a natural or physical limit, which requires that ever greater periods of time or inputs of engineering effort be expended to achieve increments of performance improvement.'

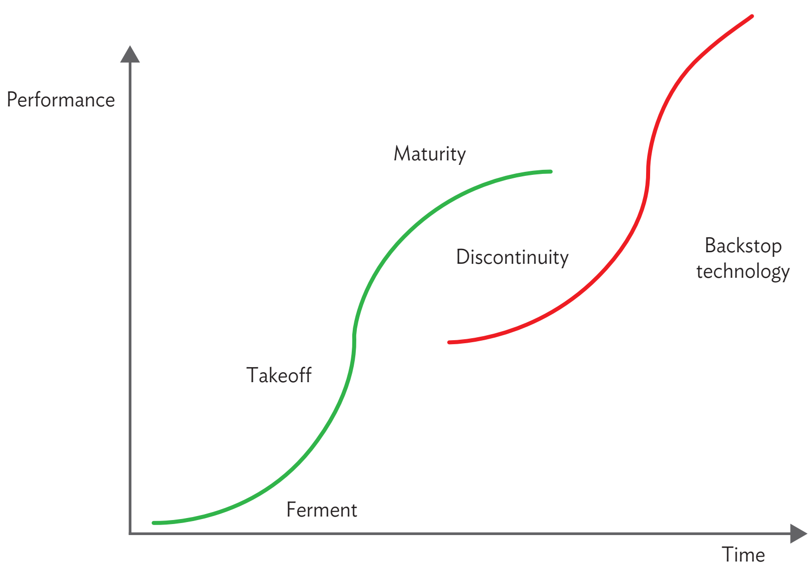
Moreover, as new phenomena, materials, and/or methods are discovered, breakthrough technologies will subsequently appear and present their own patterns of evolution – a necessary condition for the new technology to substitute for the old one. As Figure 3.6 illustrates, another S-curve then starts, beginning with a high level of performance. The new technology is sometimes referred to as a 'backstop technology'. This process is divided into four stages: ferment, takeoff, maturity, and substitution or discontinuity.

Figure 3.5: S-Curve Theory of Technological Advances and Innovation



Source: Authors.

Figure 3.6: S-Curve Theory of Technological Advances and Innovation: Backstop Technology

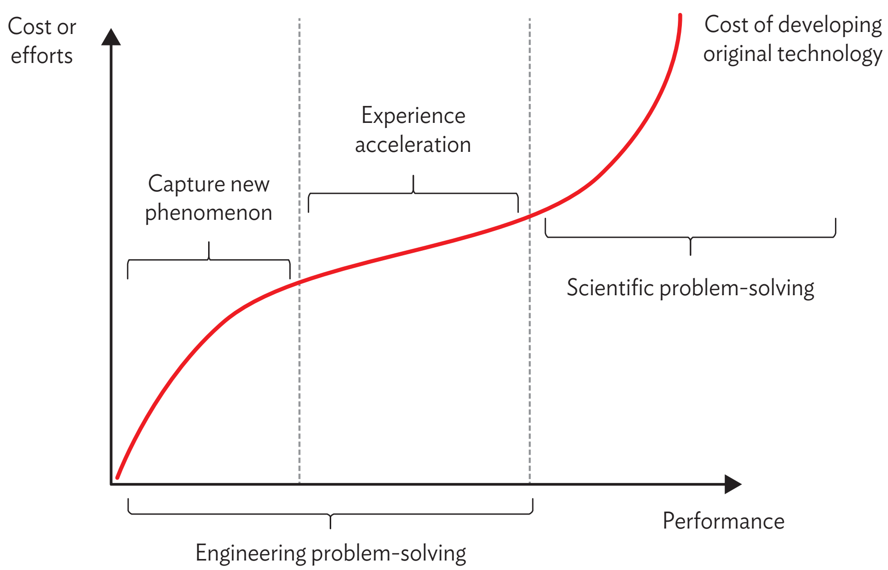


Source: Authors.

The inverted S-curve theory

This chapter proposes a new theory of technological catching up, by focusing on the cost of technological advances or innovation and the cost of learning. The theory is built on the existing S-curve theory. However, we invert the coordinate system by making the vertical axis represent the cost or efforts paid, while the horizontal axis represents the performance or sophistication of the technology. As Figure 3.7 shows, each point on the inverted S-curve represents the cost paid to arrive at a certain level of performance.

Figure 3.7: Inverted S-Curve of Technological Advances or Innovation and Learning Cost

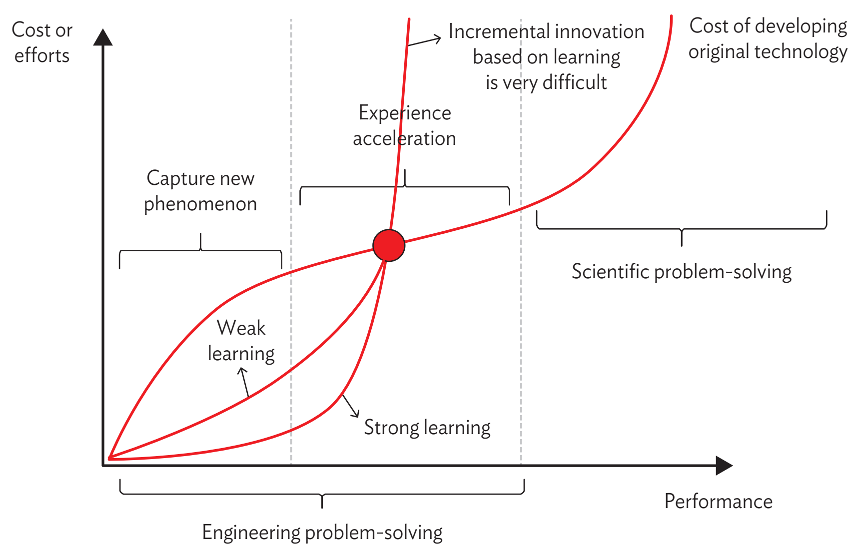


Source: Authors.

According to the type of driving force behind technological progress as well as the speed of evolution, we also divide the pattern into three phases. First, as is always the case with a new technology, a new phenomenon must be captured by some simple method, tools, equipment, machinery, or system. This can be referred to as the 'engineering problem-solving phase'. Subsequently, as experience and knowledge are built up, based on growing amounts of understanding, observation, and data about the phenomena and the performance of the initial technological solutions, incremental improvements are made that typically enable significant progress towards better performance. This can be referred to as the 'experience acceleration phase'. As the improving technology approaches the theoretical limits of the phenomena, more sophisticated knowledge based on scientific research is necessary, as science enables the discovery of in-depth mechanisms driving the phenomena, which is usually beyond the capability of observation and manipulation by intuition or experience. Arthur (2009) gives a detailed and systematic illustration of the same idea. For example, crude oil exploration used to be based on experience, such as surface indications of oil and gas seepage. Gradually, industry practice began to be based on increasingly sophisticated geological theories. Today, the oil and gas giants use supercomputers and theory-based algorithms to crunch massive amounts of geological data in searching for new reserves.

We can now model the process of learning by a latecomer (Figure 3.8). Let us consider the case that the advanced economy has already pushed the frontier of technology into the scientific problem-solving phase. With the inverted S-curve of a certain technology given, the early stage of learning should be much cheaper than conducting R&D and developing the technology, in the same way as reading a book is much easier than writing one. The shape of the learning curve depends on the learning capability of the latecomer and the availability of codified knowledge, as well as the extent to which knowledge is embedded in the products and equipment that contain the technology.

Figure 3.8: Inverted S-Curve of Technological Advances or Innovation and Learning Cost: Latecomer



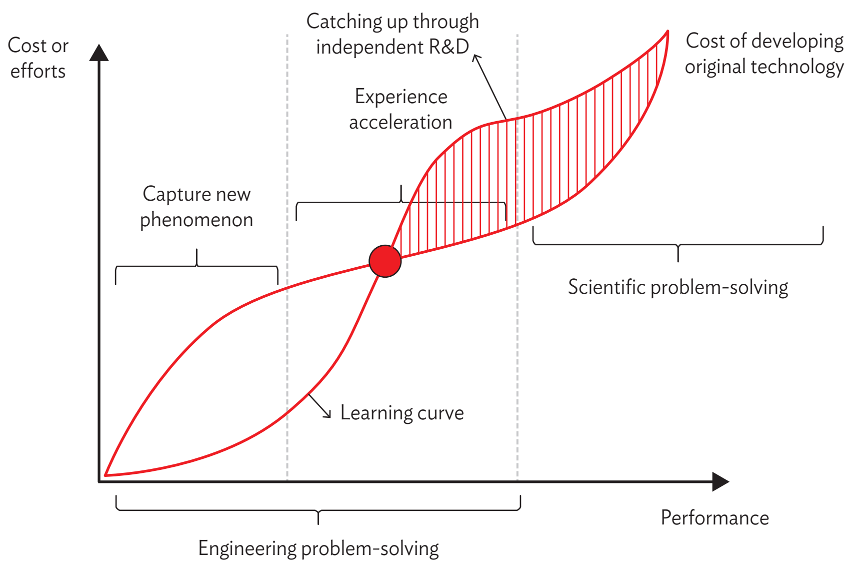
Source: Authors.

Therefore, on the one hand, the learner whose costs rise fast with slow progress in performance is considered a weak learner, while the one who makes good progress in performance with slower increases in costs is considered a strong learner. The cost of learning should be interpreted broadly to include time, staffing, money, and other resources. On the other hand, the availability of codified and embedded technology determines how far learning can go – how soon the learning curve becomes steeper than the inverted S-curve (and thus crosses the inverted S-curve). Beyond this point, technology and knowledge might be either tacit or kept as strictly protected patents and business secrets, and, thus, learning becomes almost impossible by regular means. Also, beyond this point, based on what the latecomer has already learned, incremental innovation will prove difficult and of limited potential, as indicated by the very steep extension of the learning curve. This is also intuitive: you might have read and understand Albert Einstein's books and papers, but that does not mean you can immediately become Albert Einstein and innovate as well as he could.

Intuitively, innovation is a problem-solving process. Therefore, when the latecomer has finished reading the available 'book' closest to the frontier, if they determine to catch up further in technology, they can start trying to use what they have already learned to solve new problems and, thus, acquire experience. In Figure 3.9, the learning curve stops due to the availability of codified and embedded technology, and the bold curve starts above the original inverted S-curve, rising much faster in cost, as the early stage of building up experience is intuitively much more costly. One can also consider the case of the latecomer that starts its own inverted S-curve to conduct innovation from this point. Along this 'catching-up curve', the latecomer typically has to pay more to innovate and improve the performance of the technology than the original developer did to develop it. However, intuitively, this gap narrows, especially as the evolution of the technology comes to the scientific problem-solving phase. We expect the catching-up curve to eventually converge to the original inverted S-curve and the latecomer to become a technology leader shoulder-to-shoulder with the original developers.

The tricky part is the size of the shaded area in Figure 3.9. This area implies the cost of catching up, the additional cost that the latecomer has to pay to follow the pace of the most advanced technological progresses. The size of the area, however, depends on both the nature of the technology and the structure of the market. For some technologies, the area could be thin, as it might be easy to acquire and accumulate the necessary experience, or the tacit knowledge may be easily available and codified. For other technologies, it may be difficult to accumulate the necessary experience, or the tacit knowledge may not be available or codified, and, therefore, this area could be thick. For example, it is difficult for latecomers to innovate incrementally on an integral single piece of product based on what they have learned without a long history of accumulated experiences. Motor engines and aviation engines are examples. Technologies such as supercomputers and high-speed railway belong to the 'system integration' type of technology. As long as the component technologies used to build the system are available on the market, new system designs using new component technologies can be tested, and, thus, the experience of developing the system is easier to acquire. However, if the supply chain is incomplete or incapable of supplying advanced component technologies, bottlenecks can be expected in catching up in system integration technologies.

Figure 3.9: Learning Curve and Catching Up through Independent Research and Development



Source: Authors.

The structure of the market thus also matters because the more competitive the market is (i.e. the lower the concentration of the industry), the more likely codified and embedded technology will be available from the global technology market. This could take the form of a product (component technology, or intermediate inputs or equipment); transfer; licensing (patents); education and training; acquisition and merger; partnership; original equipment manufacturing; joint venture; FDI; or imports of equipment and machinery. Therefore, in this case, the learning curve could extend further to the right, reducing the area to be covered under the catching-up curve.

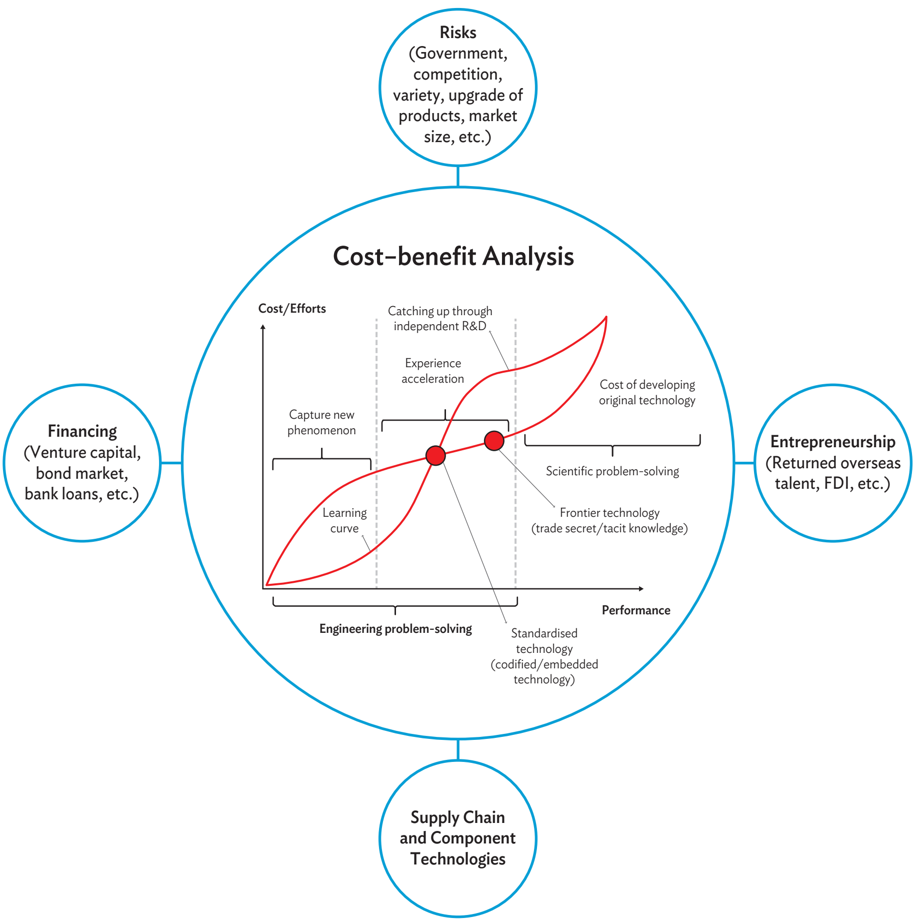
For a certain technology, if the three curves – the inverted S-curve, the learning curve, and the catching-up curve – are given, the cost of learning and catching up can be determined accordingly. The latecomer must therefore conduct its own cost–benefit analysis. The benefit of learning and catching up depends on the market demand the latecomer can expect, including both the domestic market and the potential for export. If the expected demand is high, and thus revenue could more than compensate for the exceptional cost of technological catching up, then there is an economic rationale for the decision to embark on catching up. However, market demand is not modelled in the current technological catching-up theory as it is only related to the supply side. The theory focuses on explaining the dynamic nature of technological catching up for latecomer economies.

General framework of the driving factors of technological catching up and innovation

The inverted S-curve theory explains the cost–benefit analysis of the motivation for catching up in technology in a well-defined sector or section of the sector's supply chain. However, a mature decision for investing in technological caching up and subsequent innovation is also contingent on several key external factors.

Four categories of external factors are summarised in Figure 3.10. In the first category are the risks involved in technological catching up and innovation. In this regard, government policy, regulations, and various forms of support play important roles. The market of each industry then determines the level of competition, how much variety there will be in the products and services, how soon products and services will be upgraded, and how much demand there is in each niche market. The second category concerns the source of the entrepreneurship to drive catching up and innovation. In developing countries, returned overseas talents and FDI by international MNCs are the most important sources. The third category concerns the structure of the supply chain. A country with a more comprehensive and well-developed supply chain will find it easier to upgrade technologies, as the component technologies are more readily available. If the control of supplies of core technologies, such as engines for vehicles and aircraft, is missing, this could become a bottleneck to the development of more technologically advanced cars and aircrafts. For example, if the US government does not wish to see supercomputers developed too fast in China, it could issue administrative orders to ban the export of high-end chipsets to China. The fourth category is about the financing solutions available in an economy to support technological catching up and innovation. In this regard, conventional banks and innovative financing, such as venture capital and the bond market, are important. Typically, the latter is important for creating a vibrant environment for catching up and innovation.

Figure 3.10: General Framework of the Driving Factors of Technological Catching Up and Innovation



FDI = foreign direct investment.

Source: Authors.

Quantitative analysis

Methodology. We follow Diebold and Yilmaz (2009, 2012, 2014) by using the vector autoregressive (VAR) model approach to investigate which factors contribute to innovation and to what extent. The model starts with a K variable *VAR*(p) model in the form of

$$y_t = c + \sum_{i=1}^{p} A_i y_{t-i} + u_t \tag{1}$$

where y is a $(K \times 1)$ vector of the time series variables in the system, c is a $(K \times 1)$ vector of constants, and u is a $(K \times 1)$ vector of the error terms; A represents $(K \times K)$ dimensional matrices of coefficients. After estimating the model, we use forecasting error variance decomposition (FEVD) to interpret how the variables are dynamically related.

The FEVD approach starts with constructing the mean squared error of the H-step forecast of variable y_i and examining the contribution of each variable to other variables in the system. Defining θ_{ij}^{H} as the contribution of variable j to i, and H as the forecasting horizon, the basic idea of Diebold and Yilmaz (2009) can be shown in a connectedness table, as in Table 3.2.

Table 3.2: Connectedness Table Based on Variance Decomposition

	y_1	y_2	$\cdots$	y_K	From others
y_1	θ_{11}^{H}	θ_{12}^{H}	$\cdots$	θ_{1K}^{H}	$\sum_{j=1}^{K} \theta_{1j}^{H}, j \neq 1$
y_2	θ_{21}^{H}	θ_{22}^{H}	$\cdots$	θ_{2K}^{H}	$\sum_{j=1}^{K} \theta_{2j}^{H}, j \neq 2$
$\vdots$	$\vdots$	$\vdots$	$\ddots$	$\vdots$	$\vdots$
y_K	θ_{21}^{H}	θ_{22}^{H}	$\cdots$	θ_{KK}^{H}	$\sum_{j=1}^{K} \theta_{Kj}^{H}, j \neq K$
To others	$\sum_{i=1}^{K} \theta_{i1}^{H}\ i \neq 1$	$\sum_{i=1}^{K} \theta_{i2}^{H}\ i \neq 2$	$\cdots$	$\sum_{i=1}^{K} \theta_{iK}^{H}\ i \neq N$	$\frac{1}{K} \sum_{ij=1}^{K} \theta_{ij}^{H}\ i \neq j$

As the diagonal elements represent the contributions by/to the variable itself, the remaining elements reflect how much the variables are interconnected. Diebold and Yilmaz (2012) also introduce three additional measures: from others (FC), to others (OC), and net directional connectedness (NDC):

$$FC_i = C_{i\leftarrow\cdot}^{H} = \sum_{j=1}^{K} \theta_{ij}^{H}, \ j \neq i \tag{2}$$

$$OC_i = C^H_{\cdot\leftarrow i} = \sum_{i=1}^{K} \theta^H_{ij}, i \neq j \tag{3}$$

$$NDC_i = C^H_i = C^H_{\cdot\leftarrow i} - C^H_{i\leftarrow\cdot} \tag{4}$$

FC calculates how much one variable gains from the system (excluding itself) and thus takes a value between 0 and 1. OC is not bounded by 1 as it shows how much one variable contributes to the variation of the whole system (excluding itself). NDC is negative if one variable gains more information from the system than it contributes to the system. It is possible to construct NDC in a pairwise way in that $NDC_{ij} = C^H_{ij} = C^H_{j\leftarrow i} - C^H_{i\leftarrow j}$, which shows the relative importance of all pairs in the system. The VAR model is sensitive to the order of the variables in the system, so the generalised variance decomposition approach of Koop et al. (1996) and Pesaran and Shinb (1998) is needed in practice.

Data. We set up a seven-variable VAR model including the growth rates of patents, loans, per capita GDP, FDI, fiscal expenditure, wages, and the high-tech market size. Patents are used as a measure of innovation in terms of output; loans as a percentage of GDP are used to represent financial market development; per capita GDP measures the level of income; FDI is used for international impacts; fiscal expenditure is a proxy of public investment; wages capture labour income, which is supposed to affect innovation; and the high-tech market size captures the general market environment for innovation. All data are in annual frequency from 1989 to 2015 and collected from the National Bureau of Statistics. The variables are explained in Table 3.3. The data are converted into growth rates before being added to the VAR model for further analysis.

Empirical results. We estimate a seven-variable VAR model with two lags.[2] The results are reported in Table 3.4. GDP growth is the most important contributor to the system with a total of 166.45%, and financial development is the second most important factor with a 141.57% total contribution. These two variables are the only two net contributors. All five other variables are net receivers (negative NDC). The fiscal expenditure growth rate gains the most from the system. The total connectedness of the system is 78.39%, which suggests that only 21.61% of the variation is due to self-contribution.

2 Bayesian information criteria are used to choose the optimal lag order.

Table 3.3: Summary of Variable Definitions

Abbreviation	Variable Definition
Pat	Number of patent applications granted (growth rate)
FIN	Total outstanding loans in financial institutions (growth rate)
Growth	Real gross domestic product growth
FDI	Foreign direct investment growth
Fiscal	Annual growth rate of public fiscal expenditure
Wage	Urban average wage growth
HTM	Total trading volume of the technical market (growth rate)

Source: Authors.

Table 3.4: Connectedness Table of the Estimated Vector Autoregressive Model (%)

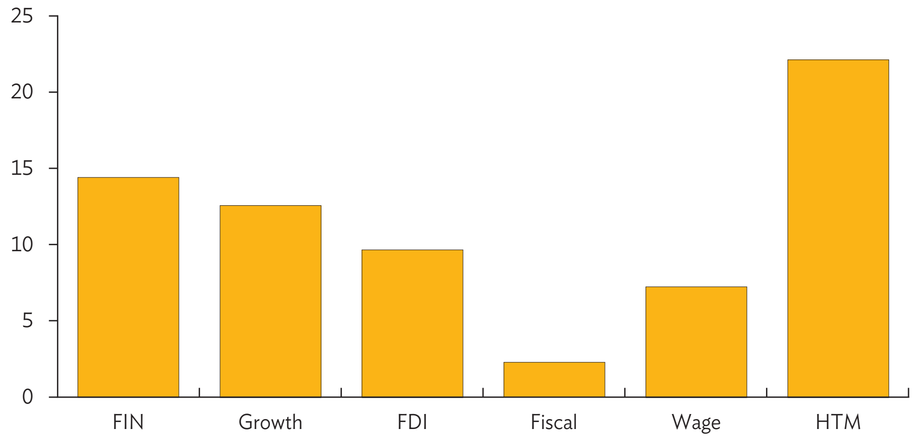
Variable	Pat	FIN	Growth	FDI	Fiscal	Wage	HTM	From others
Pat	31.92	14.38	12.53	9.63	2.28	7.25	22.00	68.08
FIN	8.69	25.64	31.83	9.73	5.82	11.83	6.46	74.36
Growth	8.41	26.62	38.41	5.52	2.91	11.42	6.72	61.59
FDI	8.16	27.60	22.05	20.97	4.91	6.99	9.32	79.03
Fiscal	7.09	24.15	39.72	4.11	7.36	12.80	4.77	92.64
Wage	9.58	25.51	32.57	8.46	4.11	11.86	7.92	88.14
HTM	13.10	23.31	27.75	8.87	3.63	8.21	15.12	84.88
To others	55.03	141.57	166.45	46.32	23.66	58.50	57.19	**78.39**

Note: The number in bold represents the total connectedness measured in this system. Please refer to Table 3.2 for the definition of 'from others' and 'to others'.

Source: Authors.

Figure 3.11 plots the contribution to patents granted (growth rate) in China from other factors. The highest contribution to patent growth rate comes from the high-tech market growth, and it explains 22% of the variation in patent growth. It shows that a healthy market-oriented system is very important for innovation. Although there are still gaps between China and the developed economies, it is clear that the efforts made by the Government of China to improve the high-tech market conditions have paid off.

Figure 3.11: Contribution to Patents Granted from Other Factors (%)



FDI = foreign direct investment growth, FIN = total outstanding loans in financial institutions (growth rate), fiscal = annual growth rate of public fiscal expenditure, growth = real gross domestic product growth, HTM = total trading volume of the technical market (growth rate), wage = urban average wage growth.

Source: Authors.

Income growth and financial development contribute to more than 10% of the variation in innovation. Growth contributes 31.83% to financial development, whereas financial development explains 26.62% of the growth variation. These two are intrinsically linked, although growth is the net contributor to financial development. The logic is that when an economy is getting richer and its financial system is becoming more developed, innovation is more likely to be funded. A caveat is that we cannot include the equity market due to the availability of data.[3] The development of the equity market should also promote innovation. In other words, the role of financial development should have stronger role in the innovation system of China.

FDI does not have a very strong role in affecting China's innovation. One may expect that international investment would bring technological progress to the host country, but it appears that the logic does not apply to China. China is indeed a very big recipient of international investment, however, being the world's biggest factory, it does not benefit much in terms of technical progress. Fiscal expenditure and wage growth have little impact on innovation. One explanation is that both variables gain significantly from 'FIN' and 'growth', the two variables that dominate here.

[3] The stock market in China started only in 1991.

3.3.2 Industry cases

Driving factors of technological catching up and successful innovations in Chinese industries

Based on the above theory, the following paragraphs and tables list four key dimensions of the characteristics of the market and technologies of a broadly defined industry in the context of China. The dimensions are (i) the market concentration of technology vendors, (ii) the type of technology (system integration or single piece of technology), (iii) the completeness of the supply chain within the economy, and (iv) the variety and frequency of upgrading of the products (or services). We focus on the characteristics of the industry or technology per se. Common factors, such as entrepreneurship, financing, public R&D, and government support for education and labour skills, are not discussed. Table 3.5 presents these dimensions and summarises the characteristics of several key industries of strategic interest to the Chinese economy. The profiling of each industry according to the four dimensions is based on trade statistics and anecdotal evidence or experience. The last row of each section of the table concludes on the effectiveness of technological catching up or innovation of the industries as a result of these characteristics. In this study, effective catching up is indicated by a significant share of exports of products with autonomous technologies, patents, or design by the Chinese industry in the global market.[4]

[4] Refer to the following for further details:
http://www.worldstopexports.com/ for statistics on broadly defined industries, such as electronics, vehicles, and aeroplanes;
http://news.xinhuanet.com/tech/2016-09/19/c_1119580852.htm for automobiles, vehicle engines, and electronic chips;
http://www.sohu.com/a/135343162_676567 for the aviation engine industry;
http://www.cccme.org.cn/news/content-274184.aspx for the telecom equipment industry;
http://www.iberglobal.com/Archivos/china_aerospace_rand.pdf for the space industry;
https://www.rand.org/pubs/research_reports/RR245.readonline.html for the aviation industry;
http://www.roboticschina.com/news/article/201706121612 for robotics;
http://www.guancha.cn/economy/2016_03_24_354912.shtml for digital machinery tools;
http://news.xinhuanet.com/globe/2017-08/15/c_136500569.htm for advanced computing;
http://paper.people.com.cn/rmrb/html/2017-04/05/nw.D110000renmrb_20170405_8-01.htm for the nuclear energy industry;
http://news.xinhuanet.com/science/2015-12/24/c_134946932.htm for high-speed rail;
http://www.biotech.org.cn/information/134424 for the medicine and biotechnology industry;
https://hbr.org/2017/07/60-countries-digital-competitiveness-indexed for e-commerce;
http://www.chinareform.net/index.php?m=content&c=index&a=show&catid=30&id=19887 for infrastructure engineering and construction; and
http://www.cailiaoniu.com/89839.html for advanced material technologies.

Table 3.5: Anecdotal Evidence of the Driving Factors in Chinese Industries' Technological Catching Up and Innovation

Industry	Space	Aviation	Automobile	Telecom System	Nuclear Energy	Electronic Chips
Market concentration	High	High	Low	High	High	High
Type of technology	SI	SI	SI	SI	SI	INT
Completeness of supply chain	Y	Y	N	N	Y	N
Variety and regeneration of products	Low	Low	High	Low	Low	High
Effective catching up or innovation	Y	Y	N	Y	Y	N
Industry	**High-speed Rail**	**Aviation Engine**	**Vehicle Engine**	**Digital Machinery Tools**	**Robotics**	**Advanced Computing (AI, cloud computing, big data)**
Market concentration	High	High	Low	Low	Low	Low
Type of technology	SI	INT	INT	SI	SI	INT
Completeness of supply chain	Y	N	N	N	N	Y
Variety and regeneration of products	Low	Low	High	High	High	High
Effective catching up or innovation	Y	N	N	N	N	Y
Industry	**Medicine and Bio-technology**	**E-commerce Application**	**Infrastructure Engineering and Construction**	**Supercomputers and Data Centres**	**Advanced Materials (chemical and metallic)**	
Market concentration	Low	Low	High	Low	High	
Type of technology	INT	SI	SI	SI	INT	
Completeness of supply chain	N	Y	Y	N	N	
Variety and regeneration of products	High	High	Low	Low	High	
Effective catching up or innovation	N	Y	Y	Y	N	

AI = artificial intelligence, INT = integral piece of technology, N = no, SI = system integration, Y = yes.

Source: Authors, based on the Thirteenth Five-year Planning for National Scientific and Technological Innovation and various media and industry consultancy reports.

A general pattern can be summarised as follows. China has performed well in the catching up of the system integration type of technologies. Where the market concentration of technology vendors is high, the supply chain is complete within the Chinese economy, and the variety and frequency of upgrading of products and services is low, successful technological catching up is almost guaranteed. Examples include space, aviation, telecoms, nuclear energy, and high-speed rail. The telecom industry deviates a little from this pattern as its supply chain of component technologies is not as complete within the Chinese economy; various components need to be imported or patents for the components need to be licensed. However, it is common practice in this industry for international giants to exchange the patents and licences they hold for free, or to provide low-cost access to each other's component technologies. Thus, Chinese telecom equipment manufacturers only need to own a certain portion of original component technologies among all patented component technologies along the supply chain to be able to exchange them for access to advanced component technologies held by other international players.

For a few other system integration technologies, even if some of these factors are different, such as e-commerce application and supercomputers and data centres, successful catching up can still occur. Thus, it seems that China has intrinsic strength in catching up in system integration technologies. Importantly, as long as high-quality component technologies are available from the international market, system integration technology by nature allows latecomers to assemble such components and turn them into products and services of acceptable quality, stay marginally competitive in the market (especially if there are cheap labour, natural resources, and land available within the latecomer economy) and, thus, survive at the early stage. Having a sufficiently big domestic market may also be crucial to the survival of these latecomers at this stage. The longer they survive, the more likely they will complete the catching-up curve by learning from their own incremental innovation efforts. This may explain the catching up of Chinese companies in e-commerce application and supercomputers and data centres, for which the domestic market is not only big but also heavily protected.

Nonetheless, the cases of the automobile, digital machinery, and robotics industries show that if all or most of the other factors deviate from the observed pattern, even if it is a system integration technology, Chinese industries could still fail to catch up. So far, China has not become a main exporter of vehicles, high-end machinery tools, or robots. Nor does it have any world-renowned vehicle, machinery tool, or robot brands.

These three industries are notably competitive, having many international technology vendors (many choices of technological paths and standards), an incomplete domestic supply chain of component technologies, and a large variety of products and services and a high frequency of upgrade.

For 'single-piece'[5] technologies, China has only managed to catch up in advanced computing. This could imply that other factors not listed here are at work, such as the high availability of codified knowledge in this industry, such as advanced algorithms, and the relatively low cost of accumulating experience through trial and error, such as computer simulation. For other industries applying single-piece technologies, such as aviation engines, vehicle engines, medicine and biotechnology, and advanced materials, catching up appears to be difficult for Chinese industries because (i) there are many international technology vendors and, therefore, many choices of technological paths and standards, (ii) the domestic supply chain of component technologies is incomplete, and (iii) there is a large variety of products and services and a high frequency of upgrade.

These characteristics of the market and technologies of these industries may determine whether China's indigenous resources, such as its large market size and its cheap land and labour – especially labour for research, development, and demonstration – can render the necessary competitive advantages to catch up in technologies and conduct subsequent innovations.

The theory that has been proposed and illustrated has ample policy implications. Three important policy-related observations are highlighted. First, protective measures against competition from advanced foreign technology developers could help ensure that the latecomer in the host country is able to generate sufficient revenue from the domestic market and thus compensate for the high cost of catching up. The theory thus also explains why some developing countries must provide subsidies or tax incentives for exporting certain industrial products and services, especially in their catching-up stage. However, this may be more applicable to system integration technologies and in cases where the international market is highly concentrated and has a low intensity of competition. Second, our theory suggests using public finance or public sector research to reduce the exceptional cost of catching up for the

[5] This is usually a single product with a complicated design and high-precision assembly, such as vehicle engines and advanced computer chips.

latecomer country. Third, establishing a complete and capable domestic supply chain could accelerate catching up in system integration technologies. In a small economy, which is unlikely to be capable of hosting a complete supply chain, the government should ensure sound partnership and cooperation with the global supply chain to enable effective and affordable cross-licensing of patented component technologies.

Firm-level strategies leveraging on state-level policies

The China General Nuclear case of catching up in nuclear energy technologies. China General Nuclear (CGN) is a young, state-owned energy company founded in 1994. Its main business is nuclear energy, although it has diversified into hydro, solar, and wind power. As of January 2017, CGN had 19 nuclear reactors with a total capacity of 20.38 gigawatts in operation and another 9 reactors under construction, making it China's largest nuclear energy producer. Being a latecomer in nuclear energy technology, this company is now already exporting its own version of second- and third-generation nuclear energy technologies as its recently announced projects with Romania and the United Kingdom show.[6]

Nuclear energy reactors are the system integration type of technology. The industry is highly concentrated, both globally and domestically. The technology also progresses slowly, usually taking two or three decades for a new generation to appear. Thus, the industry almost fits our 'pattern of success' observed in the previous subsection. Indeed, billion dollar nuclear power plant projects introduced in China in the 1980s and 1990s always came with requirements for technology transfer and licensing from international technology, vendors such as Westinghouse, Areva, and Candu. The introduction of high-speed rail technologies later on followed a similar pattern. Such a strategy is also pursued as much as possible in the acquisition of core parts of nuclear power plants. This is reflected as a higher localisation rate or import substitution rate of the parts and components. In the case of nuclear energy technology, such as large forgings of core equipment, reactor pressurised vessels, steam generators, water pumps, critical valves, main transformers, and emergency diesel generators, CGN collaborates with domestic suppliers in localising the supply chain. Therefore, a supply chain capable of supplying 80%–90% of all parts and components has been set up in China. In return, localisation of the supply of key parts and components has become a major factor in helping keep the cost of new nuclear power plants within the budget plan. Today, the 'overnight' cost

6 See http://www.world-nuclear.org/information-library/country-profiles/countries-o-s/romania.aspx and https://www.theguardian.com/business/2016/sep/15/hinkley-point-chinese-firm-to-submit-essex-nuclear-plant-plans (accessed 21 March 2017).

(i.e. with no interest incurred) of a new nuclear power plant in China is one-third less than that in the European Union, while costs in the US are 30% higher than in China (World Nuclear, 2017).

The government's policy of steadily promoting the share of nuclear energy in the national energy mix has lowered the risks and guaranteed the returns to the investment made by domestic companies along the supply chain. The relevance of technologies in the parts and components supply in conventional power generation equipment, as well as a strong domestic human resources reservoir consisting of scientists, engineers, technicians, and manufacturing specialists from the nuclear-related national defence system, all helped in the fast catching up. The government is still pouring public resources into the R&D of advanced nuclear energy technologies, such as fourth-generation nuclear fission technologies, small-module and high-temperature reactors, and even fusion technologies. With all these factors at work, this industry is becoming one of the major exporters in the global nuclear energy markets.

The Huawei case of catching up in telecommunication technologies. Huawei is a purely private enterprise originating in China. It started as a downstream assembler of existing, standardised, and marketable information and communication technology (ICT). Its programme control telephone exchanger was a symbolic product in the 1980s and 1990s. As the era of mobile and wireless communication arrived, followed by the digital communication era, Huawei gradually emerged as a telecommunication equipment supplier, especially serving the telecom service carriers. Its competitive advantage was to customise the design and functions of equipment built using standardised technologies and components. It was a system integrator and an assembler, and it also innovated on the peripheral technologies to provide customers with a better user experience. However, it was its patents for design and peripheral technologies that helped Huawei establish itself as one of the global players in the industry. From there, the company gradually moved its R&D closer to the central core of ICT technologies, especially by becoming one of the makers of the global telecom standards, such as the 3G, 4G, and 5G wireless communication technologies. Its R&D expenditure was kept at as high as 30% of its revenue. It was this intensity of R&D, combined with its practical strategy of customer-driven innovations, that allowed the company to keep increasing its sales while also going deeper into advanced ICT.

A salient feature of the ICT industry is how fast the technologies change, which provides more opportunities for a company to build up its patent pool not only by creating breakthrough innovations but also by making incremental innovations as part of the continuous improvements in performance of new technologies. The merging of information technologies and computing technologies, especially the arrival of the smartphone, also make the number of component technologies needed to make an ICT system function huge. Eventually, the patents end up in the hands of a few international giants, such as Ericsson, CISCO, Siemens, Alcatel, Nokia, Samsung, and even Google and Apple. They exchange, trade, or sue for the use of patents and designs held by each other.

Huawei gradually squeezed itself in, first by trading its peripheral technologies for the use of core technologies then subsequently by participating in global R&D efforts to establish new standards, thus introducing a new generation of technologies. Under this arrangement, Huawei need not own all the core technologies to stay in the first squadron of technology players; it only needs to contribute a fair share of the total number of patents of a new technological system. A larger share is always better, as it means it can trade its patents for the use of others' patents for free or even charge extra royalties if it is believed that Huawei's patents are more critical. This is why Huawei has started charging global giants, such as Apple, royalty fees.

Huawei continues to move up to the top tier of the industry. Today, it manufactures its own communication chips for its telecommunication equipment and central processing unit chips for its smartphones. The company has made use of any leverage it has to rapidly break into new technological areas, especially in moving from downstream to upstream technologies. It partners with international giants; establishes overseas labs and R&D centres; and identifies the mature, standardised, and available modules in a new technological field in order to focus on making incremental innovations to quickly conquer markets. In other words, contrary to the case of CGN in the nuclear energy industry, in this industry, Huawei to a very large extent makes use of the global supply chain to acquire the most advanced component technologies and then incrementally innovates on top of them. This difference may be due to the more competitive market of the telecom world in terms of how fast the technologies are being changed and upgraded.

Observations from the case studies. Both nuclear energy technologies and ICT are extremely complicated technologies. They also took more than half a century to evolve to today's levels of complexity and performance. Today, the two technologies are becoming increasingly standardised, embedded in equipment and products, or codified and, thus, available in various forms from various markets, such as licensing, consultancy, the acquisition of equipment and products, and even reading and lecturing. However, both the cost of learning and the cost of accumulating experience, as indicated in Figure 3.9, appear prohibitive to most potential market entrants. Of course, China has the second-biggest economy today and one of the largest markets in the world to absorb the costs of learning and catching up. Both CGN and Huawei started out by focusing on the domestic market and used the revenue to invest in further learning and catching up, especially conducting incremental innovation and improvement on the technologies learned at each stage. However, strong and sustained overseas demand could have the same effect if trading partners do not pursue protective trade policies.

In any case, an industry from a developing economy cannot immediately jump into the core and most advanced technologies as the target of catching up. It is more practical to import core parts or pay for the use of core technologies and at the same time focus on catching up or innovating in complementary or peripheral component technologies that are typically easier or entail lower costs of learning and catching up. Depending on how much revenue can be recouped from the market seized by these innovated products or services and how soon this can be achieved, the industry can invest more to pursue further technological development closer to the core technologies. Such is the strategy played by CGN and Huawei.

The timing of catching up is essential. If it is too slow, in a industry with frequent technological progress and upgrade, catching up may end up being futile. To do the most catching up within the shortest time, it is critical to have a catching-up strategy in areas that the company or the industry of a developing economy has comparative advantages. Neither CGN nor Huawei own a majority of the patents in the most advanced technologies in their industries. However, owning even a small fraction is sufficient as a stake on the table for negotiation and exchange to use other key players' core technologies. This is how partnerships or alliances have been formed between CGN and Areva, and between Huawei, Samsung, and Google.

Last but not least, the availability of the latest component technologies is as important as the core technologies owned by a downstream company or industry. In the case of a highly competitive and dynamic industry, such as ICT, Huawei can rely on the international supply chain. In the less competitive and less dynamic nuclear energy industry, CGN chose to foster a supply chain that mainly relied on domestic suppliers to reduce the costs of supplying key components and shorten the response time of the supply chain. In the nuclear energy industry, the lead time of a power plant project is directly translated into the cost of the project.

3.4 | Future Innovation Policies in China

In view of the global new wave of technological progress in robotics, artificial intelligence (AI), big data, cloud computing, and the digitisation of conventional industries, China has issued its future-oriented industrial technology development plan, called 'Made in China 2025'.[7] This is a comprehensive plan aimed at developing more innovative, more productive, more digitised, and, thus, more competitive Chinese manufacturing industries. It emphasises the development of localised manufacturing of core components (usually high-tech and high-value-added components) for integrated circuit chips, telecommunication equipment, operation system and industrial software, sophisticated digital machinery tools, advanced robotics, space and aviation systems and equipment, maritime engineering equipment and advanced vessels, advanced railway equipment, energy-efficient and alternative energy vehicles, advanced power-generation technologies, advanced agricultural equipment, new materials development, biomedicines, and advanced medical equipment. These are deemed to be fundamental industries that will enable other industries to innovate more rapidly and become more productive.

Two key nexuses will be developed in the future NIS. The first is the joint efforts in research, development, and demonstration by government, industry, academia, and public research institutes. The purpose of this collaboration is to better translate the engineering, technological, and scientific innovations or breakthroughs into marketable products and services and, thus, competitive advantages for the industries. The second nexus is the concept of 'smart manufacturing', which means the digitisation of conventional manufacturing industries and their integration with robotics, AI, big data, and cloud computing.

The implementation of this plan involves two salient features. The first is an emphasis on forming several innovation centres, reflecting a recognition of the importance of the proper clustering of industries, talents, expertise, and knowledge. The second is to connect to other economies' plans for advanced manufacturing, such as Germany's 'Industry 4.0'. This will occur through the development of common standards in the future smart manufacturing systems of industries in China and Germany.

7 See http://english.gov.cn/2016special/madeinchina2025/ and http://qys.miit.gov.cn/n11293472/n11293877/n16553775/n16553792/16594486.html.

3.5 | Conclusion and Implications for ASEAN Economies

China's rise in sectors such as nuclear energy, space, aviation, high-speed rail, and supercomputers seems impossible to replicate in the Association of Southeast Asian Nations (ASEAN) Member States, as China's industries benefited not only from a large domestic market but also from the ability of state-owned companies and state-owned financial institutions to substantially and continuously invest in catching up in targeted areas. However, some common lessons can be summarised.

Scientific knowledge has no administrative borders to restrain its spillover. Technologies, unless specially embedded or physically codified and thus with spillover effects that can be administered, have no border either. Thus, with very few exceptions, all advanced technologies eventually become available to anyone, no matter which country the customer comes from. What really matters about the availability of technologies is their price. That is the most important reason why technological catching up is an important part of economic growth, especially for developing countries.

For component technologies, which are usually embedded in the intermediate inputs along the supply chain, their prices determine the profitability of the downstream industries. For example, high profits in the high-tech parts and components of smartphones make the profit for smartphone manufacturers and assemblers quite marginal. Therefore, pursuing higher technologies and moving into the upper stream of the supply chain becomes critical for developing economies that have already accomplished the early stage of industrialisation to avoid the middle-income trap. In this regard, bringing up SMEs capable of supplying high-tech components in various industries seems to be a good indicator for policymakers to pursue as the outcome of their industrial technology policies.

The presence of vibrant SMEs in each industrial sector reduces the risks faced by each stream of efforts in technological catching up and innovations, as the risk of failure is relatively small in each case. Strong and well-specialised SMEs are also compatible with the age of robotics, AI, and perhaps Industry 4.0. These technologies will to a large extent minimise the need for manpower in future production and services in almost all industries. Economies of scale may assume a smaller importance compared to small-batch and customised supply in various industries. This is because there is still the possibility that specialisation will complement the automation of jobs brought by robotics and AI along the value chain of certain industries. In these industries, SMEs can thus take advantage of robotics and AI to build competitiveness in highly specialised niche markets. Such a future landscape of industrialisation in ASEAN looks very likely if one believes that China may be able to quickly commoditise robotics and AI, as it did for solar photovoltaics and wind turbines. Therefore, identifying such niche markets and fostering the competitiveness of SMEs in the future scenario in ASEAN economies could be critical for industrial policies to be successful.

Many ASEAN economies have implemented either import substitution or export-led industrial policies. Some of them, such as Thailand, have successfully integrated themselves into the global value chain or production networks in certain industries, such as for automobiles, electronics, and electrical appliances. Local SMEs supplying parts and components to manufacturing conducted using the FDI of MNCs have developed well in Thailand and have managed to slowly catch up in terms of technologies and capabilities (Asian Development Bank, 2015). Such development represents a successful conventional path of technological catching up. While public policies should continuously pay attention and give support to this stream, emphasis should also be given to prepare for the coming revolution brought by robotics, AI, and perhaps Industry 4.0. This is because in applying these new technologies, besides importing the high-tech equipment and parts, local efforts will be needed to integrate the technologies into local business and energy systems, and innovative transformation and restructuring may be needed. Such complimentary engineering and innovation should be the kind of capability and capacity that ASEAN countries, which are typically adopters of new technologies, should focus on developing. The necessity of such developments is a critical lesson we learned from the first wave of ICT revolution in the 1990s to early 2000s. This will not only accelerate the penetration of new technologies but also significantly reduce the costs of adopting the technology and ensure high performance of these technologies in ASEAN economies.

References

Arthur, B.W. (2009), *The Nature of Technology: What It Is and How It Evolves*. New York: Free Press.

Asian Development Bank (2015), *Thailand: Industrialization and Economic Catch-Up*. Manila.

Ayal, I. (1981), 'International Product Life Cycle: A Reassessment and Product Policy Implications', *Journal of Marketing*, 45(4), pp. 91–96.

Christensen, C.M. (1992a), 'Exploring the Limits of the Technology S-Curve. Part I: Component Technologies', *Production and Operations Management*, 1(4), pp. 334–357.

Christensen, C.M. (1992b), 'Exploring the Limits of the Technology S-Curve. Part II: Architectural Technologies', *Production and Operations Management*, 1(4), pp. 358–366.

Diebold, F.X. and K. Yilmaz (2009), 'Measuring Financial Asset Return and Volatility Spillovers, with Application to Global Equity Markets', *Economic Journal*, 119(534), pp. 158–171.

Diebold, F. and K. Yilmaz (2012), 'Better to Give than to Receive: Forecast-based Measurement of Volatility Spillovers', *International Journal of Forecasting*, 28(1), pp. 57–66.

Diebold, F.X. and K. Yilmaz (2014), 'On the Network Topology of Variance Decompositions: Measuring the Connectedness of Financial Firms', *Journal of Econometrics*, 182(1), pp. 119–134.

Fu, X., W.T. Woo, and J. Hou. (2016), 'Technological Innovation Policy in China: The Lessons, and the Necessary Changes Ahead', *Economic Change and Restructuring*, 49(2), pp. 139–157.

Klepper, S. (1996), 'Entry, Exit, Growth, and Innovation over the Product Life Cycle', *The American Economic Review*, 86(3), pp. 562–583.

Koop, G., M.H. Pesaran, and S.M. Potter (1996), 'Impulse Response Analysis in Nonlinear Multivariate Models', *Journal of Econometrics*, 74(1), pp. 119–147.

Krasodomskyte, V. (2015), 'China Set to Own the Second Largest Research and Development Industry by 2020', Euromonitor International, 8 December. http://blog.euromonitor.com/2015/12/china-set-to-own-the-second-largest-research-and-development-industry-by-2020.html (accessed 24 January 2018).

Levitt, T. (1965), 'Exploit the Product Life Cycle', *Harvard Business Review*, 43.

McAuliffe, R.E. (2015), 'Industry Life Cycle', Wiley Encyclopedia of Management, 8.

Organisation for Economic Co-operation and Development (OECD) (2008), 'OECD Reviews of Innovation Policy: China', Technical Report, Paris, France.

Pesaran, H.H. and Y. Shinb (1998), 'Generalized Impulse Response Analysis in Linear Multivariate Models', *Economic Letters*, 58(1), pp. 17–29.

Segerstrom, P.C., T.C.A. Anant, and D. Elias (1990), 'A Schumpeterian Model of the Product Life Cycle', *The American Economic Review*, 80(5), pp. 1077–1091.

Song, H. (2013), 'China's National Innovation System', in Carayannis, E.G. ed., *Encyclopedia of Creativity, Invention, Innovation and Entrepreneurship*, Chapter 10, pp. 191–202, New York: Springer.

Taylor, M. and A. Taylor (2012), ‘The Technology Life Cycle: Conceptualization and Managerial Implications’, *International Journal of Production Economics*, 140(1), pp. 541–553.

The Central People’s Government of the People’s Republic of China (2006), ‘The National Medium- and Long-term Program for Science and Technology Development: 2006–2020’ (in Chinese).

Vernon, R. (1966), ‘International Investment and International Trade in the Product Cycle’, *The Quarterly Journal of Economics*, 80(2), pp. 190–207.

Wall Street Journal (2014), ‘The Rise of China’s Innovation Machine’, 16 January. https://www.wsj.com/articles/the-rise-of-china8217s-innovation-machine-1389900484 (accessed 24 January 2018).

Wong, C.Y. and K.L. Goh (2015), ‘Catch-up Models of Science and Technology: A Theorization of the Asian Experience from Bi-logistic Growth Trajectories’, *Technological Forecasting and Social Change*, 95, pp. 312–327.

World Bank. World Development Indicators DataBank. http://databank.worldbank.org/data/reports.aspx?source=world-development-indicators (accessed 24 January 2018).

World Intellectual Property Organization (WIPO) (2016), *World Intellectual Property Indicators 2016.* http://www.wipo.int/publications/en/details.jsp?id=4138 (accessed 24 January 2018).

World Nuclear Association (2017), *The Economics of Nuclear Power.* http://www.world-nuclear.org/information-library/economic-aspects/economics-of-nuclear-power.aspx (accessed 24 January 2018).

Xinhua Net (2016a), ‘The Central People’s Government of the People’s Republic of China Announcing the National Strategic Program for Innovation-Driven Development’ (in Chinese).

Xinhua Net (2016b), ‘Expert Interpretation on the 13th Five-Year National Science and Technology Innovation Plan’ (in Chinese).

Zanello, G., X. Fu, P. Mohnen, and M. Ventresca (2016), ‘The Creation and Diffusion of Innovation in Developing Countries: A Systematic Literature Review’, *Journal of Economic Surveys*, 30(5), pp. 884–912.