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Xiaojun Feng
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Acronyms

AI	artificial intelligence
ACFTU	All-China Federation of Trade Unions
BCG	Boston Consulting Group
CAD	computer-aided design software
CAE	computer-aided engineering software
CCP	Chinese Communist Party
CLB	China Labour Bulletin
CNC	computer numerical control
COVID	coronavirus disease
CSR	corporate social responsibility
EU	European Union
FDI	foreign direct investment
GDP	gross domestic product
GPNs	global production networks
GPS	Global Positioning System
GVCs	global value chains
IaaS	infrastructure as a service
ICT	information and communications technology
IFR	International Federation of Robotics
ILO	International Labour Organization
IoT	Internet of Things

IT	information technology
LCD	liquid-crystal display
LED	light-emitting diode
LFP	lithium ferrophosphate
M&A	merger and acquisition
MIC 2025	Made in China 2025 Initiative
MOHRSS	Ministry of Human Resources and Social Security
NGO	non-governmental organization
SCNPC	Standing Committee of the National People's Congress
OBM	original brand manufacturing
OECD	Organization for Economic Co-operation and Development
OEM	original equipment manufacturing
ODM	original design manufacturing
OLED	organic light-emitting diode
PaaS	platform as a service
PC	personal computer
R&D	research and development
RFID	Radio Frequency Identification
SaaS	software as a service
WIPO	World Intellectual Property Organization
3D	three-dimensional
5G	fifth-generation

1 The research question and research gap

Recent technological progress has been hailed by some people as a new industrial revolution, the fourth one since the 18th century. The deployment of new technology entails comprehensive social implications. In particular, technological transformation, together with other grand processes such as demographic transition, climate change and globalization, is reshaping the future of work.

In a globalized world where production is organized into global commodity or value chains or global production networks (GPN)[1] that span multiple countries, innovation is both a global and local process: it requires global strategies to secure raw materials and labour, to capture markets for export, and to suppress competition from other economies (O'Hearn 1994); it is often facilitated by nationally or regionally bound States and multilateral institutions. The social implications of innovation are globally distributed, in the sense that those implications vary according to the position of individual capitals and territories in the asymmetrical relations within the international division of labour (Selwyn 2014). In the light of this, it makes sense to examine the social implications of technological development in a geographically bounded area while comprehending the area-level technological development in a global setting.

This report looks at what is happening in China in this regard. Understanding the ongoing technological transformation in China and its labour implications is not only key to understanding what is happening to some 20 per cent of the world population, but also sheds light on how different paces of technological transformation in different parts of the world are reshaping the global organization of production and thereby the employment prospects of different working people. China is the largest manufacturer in the world. According to the official news released by China's State Council in 2017, China's then output ranked first in the world in 220 out of 500 major types of industrial products (English.gov.cn 2017). According to the World Bank, China also has the largest labour force in the world. In 2018, China's workforce totalled 787.6 million, exceeding India which has the second largest workforce in the world (510.5 million) by a wide margin (World Bank 2019a). Moreover, China is pursuing technological innovation more

1 These are examples of competing theorizations of the global organization of production. Given that the primary concern of this report is about technological upgrading, "global value chains" (GVCs) seems to be a more adept concept than others for this report and is used thereafter.

actively than ever. In 2015, the Chinese Government launched the *Made in China 2025 Initiative* (MIC 2025). It sets concrete goals and promises multi-dimensional supports for China's manufacturing upgrading for the decade 2015–2025 (State Council 2015a). In 2016, the Chinese State Council (2016) launched the *National Strategy of Innovation-Driven Development*, which aims to build a comprehensive national innovation system to transform China's engine of economic growth.

For the purpose of this report, the research questions are: *What is happening in China regarding technological upgrading? How has technological upgrading affected social upgrading in China? What has China done to boost social upgrading amidst technological upgrading?*

This chapter begins by defining key concepts in this report: technological upgrading and social upgrading. It then unveils the rationale of pursuing both technological and social upgrading in present-day China. This is followed by a review of debates about the relationship between technological and social upgrading and about the circumstances under which technological upgrading can lead to social upgrading. The chapter ends by briefly reviewing related literature with a China focus and identifying the research gap this report aims to fill.

1.1 Definitions of technological upgrading and social upgrading

Technological upgrading is an integral part of economic upgrading. Economic upgrading and social upgrading are concepts coined by scholars studying the multi-facet dynamics among actors in global value chains (GVCs). The fact that export-oriented economies tended to enjoy growth while import-substituting economies tended to suffer stagnation in the second half of the 20th century has underpinned the proposition (albeit not without controversies) that the economic growth goal for developing countries is to increase competitiveness in the world market (Bair 2005). In other words, for individual countries, upgrading in GVCs constitutes the main content of economic development. This is not to say that upgrading is always the most appropriate strategy for economic growth regardless of circumstances. Upgrading is often costly and risky and some firms may deliberately pursue downgrading to maintain stable market share, especially during crisis. But overall, downgrading tends to be tactical and transitory (Barrientos, Gereffi and Rossi 2010).

In this context, the concept of "industrial upgrading" gains popularity. It refers to "the process by which economic actors – nations, firms and workers – move from low-value to relatively high-value activities in global production networks" (Gereffi 2005, 171).

With the industrial focus of related literature moving beyond manufacturing to include agribusiness and services, the term "industrial upgrading" becomes less appropriate and is replaced by a more generic concept, "economic upgrading", which entails the same process as industrial upgrading but applies across sectors (Barrientos, Gereffi and Rossi 2010).

The technological content of economic upgrading becomes clear when we categorize economic upgrading according to the object that is upgraded. Joseph Schumpeter (1954) distinguishes four forms of innovation due to the introduction of, respectively (1) new methods of production and/or new forms of industrial organization; (2) new commodities; (3) new sources of supply; and (4) new trade routes and markets. The first two translate into process upgrading and product upgrading in the typology of economic upgrading formulated by John Humphrey and Hubert Schmitz (2002), which is widely deployed in GVC analyses. In addition to product and process upgrading, Humphrey and Schmitz identify another two types of economic upgrading: functional upgrading, which refers to acquiring new functions (or abandoning existing functions) to increase the overall skill content of activities; and inter-sectoral upgrading which refers to moving into new productive activities by taking advantage of knowledge acquired in old activities.[2] Barrientos, Gereffi and Rossi (2010) point out that it is possible to identify a capital dimension and a labour dimension in each type of economic upgrading with the former referring to the use of new machinery or advanced technology.

The broad understanding of innovation and economic upgrading adopted in the above categorization suggests that technological upgrading is a multidimensional process. It involves not only technological changes, but also industrial and organizational transformations and beyond (Radosevic and Yoruk 2015). Given the purpose of this report, the term "technological upgrading" is used in a narrow sense which centres upon process and product upgrading. While the MIC 2025 and the National Strategy of Innovation-Driven Development aim to boost China's innovative capacity in a comprehensive and systematic manner, product and process upgrading are the core. This report defines process upgrading as the process in which goods and services are produced in a more efficient way, and product upgrading as the process during which technologically more sophisticated products and equipment are developed so that related entities can capture a higher share of value from GVCs.

Social upgrading is a concept developed by the Capturing the Gains international research network in the 2000s to correct the bias of previous GVC analyses which overwhelmingly

2 These categories are by no means exhaustive or mutually exclusive. For example, functional and inter-sectoral upgrading may or may not involve product and process upgrading. But they capture the major processes of economic upgrading.

focus on firms and treat workers as a factor of production. This network was jointly funded by the International Labour Organization (ILO) and several other unilateral and multilateral institutions. Derived from the ILO's Decent Work Agenda, social upgrading is defined as "the process of improvement in the rights and entitlements of workers as social actors, and enhances the quality of their employment": Stephanie Barrientos and her collaborators operationalize this concept by dividing it into (1) measurable standards such as employment status, wage levels, social protection, working hours and union density; and (2) enabling rights such as freedom of association, the right to collective bargaining, non-discrimination, voice and empowerment (Barrientos, Gereffi and Rossi 2010).

1.2 The rationale of technological and social upgrading in China

The rationale of technological and social upgrading in China can only be understood in a context of economic and social rebalancing in the country in response to changing economic and political factors at home and abroad. The extent to which China can rebalance its economy and society largely depends on the extent to which it can achieve both technological and social upgrading in the future.

It has been widely accepted that the Chinese growth model that has created the economic miracle is excessively dependent on investment and export, and insufficiently driven by domestic consumption and domestic productivity growth (Naughton 2006). Table 1 gives a flavour of this model by comparing the gross domestic product (GDP) composition of China and the United States in 2017. It is clear that investment in fixed capital and exports made up a larger share of GDP in China than in the United States, while household consumption constituted a smaller share. Labour productivity can be roughly measured by GDP per person employed. In 2018, GDP per person employed in China accounted for only 25.7 per cent of that in the United States and 33.9 per cent of that in countries in the Organization for Economic Co-operation and Development (OECD) (World Bank 2019b). Given that Chinese workers generally work longer hours than their counterparts in developed economies, the real labour productivity gap is even larger.

The above growth model has been underpinned by relatively low labour costs and facilitated by lax regulation on labour and environment, which has led to poor working conditions and environmental problems and has fuelled social unrest. According to the Boston Consulting Group (BCG), a consultancy, in 2004 the average labour cost in the manufacturing industry in China was lower than that in India and Mexico (Sirkin, Zinser and Rose 2014). Yet the wages of Chinese workers have increased in recent years (Feng 2017). Many Chinese workers work without labour contracts or so-

▶ Table 1. GDP composition, by end use, China and the United States, 2017 (percentages)

	China (%)	United States (%)
Household consumption	39.1	68.4
Government consumption	14.5	17.3
Investment in fixed capital	42.7	17.2
Investment in inventories	1.7	0.1
Exports of goods and services	20.4	12.1
Imports of goods and services	–18.4	–15.0

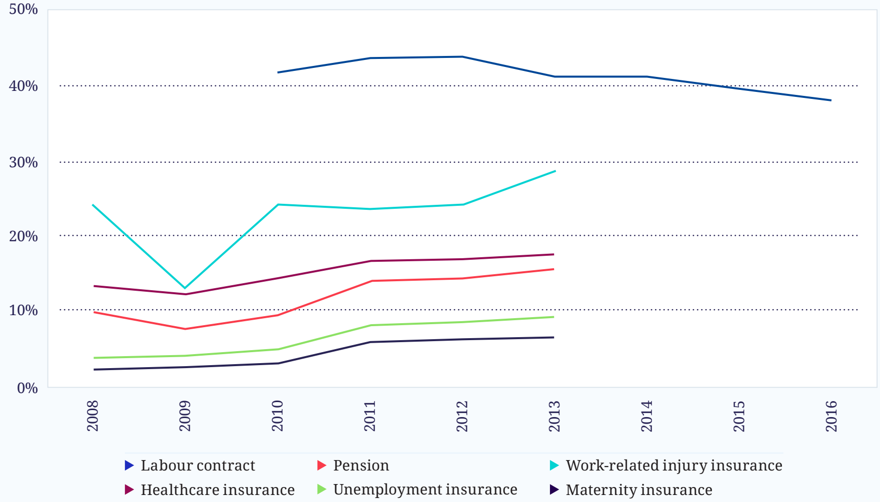
▶ Source: CIA 2019.

cial insurance. As shown in figure 1, between 2010 and 2016 the majority of China's outbound peasant workers,[3] the part and parcel of China's manufacturing workforce, worked without contracts, rendering it hard for them to safeguard their rights; between 2008 and 2013 fewer than 30 per cent of them had employment-related injury insurance; fewer than 20 per cent had either healthcare insurance or pensions; and fewer than 10 per cent had unemployment or maternity insurance. With regard to environmental problems, according to the Environmental Performance Index compiled by Yale University and Columbia University, in 2018 China ranked 120th among countries for overall environmental performance, and 177th in the score of air quality (Wendling et al. 2018). Poor working conditions and deteriorating environment have triggered social instability. As a result, between 2007 and 2017, China's spending on public security grew steadily from 348.6 billion to 1,246.1 million Renminbi (RMB),[4]

3 In the Chinese context, the term "peasant workers" refers to workers who are not registered as urban citizens but work in cities. They are excluded from some essential public services in cities, for example, child education. According to the National Bureau of Statistics (2019a, 2018b), in 2017 peasant workers constituted 36.3 per cent of China's overall population in employment and 40.5 per cent of China's urban employed workforce. Statistical materials compiled by the National Bureau of Statistics distinguish between local and outbound peasant workers. "Outbound peasant workers" refers to those who work outside their townships for at least six months in the survey year. "Local peasant workers" refers to those who engage in non-agricultural activities within their townships. According to the National Bureau of Statistics (2018b), in 2017 outbound peasant workers made up approximately 60 per cent of China's peasant workers.

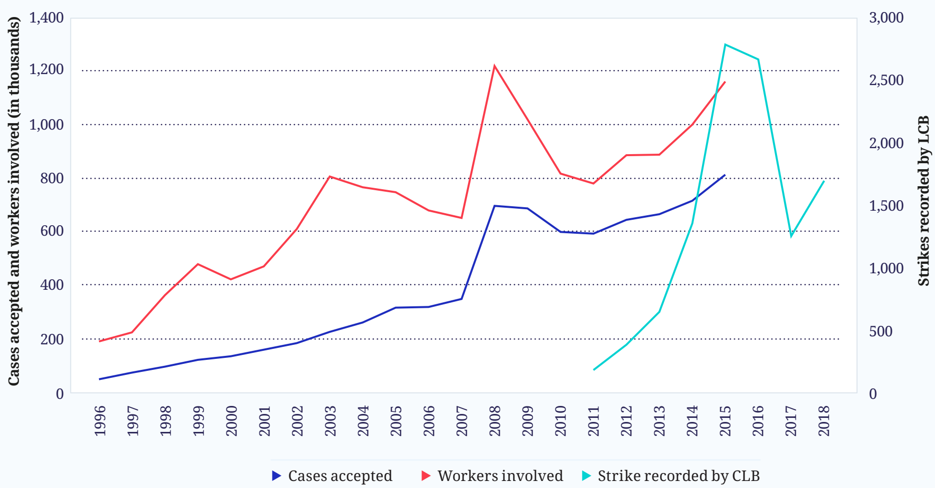
4 1 RMB ≈ US$0.14-0.15.

▶ Figure 1. Coverage of labour contracts and social insurance for outbound peasant workers in China, 2008–16



▶ Source: National Bureau of Statistics 2014b–2017b.

▶ Figure 2. Growth in number of labour disputes in China, 1996–2018



▶ Note: China Labour Bulletin (CLB) is a respected labour non-governmental organization (NGO).
▶ Source: National Bureau of Statistics 2017c; CLB 2020.

overtaking its defence expenditure for the first time in 2010 and remaining so thereafter (National Bureau of Statistics 2019a). In particular, labour disputes are looming large in China: between 1996 and 2015, both the number of labour disputes and the number of workers involved in these disputes increased (figure 2); also, workers are increasingly favouring strikes to voice their grievances.

Moreover, in the face of soaring labour costs at home and slumped demand overseas, the above model of growth is losing its vigour. According to the BCG, in 2014 the manufacturing labour cost in China was higher than in India and Mexico, and the gap between China and the United States and Germany had significantly narrowed between 2004 and 2014 (Sirkin, Zinser and Rose 2014). At Foxconn, an electronics assembly factory that employed over one million workers at its peak in mainland China, between 2002 and 2013 labour costs of production workers rose from 2.63 to 5.67 per cent of its revenue (Feng 2017). As a result, the average profit rate of China's top 500 manufacturing enterprises with the largest revenue fell from 5 per cent in 2007 to 2.18 per cent in 2015 (Lian 2017). In addition, China's annual export growth rate has plummeted from over 20 per cent in the first decade of the millennium to single-digit numbers since 2012, and further to negative numbers in 2015 and 2016 before rebounding in 2017 (Ministry of Commerce 2018c). Consequently, China's annual GDP growth rate has dropped from over 10 per cent between 2003 and 2010 to around 7 per cent between 2012 and 2014, and further to around 6 per cent since 2015 (World Bank 2019c).

In light of this, the Chinese Government as early as 1995 put transforming the pattern of economic development on its policy agenda (Guo 2005). In 1997, in the speech delivered by President Jiang Zemin at the 15th National Congress of the Chinese Communist Party (CCP), together with streamlining the market economy system, overhauling China's growth model was highlighted as the key to quadrupling China's GDP by the end of the 20th century, the goal of the second step in China's three-step development strategy put forward in the 1980s; and increasing China's GDP per capita to the level of moderately developed countries by the mid-21st century, the goal of the third step in the same strategy (Jiang 1997). In 1998, owing to looming domestic industrial overcapacity, the Chinese Government for the first time proposed to take measures to increase domestic consumption (Renminnet 2014). Later, ideas of the new model of economic growth gradually took shape. In 2007, at the dawn of the global financial crisis, Chinese President Hu Jintao elaborated the goals of overhauling China's growth model at the 17th National Congress of the CCP: to pursue the policy of boosting domestic demand, particularly consumer demand; the transition from relying mainly on investment and export to a well-coordinated combination of consumption, investment and export; and the transition from heavily relying on increased consumption of material resources to mainly relying on advances in science and technology, improvement in workforce quality and innovation in management (Hu 2007). However, China had made little progress in approaching these goals before 2013, in which year Xi Jinping took office. Even worse, the old model was reinforced in the aftermath of the global financial crisis because of the injection of massive investment to reignite the economy. In 2014, in the light of significant economic slowdown, President Xi reiterated that China needed to adapt to a "new normal" characterized by slower growth, industrial upgrading and an innovation-driven economy (China Daily 2017).

Clearly, both technological and social upgrading fit well into the Chinese Government's policy agenda of economic rebalancing and social stability maintenance. Technological upgrading is essential for China to climb up the GVCs and thus boost manufacturing profit margins. Social upgrading can help enlarge domestic consumption, pacify disgruntled workers, and ease social tensions. Social upgrading is predicated upon technological upgrading. Without the expansion of the market through the GVCs, social upgrading lacks the essential financial foundation. In this sense, technological and social upgrading, as strategies of the State, are in line with workers' interests.

Technological and social upgrading also fit well into capital's strategy portfolio to restore profitability. The recent decade has witnessed the relocation of capital from coastal China to inland China and to other Asian countries and even to Africa in pursuit of cheap and docile labour, and the relocation of capital from manufacturing to financial speculation. Alternatively, capital can also pursue process upgrading to lower labour costs, or pursue product upgrading to capture more gains from the GVCs. Haunted by labour unrest, while capital prefers to deploy process upgrading to reduce labour, it certainly relies upon skilled labour to advance technological upgrading, both kinds. Moreover, "new machinery cannot be used to its fullest potential without changes in work practices and the management of production" (Schwartz 2009, 72). Thus, capital simply cannot dismiss social upgrading as an undesired burden.

Under the above circumstances, for the shared interests of the developmental State, capital, and labour, it is desirable that technological upgrading advances hand in hand with social upgrading. The question is, will they? And, if they do not, under what circumstances can the two come together?

1.3 Impacts of technological upgrading on social upgrading: A literature review

Technological upgrading is not a new phenomenon. There has been a plethora of studies that examine the social implications of technological advances and how to take advantage of them to enhance social welfare. This section summarizes the main ideas of the engineering and neoclassical approach, the Keynesian–Schumpeterian and institutionalist approach, and the Marxist approach in this regard.

1.3.1 The engineering and neoclassical approach

Technological optimists celebrate the seemingly endless potential gains that innovation presents for both employers and employees, while sober engineers highlight the bottlenecks of technological advances. Neoclassical economists find that the labour implications of process upgrading are controversial while those of product upgrading are largely positive. These economists promote human capital investment as a way to synchronize technological and social upgrading.

Technological optimists tend to promote technological progress as a panacea for inefficiency and social problems based on technological potential, rather than on empirical studies. Such a view suggests that technological upgrading will lead to social upgrading. With regard to process technology, for example, the International Federation of Robotics (IFR) claims that robot automation will reduce operating and capital costs and material waste; increase product quality, production consistency and flexibility, and output rates; improve the quality of work for employees; and help employers to better comply with health and safety rules, among other advantages (IFR 2016a). In another report, the IFR identifies employment directly generated by the robot industry, including jobs to produce robots, jobs to operate robots, jobs to support such production and operation, and employment indirectly generated by robotics such as downstream activities, with retailing as one popular form (IFR 2013c). The US Robotics Roadmap, compiled by several major US research institutions, argues that improved robotics and automation in manufacturing will retain intellectual property, reduce manufacturing lead time for finished goods, provide jobs for developing, maintaining and training robots, improve working conditions, reduce expensive medical problems, allow factories to employ human–robot teams to leverage each other's skills and strengths, and so forth (University of California San Diego et al. 2016). With regard to product technology, the IFR argues that the increasing demand for services and the creation of new products and markets are often related to the application of electronics to communication and can contribute to rising overall paid employment in most countries (IFR 2013c). In addition, there are burgeoning studies on how technology alters the organization of work, for example though digital platforms (Valenduc and Vendramin 2016).

Neoclassical economists and some engineers have soberer and more sophisticated views about the labour implications of technology. They distinguish not only between process and product technology upgrading, but also between skilled and low-skilled workers. Their main approach is to operationalize technological and social upgrading into sets of indicators, draw upon panel data to quantify the indicators, and build econometric models to examine how certain kinds of technological progress, mediated by what factors, affect job quantity, wages, and the skill structure of jobs at firm, sectoral or regional levels (Calvino and Virgillito 2018).

Process upgrading

With regard to process upgrading, in contrast to technological optimists, neoclassical economists and some engineers are well aware of the co-existence of multiple factors that mediate the impacts of technology on employment. A seminal article published in 2003 distinguishes between cognitive and manual tasks on the one hand, and routine and non-routine tasks on the other hand. The authors argue that computer capital can (1) substitute for workers in performing routine manual and cognitive tasks; and (2) complement workers in performing non-routine problem-solving and complex communication tasks, for example, via collaborative robots (co-bots), resulting in reduced labour demand for routine manual and routine cognitive tasks and increased labour demand for non-routine cognitive tasks (Autor, Levy and Murnane 2003; Tobe 2015). In other words, the substitution and complementation effects combined can lead to the polarization of the workforce. Another article by David Autor (2014) argues that Michael Polanyi's paradox – "we know more than we can tell" – on the one hand constrains the extent of the substitution effect, but on the other hand underpins the complementation effect. However, with technological advances in recent years, computer capital can now substitute for a wide range of tasks commonly defined as non-routine, both cognitive and manual; nonetheless, engineering bottlenecks remain such as perception and manipulation tasks and creative and social intelligence tasks (Frey and Osborne 2017). Moreover, technological potential cannot automatically translate into technological upgrading on the ground. For example, typical obstacles for small and medium-sized enterprises (SMEs) to use robots are the perceptions that robots are inflexible and expensive to use for small runs and that small firms may not have enough skills to support robot operations (IFR 2013c).

In addition to the effects of substitution and complementation as mentioned above, researchers also identity other effects of process technology on employment: (3) the price and demand effect: the introduction of process technology will boost productivity and thus reduce product price; lower product price may translate into higher demand and thereby higher employment (Acemoglu and Restrepo 2016); (4) the profit and re-investment effect: enterprises which introduce new process technology may enjoy a temporal "super profit" between the decrease in production costs and the subsequent decrease in product price; the reinvestment of super profit can expand labour demand (Calvino and Virgillito 2018); (5) the productivity and distribution effect: robots can free up human beings for other tasks and leisure; workers will better off if they have access to the productivity gains brought by robots (Nübler 2016); (6) the GVC recalibration effect: by making onshore production attractive in developed countries, automation may bring about waves of reshoring, which displaces jobs in developing economies and creates jobs in developed economies (Frey and Osborne 2016).

Of the above effects, the substitution effect is well studied while the other effects are underexplored, which results in an overstatement of the extent of machine substitution for human labour. Initially in 2013, Carl Frey, an economist, and Michael Osborne, a machine learning scientist, released a seminal report that examines the potential of the substitution effect of recent technological advances. They developed a methodology to categorize occupations according to their susceptibility to computerization and implemented this methodology to estimate the probability of computerization for 702 occupations in the United States whose key features are defined as a standardized and measurable set of variables. They conclude that at the time of calculation approximately 47 per cent of US employment was at risk (Frey and Osborne 2017). Using the same methodology, scholars from the World Bank (2016) estimate the same substitution effect in the other parts of the world. They conclude that on average, 57 per cent of OECD jobs can be automated by the mid-2030s. Following the same logic that low-skilled jobs are more susceptible to computerization, the Brookings Institution points out that automation is likely to replace jobs faster in developing countries than in developed ones (Chandy 2017) . In fact, the ILO reports sensational numbers of jobs that are threatened by automation in countries in the Association of Southeast Asian Nations (ASEAN): for example, 56 per cent of wage and salaried workers in Indonesia and 44 per cent of wage and salaried workers in Thailand face high risk of automation at the time of research (Chang, Rynhart and Huynh 2016). In addition, an International Monetary Fund (IMF 2018) report finds that the substitution effect of robots in the post-crisis era was more pronounced in countries with more rigid labour market policies.

In contrast to these studies that use expert assessment to identify a set of bottleneck tasks which reflect average task structures at the occupational level, another study used self-reported data which better indicate individual workers' actual tasks and matched these data with the automatibility indicators developed by Frey and Osborne, only to conclude that on average, 9 per cent of jobs were automatable across 21 OECD countries at the time of research (Arntz, Gregory and Zierahn 2016). The substitution effect of automation also depresses wages. One study examining the effects of the increase in industrial robot usage on the US labour market between 1990 and 2007 finds that one more robot per 1,000 workers reduces the employment-to-population ratio by 0.18 to 0.34 per cent, and wages by 0.25 to 0.5 per cent (Acemoglu and Restrepo 2017).

Scholars who have examined the comprehensive effects of automation present a less pessimistic picture. In addition to the aforementioned pioneering research by Autor, Levy and Murnane (2003) which is based on data in the United States between 1960 and 1998, with regard to recent technological advances Autor (2014) predicts that these advances will continue to boost demand for skilled labour while employment polarization will not continue indefinitely because middle-skill jobs that combine routine and non-routine tasks in which workers hold comparative advantage will persist. Another study using panel data on robot adoption in 17 countries between 1993 and 2007 finds that the deployment of robots reduced the working hours of both low-skilled and middle-skilled workers and increased labour productivity and wages (Graetz and Michaels 2018). The existing literature also confirms the effectiveness of the price and demand effect in offsetting the substitution effect by boosting demand for lower-price goods (Vivarelli 1995; Simonetti, Taylor and Vivarelli 2000). Overall, using survey data between 1995 and 2003, Hall, Lotti and Mairesse (2009) do not find any significant evidence of displacement induced by process innovation in Italy. Controlling investment and sectoral patterns, Benavente and Lauterbach (2008) do not find any significant impact of process innovation on employment in Chile between 1998 and 2001. Crespi and Tacsir (2012) discover labour displacement effects of process innovation in Chile, but not in Argentina, Costa Rica or Uruguay in the late 1990s and early 2000s.

Product upgrading

While the comprehensive effects of process upgrading on employment appear controversial, the effects of product upgrading on employment seem quite positive in fast-growing and high-tech firms. Using a database setting in the Netherlands between 1994 and 2000, Stam and Wennberg (2009) found that the top 10 per cent fastest-growing firms saw a significant correlation between research and development (R&D) activities and employment growth, while other firms did not. Using a database of approximately 700 large European publicly traded companies, Bogliacino, Piva and Vivarelli (2012) found that services and high-tech manufacturing firms saw a positive impact of R&D expenditures on employment while low-tech manufacturing firms did not. Using data on patent, R&D, and employment in the United States, Coad and Rao (2011) confirm that innovation is only positively associated with subsequent employment growth in the high-tech manufacturing industry in the United States. Using panel data covering European patenting firms between 2003 and 2012, Van Roy, Vertesy and Vivarelli (2015) confirm that the same phenomenon took place in Europe.

Overall labour implications of process and product upgrading

As distinct from articles that examine the impacts of one type of upgrading, some studies develop comprehensive frameworks to examine the labour implications of process and product technology together. Using data on France, Germany, Spain and the United

Kingdom between 1998 and 2000, Harrison et al. (2014) found that at the firm level, an overall positive relationship between innovation and employment held because product innovation, together with the price and demand effect of process innovation, overcame the substitution effect of process innovation. Using data on manufacturing firms in Germany between 1982 and 2002, Lachenmaier and Rottmann (2011) found that both process and product innovation boosted employment, and the net employment effects of process innovation were greater than the effect of product innovation. The econometric study by Evangelista and Vezzani (2012) confirms the overall positive impact of innovation on employment in selected European Union (EU) countries and they find no net negative effect of process innovation on employment.

Measures to synchronize technological and social upgrading

How to buffer the technological shock and take advantage of it to benefit workers? Neoclassical economists believe that the economic system is self-adjusting and unemployment amidst technological transformation is temporary. In contrast to institutionalists and Marxists who promote more equal distribution of innovation-enabled productivity gains between employers and employees via state regulation or collective action of labour, neoclassical economists dismiss regulations and collective actions of labour as distortions of the labour market. Instead, they promote training to better match the skill supply of employees with the skill demand of employers, thus augmenting the complementation effect and constraining the substitution effect (Shook and Knickrehm 2017).

1.3.2 The Keynesian–Schumpeterian and institutionalist approach

Researchers in this camp also recognize the potential curse of process technology and the blessing of product technology. While they are in line with neoclassical economists in the importance of training to buffer the technological shock, their policy emphasis lies in the improvement of social institutions, such as better governance of the GVCs, and collective bargaining that aims at the sharing of productivity gains between employers and employees.

John Maynard Keynes (1930) defined technological unemployment as unemployment arising when the deployment of means of economizing the use of labour outpaces job creation. Keynes developed a theory of economic cycles led by investment. Schumpeter (1961) regarded innovation as the engine of investment and therefore that the alternation between the launch and diffusion of new products and market saturation determines the alternation between growth and recession. Innovation creatively destroys the old and opens the way for the new, and unemployment arises during this process. Calvino and Virgillito (2018) summarize the compensation mechanisms against technological displacement of labour in the Keynesian–Schumpeterian approach: (1) the new product effect: new products will satisfy the previously unmet demand and thereby translate into new employment; but positive product employment effect only holds on the condition that it is not entirely offset by the decrease in employment because of the eroding market shares of old products and of products of non-innovators; (2) the productivity and distribution effect: innovative entrepreneurs win entrepreneurial profits on top of wages to management earned by normal businessmen, which may lead to a wage increase; an increase in wages will lead to an increase in consumption and thereby an increase in employment, thus compensating for the initial labour displacement.

The Capturing the Gains research network examines the relationship between economic and social upgrading at the level of GVCs. Although technology is a key component of economic upgrading, this network devotes limited attention to it. Nonetheless, the findings of the network are enlightening in this regard. First, they disillusionize the common belief in GVC studies that economic upgrading of suppliers in the GVCs will surely lead to social upgrading. Based on analysis in four manufacturing GVCs – apparel, wood furniture, automotive industries, and mobile phones – they argue that economic upgrading is conducive to, but not sufficient for, social upgrading. Second, they identify a number of factors that mediate the relationship between economic and social upgrading, including firm size, firms' position within the GVCs, product mix, buyer needs, labour market conditions, the type of work undertaken, the employment status of workers, and so on (Bernhardt and Pollak 2016; Bernhardt and Milberg 2011). For example, Rossi's study of the garment sector in Morocco finds that process upgrading helped to reduce overtime and to improve health and safety standards, but also resulted in dismissal of low-skilled workers; product upgrading that involved upskilling in the manufacturing process might increase the wages of skilled workers, who were often regular workers, while other kinds of product upgrading did not significantly affect working conditions; functional upgrading often led to the bifurcation of the workforce: regular workers tended to benefit from functional upgrading while irregular workers did not (Rossi 2013).

With regard to solutions to synchronizing technological and social upgrading, the Keynesian approach contends that unemployment brought by automation will persist unless the State intervenes (Calvino and Virgillito 2018). In an era of pervasive automation, the idea of universal basic income has gained popularity (Winick 2018). For scholars in the Capturing the Gains network, the power imbalance between lead firms and suppliers in the GVCs fundamentally constrains the extent of social upgrading. While these scholars acknowledge that labour agency by precarious workers can contribute to the improvement of their conditions, they emphasize that labour agency is unable to garner enough cross-border support within the GVCs or from government agencies to pressure lead firms (Alford, Barrientos and Visser 2017). Instead, they argue that the hope of synchronizing economic and social upgrading lies in better governance of the GVCs: hybrid and complementary institutions of governance, both public and private, operating at multiple levels – global, national and local (Barrientos et al. 2011; Gereffi and Lee 2016). The institutionalist approach also brings back the role of workers' organizations into the discussion of solutions. For trade unionists, the key to promoting social upgrading amidst technological advances is to ensure that wages follow the growth of labour productivity via collective bargaining (Haipeter, Schulten and Boewe 2017).

1.3.3 The Marxist approach

On the one hand, Marxist theory celebrates the colossal productive forces – machinery, steam-navigation, railway, electric telegraphs, and the like – created by the capitalist system (Marx and Engels 2002). In this sense, it suggests the potential for positive correlation between technological and social upgrading. On the other hand, Marxist theory regards technological advancements as capital's tools to intensify its exploitation of labour and secure more surplus value: first, it automates the labour process and displaces labourers; second, it deskills labourers and intensifies capital's control over the labour process (Marx 1996; Braverman 1998; Noble 2017). Marxists also argue that the drive for less human involvement in the labour process has limits. For example, engineers need factory workers' know-how to improve machines, and machines need factory workers' motivation, skill and attention to function well (Noble 2017). Marxists criticize institutionalists for denying capitalist exploitation and anchoring the hope of decent work on the collaboration between elite bodies, particularly firms, States, and international organizations, without prudence concerning the danger of co-option by these institutions. In contrast to institutionalists' top-down approach, Marxists suggest a bottom-up approach in which labour resistance is of fundamental importance to achieving social upgrading (Selwyn 2013; Lerche 2012).

1.4 Existing literature on China and the research gap

Research into the labour implications of technological upgrading in China is a burgeoning field. Two strands of literature stand out in this regard. The first examines how technological upgrading in advanced economies affects employment in China by reshaping the GVCs. The reshoring narrative argues that massive process upgrading in advanced economies will make manufacturing at home more attractive; as cost-chasing companies disinvest in China and re-shore, China will lose many jobs. There is anecdotal evidence to support this narrative (Cohen et al. 2016; De Backer et al. 2016; Frey and Osborne 2016) but the narrative has been challenged. Gereffi (2009) argues that a unique form of industrial organization called supply-chain cities is key to China's success story. Supply-chain cities enable the agglomeration of multiple stages of the value chain, in particular locales, by hosting clusters of related suppliers, thus allowing both economies of scale and scope in GVCs. China's richness in supply-chain cities may help it to retain foreign investment.

An example for reference in this regard is Adidas. In 2015 Adidas reduced its production capacity in Asia and built automated factories in Germany and the United States. However, four years later, in 2019, Adidas announced that it would shut down "reshored" factories and went back to Asia, as Asia is where the know-how and its suppliers are located (Bain 2019).

Moreover, Butollo (2020) points out that digitalization affects a range of variables that determine the localization of manufacturing, including the substitution of work through automation, the deepening of the customer–producer relationship, the rationalization of distribution through digitalized logistics networks, and the increased modularization of supply chains through standardization and "platformization"; the complexities in the combined effects of these variables defy expectations of a straightforward "reshoring".

The second strand of literature examines how technological upgrading in China affects working conditions in that country. With regard to process upgrading, using the methodology developed by Frey and Osborne, a World Bank report estimates that 77 per cent of jobs in China are at high risk of automation (World Bank 2016). As mentioned in Chapter 3 of the present report, there is also a plethora of case studies and surveys that examine both the curse and the blessing of automation for workers on the ground.

With regard to product upgrading, based on fieldwork research in Dongguan in 2010–11, Butollo (2013) found that product upgrading in China was often intertwined with functional upgrading; in the fashion and the light-emitting diode (LED) industry, brand building and the development of LED chips and applications fuelled the bifurcation of the workforce: on the one hand, to enhance design capabilities and to streamline marketing operations, these companies significantly increased the proportion of technically trained personnel in the workforce; on the other hand, on the shop floor, particularly where the lean production system and automation machines were deployed, the increased complexity of products did not necessarily require higher skills from line workers and thereby failed to improve working conditions.

With regard to measures to buffer the technological shock and promote social upgrading, training provided by employers, occupational schools or commercial training agencies to reskill workers has been repeatedly emphasized (Xu 2018). Huang and Sharif (2017) point out the peculiar plight of workers in present-day China in the face of technological displacement: in contrast to workers in the global North in the 1960s and 1970s who secured wage increases amidst automation in a context of strong union activism and welfare state labour protectionism, workers in present-day China are hardly in a position to capture the "robot dividend"; they not only lack the protection of trade unions, but also face tremendous obstacles to organizing themselves to engage in collective bargaining. Butollo and Lüthje (2017) found that the presence of trade unions in two surveyed home appliance giants failed to safeguard workers from technological changes in the workplace, since these unions were not involved in collective bargaining on working conditions.

To my knowledge, the existing literature does a good job in shedding light on how technological changes affect working conditions in certain companies, certain industries, and certain regions in China. Huang and Sharif (2017) suggest that we should further examine the industrial, sectoral, regional and gender patterns of job displacement by robots. This report aims to provide a more comprehensive picture of the labour implications of technological upgrading in China by mapping it in a multi-dimensional way, including both process upgrading (which goes far beyond robots) and the understudied product upgrading, the wide-ranging implications of technological upgrading for employment and working conditions on a national scale, and endeavours from multiple stakeholders to synchronize technological and social upgrading. The next chapter maps the scope and content of technological upgrading in China.

2 Scope and content of technological upgrading in China

Technological upgrading has been a relentless imperative for the Chinese Government. This chapter examines how widespread and profound is the ongoing technological upgrading in China. The first section provides an overall picture of R&D inputs and outputs, while the second and third sections examine the scope and content of China's process and product upgrading respectively.

2.1 Technological upgrading in China: An overview

The *National Strategy of Innovation-Driven Development* launched by China's State Council in 2016 sets the goal of formulating a national innovation system by 2020, fundamentally shifting the engine of economic growth towards innovation by 2030, and becoming a major hub of innovation in the world by 2050 (State Council 2016). The MIC 2025 sets the mid-term goal of technological upgrading of Chinese manufacturing, which is to "transform China into a global manufacturing leader before the centennial of the founding of New China (2049), which will lay the foundation for the realization of the Chinese dream to rejuvenate the Chinese nation" (State Council 2015a). These national strategies grant Chinese enterprises access to a wide range of support to strengthen their innovation capabilities and facilitate their overseas mergers and acquisitions (M&A).

Two vehicles for technological upgrading are: (1) indigenous innovation; and (2) foreign technology transfer. Facing a US-led embargo, planned-economy China overwhelmingly relied on indigenous innovation. In the reform era, first in 1985, the Chinese Government changed gear to pursue the acquisition of foreign technology as the main strategy of technological development; then in 1995, the Government began to re-focus on indigenous innovation and adopted an education-led innovation strategy. In 2006, indigenous innovation was listed among the Government's top priorities (Fu and Gong 2011).

Over the years, China has increased its investment in indigenous innovation; the innovation input gap between China and advanced economies has been dramatically narrowed. As shown in figure 3, between 1996 and 2016 the share of R&D expenditure in GDP jumped from 0.56 to 2.11 per cent while in OECD countries this share rose mildly from 2.12 to 2.49 per cent, and in the US alone from 2.44 to 2.74 per cent. According to the

National Strategy of Innovation-Driven Development, the Chinese Government plans to boost this share to 2.5 per cent by 2020 and to 2.8 per cent by 2030 (State Council 2016).

Enterprises are one of the major contributors to national R&D investment. Figure 4 demonstrates the increasing footprints of Chinese[5] enterprises in the world's corporate R&D activities. Of the top 2,000 or 2,500 companies[6] that invested the largest sums of money in R&D in the world between 2012/13 and 2017/18, the proportion of Chinese enterprises increased from some 4.7 to 17.5 per cent; during the same time frame, of the aggregate amount of R&D investment of these top companies, the share of Chinese enterprises increased from 3.0 to 9.7 per cent. It is worth noting that in 2017/18 China had more companies shortlisted in the top 2,500 scoreboard than Japan, albeit with a smaller aggregate amount of R&D investment than the latter. Moreover, the R&D investment of China's top corporate R&D investors has been growing much faster than that of the European Union, Japan or the United States. In 2017/18, these investors increased their R&D investment by 20.0 per cent, while the corresponding growth rates were 9.0 per cent in the United States, 5.5 per cent in the European Union, and minus 6.7 per cent in Japan. If this trend continues, the corporate R&D investment gap between China and developed economies will continue to narrow.

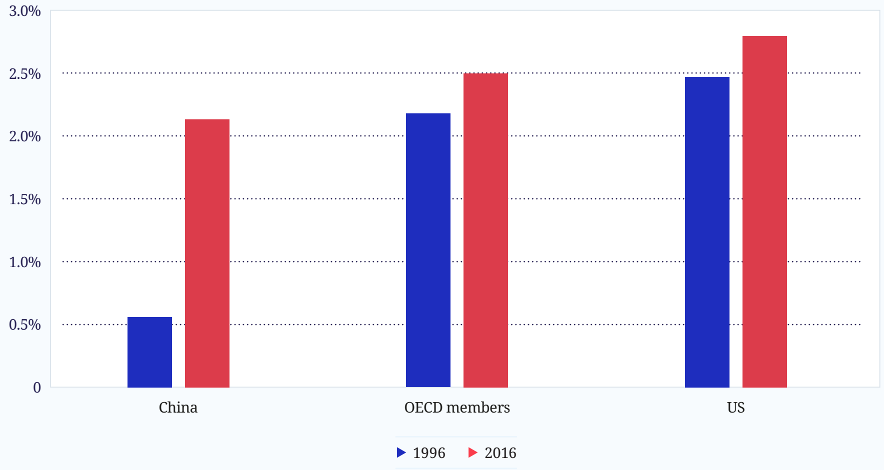
The engagement with foreign capital helps to boost China's capacity of innovation. Recent years have seen growth in high-tech foreign direct investment (FDI) inflows to China. In 2017, 22.5 per cent of R&D staff and 21.6 per cent of R&D expenditure in manufacturing enterprises above the designated size[7] in China were contributed by foreign enterprises; 49.2 per cent of HongKongese, Macanese, and Taiwanese manufacturing enterprises and 48.3 per cent of other foreign manufacturing enterprises above the designated size achieved some extent of process or product upgrading, which were higher than the national average (42.1 per cent) (National Bureau of Statistics 2019a). In recent years, although labour-intensive FDI has been withdrawing from China, high-tech FDI has flooded to China more actively than ever (Zhao 2017). As shown in table 2, between 2015 and 2017, overall, China outperformed the world average in attracting FDI, the high-tech sector significantly outperformed the national average, and services considerably outperformed manufacturing regarding high-tech FDI growth.

5 In this report, unless otherwise specified, China refers to mainland China and the scope of "foreign" and "overseas" includes the Special Administrative Regions of Hong Kong and Macao as well as Taiwan, China.

6 According to the data source, the 2012/13 figures include the top 2,000 corporate R&D investors in the world. The 2017/18 figures include the top 2,500.

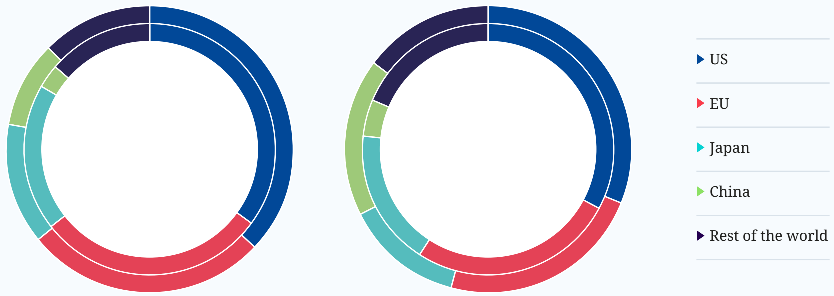
7 In statistics compiled by the Chinese National Bureau of Statistics, from 2011 onwards, manufacturing enterprises above the designated size refer to those with an annual revenue of 20 million RMB or beyond in major businesses.

Figure 3. R&D expenditure share in GDP, China and developed economies, 1996 and 2016



Source: World Bank 2019d.

Figure 4. Global composition of the top 2,500 corporate R&D investors, 2012/13 and 2017/18



Note: Left side: the number of investors by main country/region; right side: the value of R&D investment by main country/region; inner circle: 2012/13; outer circle: 2017/18. According to the data source, these top 2,500 companies accounted for approximately 90 per cent of the world's business-funded R&D.

Source: European Commission 2019.

▶ **Table 2. Annual growth rates of FDI inflows, China and world, 2015–17**

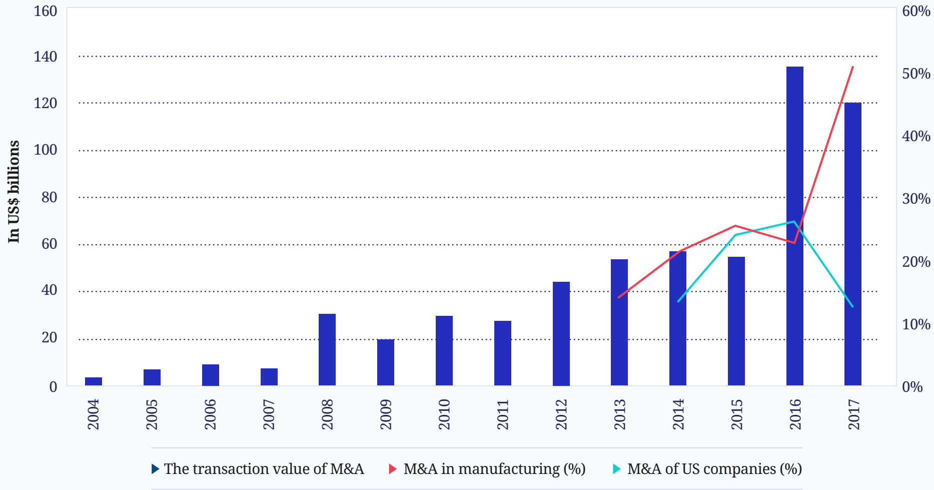
	Global FDI inflows (%)	FDI inflows to China (%)	High-tech manufacturing FDI inflows to China (%)	High-tech service FDI inflows to China (%)
2015	38.0	5.6	8.5	51.7
2016	–2.0	4.1	3.0	81.9
2017	–23.0	2.0	7.6	106.4

▶ Sources: Data on global FDI inflows from UNCTAD 2019. Data on Chinese FDI from Ministry of Commerce, 2016a, 2018a, 2018b.

Moreover, in order to gain access to foreign intellectual property, China has actively engaged in overseas M&A, particularly in developed economies. According to figure 5, between 2004 and 2017 the transaction value of China's overseas M&A showed an upward trend, of which the share of M&A in manufacturing rose dramatically from 13.8 per cent in 2013 to 50.8 per cent in 2017. The foreign industry of software and information and communications technology (ICT) services has also attracted many Chinese investors. According to the same data source, 15.5 per cent and 19.5 per cent respectively of Chinese overseas M&A took place in this industry in 2015 and 2016. Developed countries are China's preferred destinations for overseas M&A. As shown in table 3, between 2014 and 2017 the majority of China's top ten destinations for overseas M&A in terms of transaction value were OECD economies. The United States was particularly attractive for Chinese M&A investors: it either topped or ranked the second place in the list. In 2015 and 2016, over 20 per cent of China's overseas M&A took place in the United States (Ministry of Commerce 2019).

China's growing input in innovation has paid off. Although the quality of Chinese patents is dubious (Chen 2018a), the number of patent applications filed by China has been increasing. As shown in figure 6, between 2007 and 2017 China significantly expanded its share in global patent filings. In 2017, Chinese entities filed the largest number of patents in the world, outperforming their counterparts in Japan and the United States by wide margins. In 2017, among all manufacturing companies above the designated size in China, 28.0 per cent achieved some extent of product upgrading and 28.7 per cent achieved some extent of process upgrading (National Bureau of Statistics 2019a).

Figure 5. China's overseas M&A, 2004–17



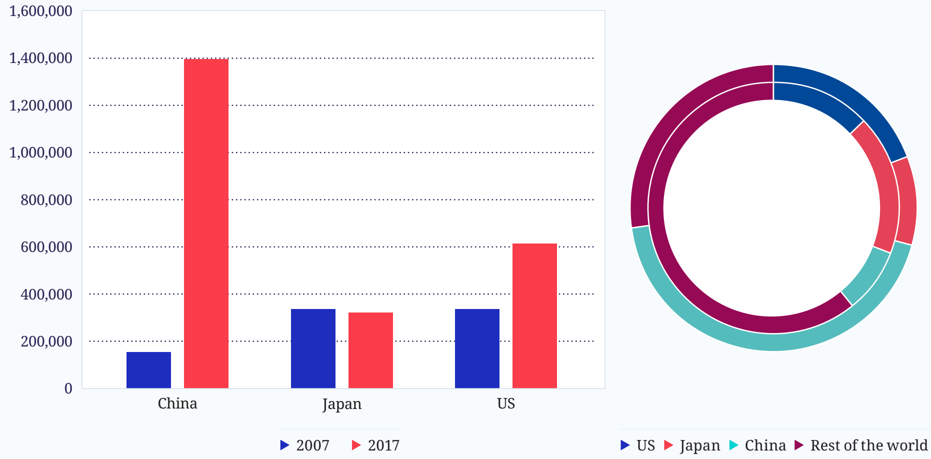
Source: Ministry of Commerce 2019.

Table 3. China's top ten overseas M&A destinations, 2014–17

	2014	2015	2016	2017
1	Peru	US	US	Switzerland
2	US	Cayman Islands	Hong Kong, China	US
3	Hong Kong, China	Italy	Cayman Islands	Germany
4	Australia	Hong Kong, China	Brazil	Brazil
5	Canada	Australia	Germany	UK
6	Italy	Netherlands	Finland	Indonesia
7	Cayman Islands	Israel	UK Virgin Islands	Hong Kong, China
8	Germany	Bermuda	Australia	Australia
9	France	Kazakhstan	France	United Arab Emirates
10	Netherlands	UK	UK	Singapore

Note: OECD countries are shadowed in light blue.
Source: Ministry of Commerce 2019.

Figure 6. Global composition of patent filing activities, 2007 and 2017



Note: Left side: the number of patents filed; right side: the percentage of patents filed; inner circle: 2007, outer circle: 2017.

Source: WIPO 2019.

That said, the growing hostility to China's rise from developed economies, epitomized by the US's trade war against China, is overshadowing China's endeavours in both foreign technology transfer and indigenous innovation. Ever since the trade war was ignited in early 2018, the US Government has imposed restrictions on exporting high-tech parts and components to China and on the M&A of US high-tech enterprises by Chinese enterprises. On 19 November 2018, the US Government released a list of proposed export controls on several strategic technologies, including artificial intelligence (AI) technologies, robotics and quantum computing that are key to the new wave of technological transformation. These rules do not specify China but are considered to be related to the US efforts to prevent China from acquiring these technologies (Sevastopulo and Mitchell 2018; Wong and Koty 2019). The US Government has also tightened visa controls over Chinese students who plan to pursue degrees in science, technology, engineering and mathematics in the United States (Jing 2019). Moreover, it says that the MIC 2025 encourages state subsidies for domestic companies and forces technology transfer from foreign partners. It has called the Chinese Government to halt all subsidies to industries in this initiative and to accept the US's tariffs on these industries for reasons of national security (Bradsher 2018a). In December 2018, it was reported that to ease tensions the Chinese Government was drafting a replacement of MIC 2025, which would play down China's bid to dominate manufacturing and open the Chinese market wider to foreign companies. Some US officials interpreted this move as more cosmetic than real (Wei and Davis 2018).

2.2 Process upgrading

This section maps the status quo of production technologies and the prospects for process upgrading in China. Historically, in advanced economies the evolution of process technology underwent several stages: (1) the First Industrial Revolution in the late 18th century (Industry 1.0) underpinned by machinery driven by steam and water power; (2) the Second Industrial Revolution in the late 19th century (Industry 2.0) underpinned by electrification of machines and mass production; (3) the Third Industrial Revolution in the 1970s (Industry 3.0) underpinned by industrial robots, computer numerical control (CNC) machine tools, and information technology (IT)-based production management (Wübbeke et al. 2016). Now, the world is witnessing what is called by some the Fourth Industrial Revolution (Industry 4.0).[8] Industry 4.0 is underpinned by technological progress in the Internet of Things (IoT), cloud computing, AI and robotics, among others (Bloem et al. 2014).

This classification is over-simplistic and overlooks the comprehensive interactions between technology and social forces. Nonetheless, it helps us to situate China's position with regard to process technology. In China, different levels of process technologies are unevenly deployed in different enterprises and most enterprises are at the stage of Industry 2.0. Therefore, while enterprises in advanced economies are pursuing Industry 4.0, enterprises in China are pursuing Industry 3.0 and 4.0 at the same time. As shown in Chapter 1, the development, manufacturing, and use of process technologies all have labour implications. This section maps the status quo and prospects for the development, manufacturing and adoption of the following process technologies: CNC machine tools, robots, 3D printing, enterprise software, IoT, and AI.[9] Overall, with regard to the development and adoption of process technologies, China lags behind developed economies. The gap is wider in technologies that underpin Industry 3.0 than it is in technologies that underpin Industry 4.0. Chinese companies have made efforts to narrow these gaps and their attempts have been facilitated by government support. It is worth noting that rather than being a pure imitator and follower of foreign industrial leaders, Chinese companies are forging ahead in certain technologies such as the fifth-generation (5G) mobile network.

8 In daily use, Industry 4.0 and the Fourth Industrial Revolution are largely interchangeable concepts and this report follows this kind of usage henceforth. For convenience, this report uses shorthand such as Industry 3.0 for previous industrial revolutions.

9 These concepts overlap with each other heavily. For the sake of convenience, they are treated separately.

2.2.1 CNC machine tools

CNC machine tools are computer-controlled tools that create complicated parts to high specifications. They are essential tools for manufacturing. In 2009, China became the largest producer of machine tools in the world (Gardner 2012). In 2015, machine tool production in China totalled US$22.1 billion and accounted for 27.6 per cent of world output value (Gardner 2016). But with regard to technological sophistication, Chinese machine tool manufacturers lag behind their counterparts in advanced economies. Most machine tools made by Chinese companies are manually controlled, rather than using the numerical control system (Machine Tool Manufacturing Net 2019). Between 2004 and 2015, the annual output value of indigenous machine tools in China was much lower than the average level of 80–90 per cent in developed economies.

When it comes to medium-end and high-end machine tools, Chinese manufacturers have been largely assemblers owing to the lack of key technologies. Generally, they make the skeleton body of machine tools themselves, purchase key parts and components and numerical control systems from Japan, Republic of Korea, Taiwan (China) and European countries, and then put all the parts together. Compared with those made by global leading companies, Chinese-brand machine tools tend to have shorter operational life expectancy, lower precision and lower stability. As a result, China is an exporter of low-end machine tools and an importer of high-end ones. In 2013 the average export prices for metal-forming machine tools and metal-cutting machine tools in China were US$17,600 and 14,100 respectively, while the average import prices were US$195,200 and 181,100 respectively (Ren and Fan 2018). In 2015, imported machine tools accounted for 31.3 per cent of machine tool consumption value in China (Gardner 2016).

In light of this, China has attempted to improve its own machine tool technologies. In 2009, the Chinese Government launched a major national science and technology project[10] that aimed to achieve breakthroughs in the development of key parts and components and the numerical control system used in high-end CNC machine tools and other fundamental manufacturing machines. The Government planned to invest 22.1 billion RMB in this project (China International Industry Fair n. d.). The MIC 2025 also highlights high-end numerical control machine tools, together with robots, as one of the ten key fields for which the State will provide massive support to fuel technological breakthroughs. Table 4 shows the goals of the share of indigenous products in the domestic machine tool market set by the MIC 2025.

10 In 2006, the Chinese Government released the *Outline of the National Mid-to-Long-Term Science and Technology Development Plan (2006–2020)*. The Outline designated 16 national science and technology major projects which the Government would support to push for breakthroughs.

Table 4. Goals of the share of indigenous products in the Chinese machine tool market, 2020 and 2025

	2020 (%)	2025 (%)
High-end numerical control machine tools and other fundamental manufacturing machines	70	80
Intelligent numerical control system	10	30
Standard numerical control system	60	80
Key parts and components	50	80

Source: National Consulting Commission for the Strategy of Manufacturing for a More Prosperous China 2015, 28–29.

With support from the State, Chinese research institutions and enterprises have made some technological progress with regard to machine tools. But indigenous machine tool technologies in China remain far from the international frontier and far from the ambitious goals set by the MIC 2025. As mentioned above, Chinese manufacturers have increased the share of numerical control machine tools in their overall machine tool offering. Moreover, China has made progress in key machine tool technologies. In the domestic machine tool market, the share of indigenous high-end numerical control systems rose from less than 1 per cent before 2009 to 3 per cent in 2015 and 5 per cent in 2016; the share of certain key parts and components made by Chinese companies rose from some 5 per cent before 2009 to 20 per cent in 2016 (Chen 2018b; *Economy Daily* 2017). Five-axis CNC machine tools are one kind of high-end machine tools that provide great manufacturing precision and efficiency; in 2016, a set of Chinese-proposed testing standards for five-axis CNC machine tools gained international approval (Ren 2017). Moreover, between 2014 and 2016, 4.7 per cent of published Chinese patent applications were in the field of machine tools, a percentage higher than that in other countries (WIPO 2019).

Intelligent machine tools which combine traditional CNC machine tools with the concept of intelligent manufacturing is regarded as the future of the industry. It is unclear whether China can seize this gear-changing opportunity and become a leader in the new-generation machine tool. In 2014, Shenyang Machine Tool Co Ltd, China's leading manufacturer of machine tools and a state-owned enterprise, released the first model of its i5 (which stands for industry, information, internet, integrate and intelligent) series. In 2016, it launched i5M8, a machine tool model reported to be capable of intelligent programming, graphic diagnosis and simulation, and online analysis (Liu and Sankar

2016). The i5 ecosystem resembles that of Apple: it has an operating system which is an equivalent to Apple's iOS, i5 machine tools like iPhone and iPad, a cloud platform like Apple's iCloud, and a shop floor management system, which together enable it to gather real-time data from the production process and analyse the data to optimize the operation of machine tools and production. To encourage manufacturers to use the i5 ecosystem, Shenyang Machine Tool has built an intelligent production park that employs the i5 system and invited multiple manufacturers to move to the park and share the i5 service. They are charged only for the time they use the service.

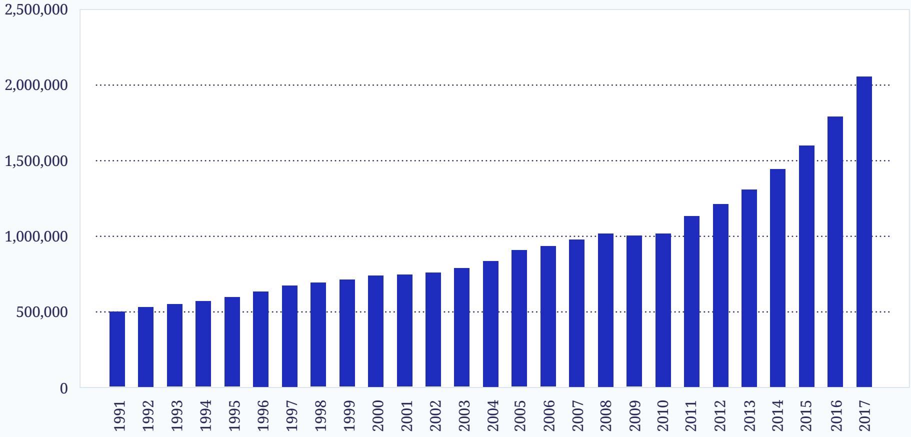
The i5 series is far from mature. Up to 2020, i5 series had mainly been used to make two-axis and three-axis products, rather than more precise ones. The sharing model also strains Shenyang Machine Tool's cash flow. In late 2019, it was reported to be on the brink of bankruptcy and received a bailout from another Chinese state-owned company (Kegongliliang 2020). Shenyang Machine Tool is not the only player in this field. For example, Siemens has introduced the Digital Enterprise solution portfolio, which provides users with IT integration and simulation solutions to link manufacturing with the IT environment (Siemens n.d.).

Since 2002, China has been the largest consumer market for machine tools in the world. In 2017, China consumed 30.0 billion USD worth of machine tools, which accounted for 36.2 per cent of the global consumption (Kline, 2018). The majority of machine tools in operation in present-day China are manually controlled, rather than using the numerical control system (Machine Tool Manufacturing Net, 2019). In 2013, in China, only 27 per cent of key manufacturing procedures involved numerical control machine tools. This proportion rose to 33 per cent in 2015 and is expected to further rise to 50 per cent by 2020 and 64 per cent by 2025 according to the MIC 2025 (State Council, 2015a). In response, local governments in China have put forward various subsidy programs for the upgrading of manual machine tools into numerical control ones and for the purchase of new numerical control machine tools (Department of Equipment, 2016).

2.2.2 Robots

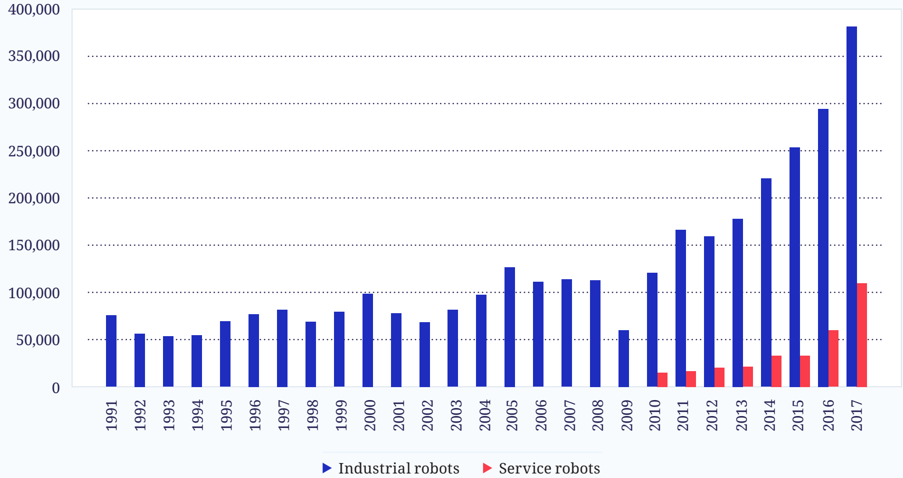
Robots are also a child of Industry 3.0. Recent progress in robotics has made a wide variety of tasks previously done by hand automatable. As shown in figures 7 and 8, the past three decades have witnessed a growing popularity of robots worldwide. In particular, since 2010 the increase both in the operational stock and in annual sales of robots has accelerated. According to the IFR, between 1991 and 2017 the operational stock of industrial robots in the world jumped from 506,475 to 2,097,500 units. Industrial robots dominate the global robot market, but service robots are quickly gaining in popularity. Globally, between 2010 and 2017 the annual sales of industrial robots rose from 120,585 to 381,335 units while the annual sales of service robots rose from 15,027 to 109,543 units.

Figure 7. Estimated global operational stock of multipurpose industrial robots, in units, 1991–2017



Source: IFR 2005a–2018a.

Figure 8. Estimated global annual sales of industrial and service robots, in units, 1991–2017



Source: IFR 2005a–2018a; 2010b–2018b.

China has emerged as a world-class manufacturing hub of robots. With regard to technological capabilities, Chinese robot manufacturers lag far behind their counterparts in advanced economies but are making efforts to catch up. China is also an active adopter of industrial robots, the world's largest market for them. But it is still at the early stage of robot adoption, with eastern China adopting robots more actively than other regions. Industrial robot density in Chinese manufacturing is much lower than in the manufacturing industries of advanced economies. The gap is smaller in the automotive industry than in other manufacturing industries. Newly installed industrial robots in China increasingly go to the electrical/electronics industry, rather than to the automotive industry. Owing to a confluence of factors such as the progress in robotics and strong state incentives, the industrial robot density gap between China and advanced economies is gradually narrowing. But shortage of capital (both for enterprises above the designated size and for micro, small and medium-sized enterprises), shortage of the capability to tailor automatic equipment to their needs, failing to find appropriate automatic equipment in the market, and shortage of related skilled labour are putting off Chinese enterprises from adopting or expanding their use of automatic equipment, including robots.

China as a robot manufacturer

China has emerged as a global manufacturing hub of robots. In addition to Chinese robot makers, in recent years the global leading industrial robot giants have expanded their production in China (table 5). *The Development Plan of the Robot Industry (2016–2020)* released by the Chinese Government in 2016 set the goal that, by 2020, the annual production capacity for indigenous industrial robots should have reached 100,000 units, including over 50,000 units of six-axis or technologically more sophisticated ones (Ministry of Industry and Information Technology 2016a). In fact, between 2016 and 2019, the annual production capacity of industrial robots produced by enterprises above the designated size in China jumped from 72,426 to 186,943 units (National Bureau of Statistics 2020); this number as a percentage of global sales jumped from some 13 per cent in 2015 to 38.7 per cent in 2018 (National Bureau of Statistics 2020; Xinhuanet 2016; IFR 2019a).

Owing to the lack of key technologies, Chinese robot manufacturers are largely assemblers in the current robot GVCs. According to a Chinese robot scientist, Chinese robot makers lag far behind their foreign competitors in developed economies in both software and hardware, and in both design and manufacturing.[11] According to an official survey, in 2016, of some 800 Chinese enterprises which claimed to be robot manufacturers, half had no related products; of the remaining half, 70–80 per cent were import agencies of

11 Interview with a Chinese robot scientist by the author, 17 November 2018.

Table 5. Presence of the global top four industrial robot manufacturers in China

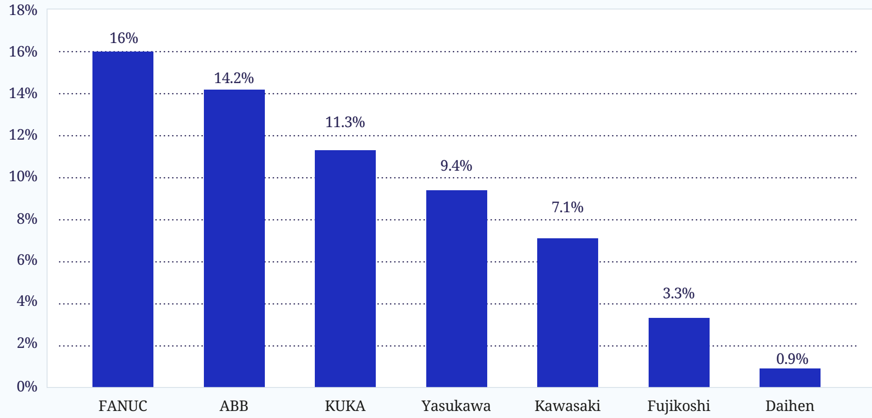
Companies	Operations in China
ABB	In 2006, ABB moved its global robotics headquarters to Shanghai and in 2013 announced the successful delivery of its 20,000th robot made in China. In 2018, the company announced an investment of US$150 million to expand its Shanghai facilities.
FANUC	In 2002, FANUC built a factory in China and expanded rapidly thereafter. In 2018, the company began to build a new factory in Guangzhou, Guangdong province, with an investment of 150 million RMB.
Yaskawa	In 2012, Yaskawa began to produce robots in China and in 2017 began to build its third factory in the country. Three Yaskawa Chinese factories combined will produce 1,500 robots monthly.
KUKA	In 2000, KUKA built its first robot factory in China. In late 2016, the company was acquired by Midea, a Chinese home appliance manufacturer. Midea has been expanding KUKA's Shanghai factory and building new facilities in Shunde, Guangdong. It hopes to reach an annual production capacity of 100,000 robots by 2024.

Source: Official websites of these companies (data from November 2018).

foreign robots. Only some 100 companies were engaged in the manufacturing of robots or robot parts and components, and these companies relied heavily on foreign suppliers for core parts and components such as servo motors, decelerators and control systems. In 2015, over 80 per cent of servo motors and approximately 75 per cent of precise decelerators installed in Chinese-brand robots were from foreign suppliers, particularly Japanese companies (*Daily Economic News* 2016a).

As a result, as with what has happened in the Chinese machine tool market, China is an exporter of cheap low-end robots and an importer of high-end robots. The main application areas of robots made by Chinese companies are loading, unloading and transport, activities that do not require high precision (*Daily Economic News* 2018). The average price for one unit of industrial robot exported by China was US$5,100 in 2016 and 7,600 in 2017, while the average price for one unit of industrial robot imported to China was US$16,300 in 2016 and 15,300 in 2017 (Yang 2018). In 2017, the self-sufficiency

Figure 9. Share of leading foreign brands in the Chinese industrial robot market, 2017



Source: Cheng, Chen and Li 2018.

rate of industrial robots (the share of sales contributed by indigenous companies in the domestic market, in units) was a mere 27 per cent, a slide from 33 per cent in 2016 but much higher than earlier years when the self-sufficiency rate was lower than 5 per cent (Science and Technology Daily 2018). Figure 9 shows the share of leading foreign-brand industrial robots in the Chinese market at the end of 2017.

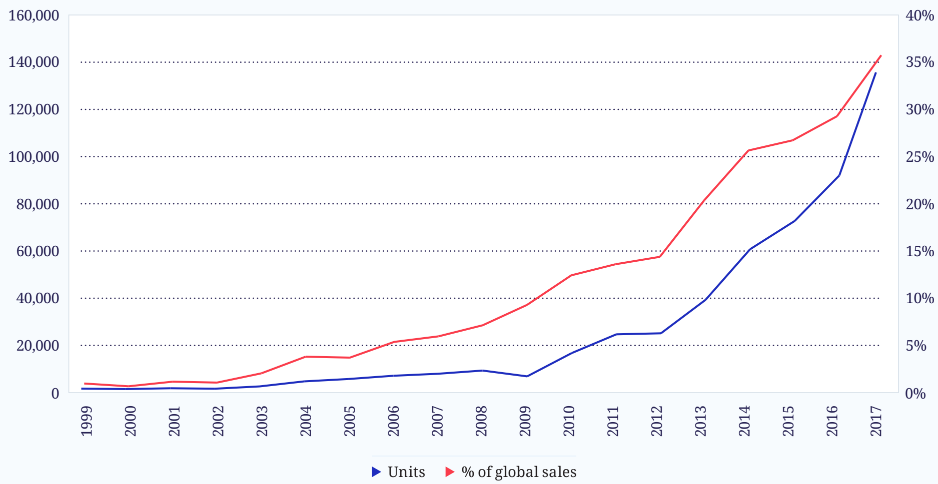
In light of this technological backwardness in robotics and the huge demand for robots from domestic industries, China has attempted to catch up both by investing in indigenous R&D and by purchasing foreign technologies. The Chinese Government includes robots, together with high-end numerical control machine tools, as one of the ten key fields in the MIC 2025 into which it would pour tremendous resources to fuel technological breakthroughs. *The Intelligent Manufacturing Development Plan (2016–2020)* of the Chinese Government sets the goal of the self-sufficiency rate at 50 per cent for key intelligent manufacturing equipment (of which robots are a major category) and at 30 per cent for key intelligent manufacturing software by 2020 (Ministry of Industry and Information Technology 2016b). Except for indigenous innovation, Chinese companies have also engaged in M&A to gain access to foreign robotic technology. A high-profile case in this regard is the Chinese home appliance manufacturer Midea's acquisition of German industrial robot leader KUKA in late 2016 (see table 5).

China as a robot consumer

According to the IFR, since 2013 China has been the largest market for industrial robots in the world, and also the fastest-growing market. As shown in figure 10, since 2009 the annual sales of industrial robots have dramatically increased in China; in 2017, 36 per cent of global sales of industrial robots was contributed by China. As a result, the operational stock of industrial robots in China has soared. With regard to the number of industrial robots in stock, figure 11 shows that China surpassed the Republic of Korea in 2014, and overtook North America (Canada, Mexico and the United States combined) in 2016.

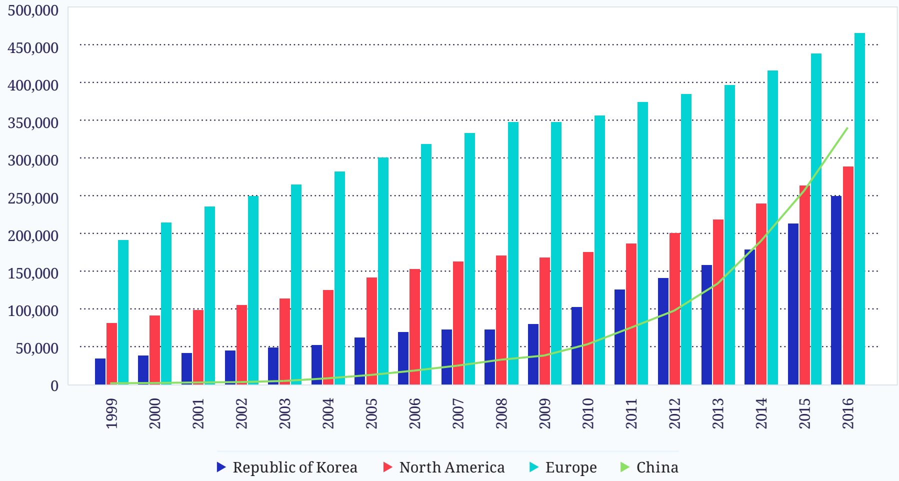
Nonetheless, owing to the gigantic scale of the Chinese workforce, the increase in robot density (number of robots per 10,000 employees) is less impressive. In 2016, industrial robot density in the manufacturing industry in China was 68 (global ranking: 23), which was 36.0 per cent of that in the United States, some 22 per cent of that in Germany, and 10.8 per cent of that in the Republic of Korea (figure 12). Moreover, several Chinese scholars criticize the IFR's data on China as being mainly based on large-scale enterprises and therefore overestimating the robot density in China; using probability-proportional-to-size sampling in enterprises in five industrial provinces in China, the China Employer–Employee Survey estimates that industrial robot density in these provinces at

▶ **Figure 10. Estimated annual sales of multipurpose industrial robots in China, 1999–2017**



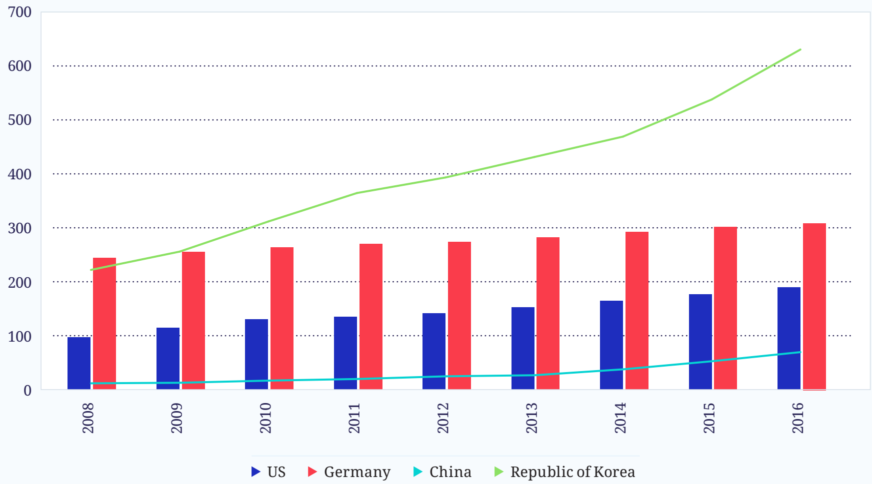
▶ Source: IFR 2005a-2018a.

Figure 11. Estimated operational stock of multipurpose industrial robots, various regions, 1999–2016



Source: IFR 2005a–2017a.

Figure 12. Estimated multipurpose industrial robot density in the manufacturing industry, top user countries, 2008–16

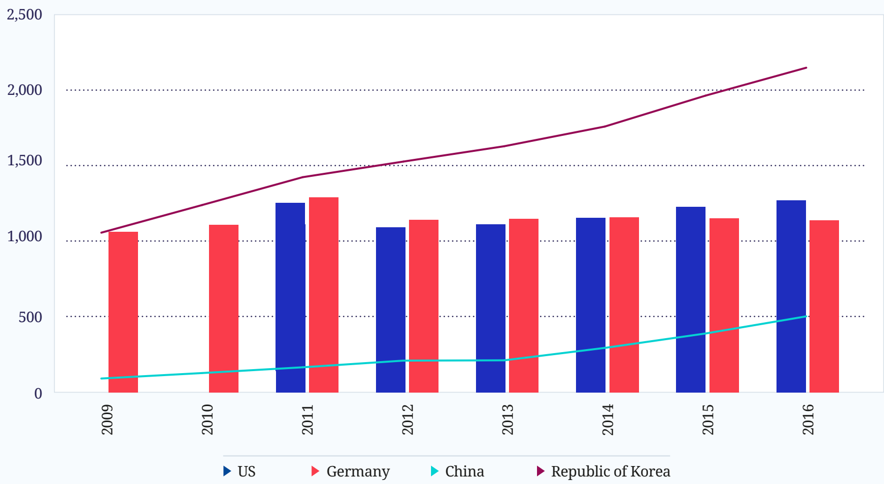


Source: IFR 2005a–2017a.

the end of 2017 was merely 39, albeit with provincial variations (more details in table 6) (Cheng, Chen and Li 2018). It is worth noting that industrial robot density has risen much more rapidly in China than in the world's top users of robots. It can be calculated from figure 12 that between 2008 and 2016 industrial robot density in the manufacturing industry in China increased by 580 per cent, compared with an increase of 26.6 per cent in Germany, 96.9 per cent in the United States, and 185.5 per cent in the Republic of Korea.

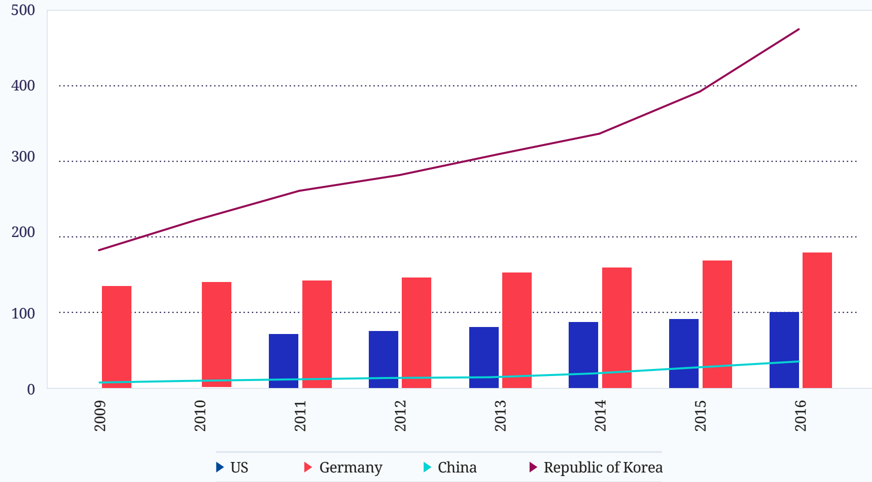
With regard to distribution, the automotive industry is a leading user of industrial robots at the international level. The industrial robot density gap between China and advanced economies is smaller in the automotive industry than it is in other manufacturing industries. As shown in figure 13, between 2009 and 2016 industrial robot density in the automotive industry almost stagnated in Germany, increased mildly in the United States, increased significantly in the Republic of Korea (from 1,057 to 2,145), and increased dramatically in China (from 95 to 505). In 2017 industrial robot density in the automotive industry in China was some 40 per cent of that in Germany and the United States, and 23.5 per cent of that in the Republic of Korea. In all the other manufacturing industries, between 2009 and 2016 industrial robot density grew from 5 to 33 in China; as a percentage of that in the Republic of Korea it rose from 2.8 to 6.9 per cent (figure 14).

▶ Figure 13. Estimated multipurpose industrial robot density in the automotive industry, top user countries, 2009–16



Source: IFR 2005a–2017a.

Figure 14. Estimated multipurpose industrial robot density in all manufacturing industries excluding automotive, top user countries, 2009–16

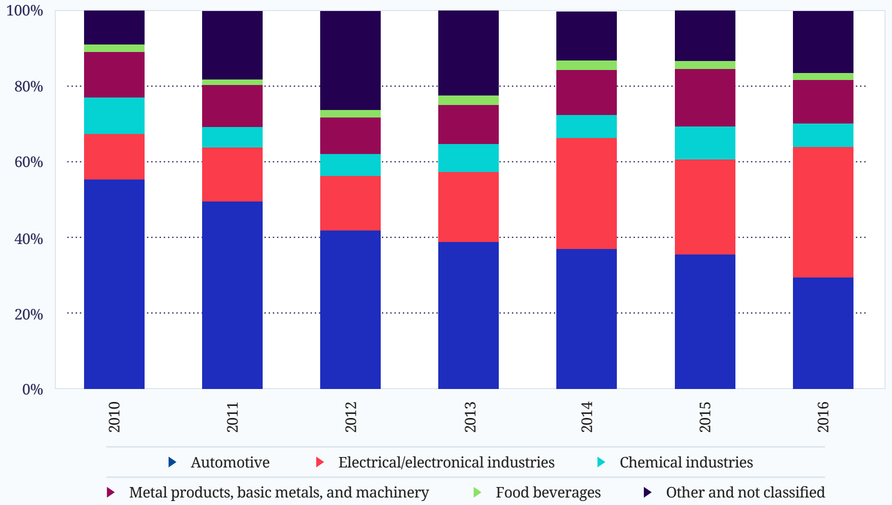


Source: IFR 2005a–2017a.

Nonetheless, in recent years, robot instalment in electrical/electronics companies in China has been picking up. With regard to the industrial distribution of newly installed industrial robots in China, automotive and electrical/electronics companies are the main users (figure 15). Between 2010 and 2016, they together accounted for some 60 per cent of the annual sales of industrial robots (in units) in China. During the same time frame, an increasing share of annual industrial robot sales went to the electrical/electronics industry, while a decreasing share went to the automotive industry. In 2016, for the first time, 34.5 per cent of annual industrial robot sales took place in the electrical/electronics industry, overtaking the 29.5 per cent in the automotive industry.

Compared with national-level data, the firm-level data collected by the China Employer–Employee Survey gives a more concrete flavour of the extent to which robots have penetrated into Chinese factories. As shown in table 6, in all the five provinces surveyed, between 2008 and 2017 the popularity of robots increased significantly. Nonetheless, in all these provinces at the end of 2017, less than 20 per cent of manufacturing enterprises used industrial robots. In the most avid provincial adopters of robots in China – Jiangsu and Guangdong (two top-tier economic powerhouses in eastern China) – only 19 and 18 per cent respectively of manufacturing enterprises were using industrial robots in 2017. Nonetheless, these figures were significantly larger than those in Hubei (in central China), Jilin (in northeast China), and Sichuan (in western China). Moreover, even

▶ **Figure 15. Estimated annual consumption of industrial robots in China, by industry, 2010–16**



Source: IFR 2005a–2017a.

in enterprises that did use robots, the number they used was quite small: on average, in 2017 in Guangdong, every 100 manufacturing enterprises used 177 robots; in Jiangsu, the number was 165.

Compared with firms that turn their back on robots, firms that deploy robots tend to be more capital-intensive, more innovation-driven, more export-oriented, and more likely to be foreign-owned or state-owned (the latter have better access to government subsidies or credit than Chinese private enterprises) (Cheng, Chen and Li 2018; Cheng et al. 2019). In early 2018, Guangdong had 47,242 industrial enterprises above the designated size (Department of Industry 2018). According to its provincial plan for industrial transformation and upgrading between 2015 and 2017, while the Government planned to help some 20,000 of the above enterprises to achieve some extent of technological upgrading regarding process or product, it planned to help only some 1,950 of those enterprises (4 per cent) to introduce robots to their shop floor (Guangdong Government 2015).

In addition, the automation of manufacturing may take place at the level of individual production processes, assembly lines, shop floors, or entire facilities. Despite the regular media hype of unmanned factories in China, according to an experienced investigator in robotics even the automation demonstration factories in present-day China are far from unmanned; what is happening on the ground is that a minority of companies

▶ Table 6. Popularity of industrial robots in manufacturing enterprises in five Chinese provinces, 2008–17

	Overall sample (n=1,882)	Guangdong (n=439)	Jiangsu (n=335)	Hubei (n=428)	Sichuan (n=343)	Jilin (n=319)
% of firms using industrial robots before 2008	2%	3%	5%	1%	1%	3%
% of firms using industrial robots before 2013	7%	9%	11%	4%	4%	7%
% of firms using industrial robots in 2017	13%	18%	19%	8%	10%	10%
% of firms planning to use industrial robots in the next few years	10%	9%	17%	8%	10%	10%
Average number of industrial robots used per 100 firms, 2017	112	177	165	58	49	108
Industrial robot density, 2017	39	53	33	22	35	54

▶ Source: The China Employer–Employee Survey, from Cheng, Chen and Li 2018.

use robots to automate various production processes on some assembly lines.[12] A survey involving multiple enterprises in the textile sector conducted in 2018/19 confirms this. According to this survey, robots were used only in some production processes in some sub-sectors of textiles, which had not changed the labour-intensive nature of the whole industry (National Trade Union of the Finance, Trade, Textiles, and Tobacco Sector 2019).

12 This is from an online lecture given by Hui Xu hosted by the author in October 2018. Hui Xu is a PhD student from the University of Jena who researched automation in China.

It is safe to expect that in the near future the robot density gap between China and advanced economies will be further narrowed. *The Development Plan of the Robot Industry (2016–2020)* sets the goal that by 2020 robot density in China shall reach 150 or higher (Ministry of Industry and Information Technology 2016a), which requires an average annual growth rate of at least 21.9 per cent between 2016 and 2020 (if we use the data from the IFR for calculation). Given that it can be calculated from the data in figure 12 that robot density in China's manufacturing industry grew by some 30–45 per cent annually between 2014 and 2016, this goal seems achievable.

Thanks to the ongoing technological progress in robotics, robots are becoming functionally more capable and financially more accessible, which will greatly fuel their popularity in China. Frey and Osborne (2016) estimate that the payback period for a welding robot in the Chinese automotive industry dropped from 5.3 to 1.7 years between 2010 and 2015 and would have shrunk to 1.3 years by 2017. Analysts at the BCG estimated in 2015 that in the next decade the performance of robotics systems would improve by approximately 5 per cent each year, while the price of their hardware and enabling software would drop by more than 20 per cent over the same time (Sirkin, Zinser and Rose 2015). Rising wages, declining working population, growing domestic demand for consumer goods, and relentless enthusiasm for automation in the electronics and automotive industries in China will continue to boost robot popularity, too (IFR 2017a).

Support from the Government has amplified the above facilitators in robot adoption, and will continue to do so. According to the China Employer–Employee Survey, firms that used robots received more subsidies from the Government than firms did not (Cheng, Chen and Li 2018). In the city of Dongguan, a top-tier manufacturing hub and automation spearhead city in Guangdong, China, between 2014 and 2016 the municipal government invested 200 million RMB annually in the implementation of the Replacing Humans with Machines strategy.[13] The top three subsidized sectors were electrical machinery and equipment (37 per cent of recipients), electronics (33 per cent of recipients), and printing and packaging (6–7 per cent of recipients) (Sharif and Huang 2019). In 2018, the municipal government of Dongguan allocated 385 million RMB to advance intelligent manufacturing of all kinds, including the adoption of industrial robots (Bureau of Finance, Dongguan 2018). In the city of Foshan, another manufacturing hub and avid adopter of industrial robots in Guangdong, between 2015 and 2017 the municipal government invested 53 million RMB annually in intelligent manufacturing with a focus on industrial robots; in some cases, it subsidized as high as 15 per cent of the purchase cost of

13 Particularly after the launch of the MIC 2025 in 2015, process upgrading and "replacing humans with machines" become interchangeable terms. In media and academic reports on the strategy of "replacing humans with machines", "machines" mainly refer to robots, but including other automatic devices as well. Table 7 uses the term "automatic equipment" to refer to robots and other automatic devices.

robots. Between 2018 and 2020, the municipal government planned to invest 130 million RMB annually to boost the local industry of robot manufacturing and the adoption of robots. For robot buyers, it promised to subsidize 12 per cent of the purchase cost for robots made in Foshan (no more than 3 million RMB per enterprise per year), and 8 per cent for robots made out of Foshan (no more than 2 million RMB per enterprise per year). For (potential) robot makers, the municipal government has multiple subsidy schemes to support their incubation and growth (Foshan Government 2018).

Nonetheless, Chinese enterprises still face multiple obstacles in adopting robots and other automatic equipment. Table 7 summarizes these obstacles: shortage of capital (both for enterprises above the designated size and for micro, small and medium enterprises), shortage of the capability to tailor automatic equipment to their needs, failing to find appropriate automatic equipment in the market, and shortage of related skilled labour are among the most cited hindrances by enterprises surveyed. In addition, lack of familiarity with automatic equipment and subsidy policies, and the lack of incentives amidst economic slowdown, and in central and western China where labour costs are lower than coastal regions, also cool down enterprises' enthusiasm for the adoption of automatic equipment.

▶ Table 7. Survey data on the constraints of automatic equipment adoption in China

Time, region	Survey conductor	No. of surveyed enterprises, sectors	Main constraints	Source
2013 Zhejiang	Provincial government of Zhejiang	515*, M	71.1%-short of capital as the primary constraint (Over 50%-invest over 10 million RMB; 36.8%-with a payback period of over 4 years) 35.3%-lack the capability to tailor automatic equipment to their needs 38.6%-fail to find appropriate automatic equipment in the market Lack familiarity with subsidy policies	Jia, Lin and Yi 2013

Time, region	Survey conductor	No. of surveyed enterprises, sectors	Main constraints	Source
2014 Zhejiang	Provincial government of Zhejiang	4,445 micro, small, and medium enterprises	Short of capital as the primary constraint Lack incentives to embark on process upgrading amidst economic slowdown	Electronic Infor-mation Industry Network, 2015
2015/16 Taizhou, Zhejiang	Zhejiang branch of the NBS	103* enter-prises above the designat-ed size, M	60.3%-short of capital as the primary constraint (57.1%-invest less than 20 million RMB; 13.3%-invest more than 50 million RMB; 44.6%-with a payback period of over 4 years) 54.8%-only consider it on the condition of more government subsidies 30.8%-lack the capability to tailor automatic equipment to their needs 30.7%-fail to find appropriate automatic equipment in the market Lack familiarity with subsidy policies	Zhejiang branch of the NBS, 2016
2017/18 Xiaoshan, Hangzhou, Zhejiang	Two univer-sity scholars	80*	29%-short of related skilled labour 23%-lack the capability to tailor automatic equipment to their needs 20%-short of capital 6%-difficulties with maintenance of automatic equipment	Jin and Gu 2018

Time, region	Survey conductor	No. of surveyed enterprises, sectors	Main constraints	Source
2017 Foshan, Guangdong	Local government of Foshan	173*, M	60.8%-short of capital as the primary constraint 35.1%-short of related skilled labour as the primary constraint Lack familiarity with automatic equipment and government support policies	Jinyangnet 2017
2017 Huizhou, Guangdong	Huizhou branch of the NBS	31 micro and small entepises, M, services	Short of capital Short of related skilled labour	Zhou and Yang, 2017
2017/18 Jiangxi	Jiangxi branch of the NBS	60, M	Fail to find appropriate automatic equipment in the market Short of capital Short of related skilled labour Difficulties of getting rid of redundant labour	Zheng, Chen and Zhu 2018
2018/19 Multiple provinces	A related national trade union	Multiples enterprises, textiles	Short of capital Fail to find appropriate Chinese-brand automatic equipment in the market while foreign-brand ones are too expensive Short of related skilled labour Low wages and thereby low incentives to replace humans with machines in Central and Western China	National Trade Union of the Finance, Trade, Textiles and Tobacco Sector 2019

- Notes: In the third column, numbers refer to the number of enterprises that responded to the survey; numbers with asterisk indicate that all surveyed enterprises were confirmed to have used automatic equipment at the time of survey. NBS=National Bureau of Statistics; M=Manufacturing.
- Sources: As indicated in the table.

2.2.3 3D printing

3D printing, often used as a synonym of additive manufacturing, appeared in the 1980s and has gained currency in recent years. 3D printing is additive in the sense that 3D objects are constructed by successively depositing material in layers such that the result becomes a predesigned shape. 3D printing has the potential to outperform conventional manufacturing in the creation of very complex shapes in need of mass customization without added costs (Creative Mechanisms 2016). It is thus perceived to have the potential to reshape manufacturing and thereby disrupt the labour market.

China is an emerging manufacturer and exporter of low-end 3D printers but is catching up technologically. Even in advanced economies, the application of 3D printing technologies in end use production is limited. In China, because of technological bottlenecks and the lack of state support, 3D printing technologies are mainly used for prototyping and are highly unlikely to be used for mass production in the near future.

In 2014, the US President's Council of Advisors on Science and Technology (2014) released a report titled *Accelerating U.S. Advanced Manufacturing*. It identifies a number of steps the US Government can take to reinvigorate US manufacturing, including incentives for the development of additive manufacturing technologies. Such technologies are also regarded as a key enabler for the German Industry 4.0, which is a master plan issued by the German Government to further strengthen German manufacturing amidst this wave of technological transformation (German National Academy of Sciences Leopoldina et al. 2017). Following Germany and the US, in the MIC 2025 the Chinese Government recognizes additive manufacturing as one of the key technologies concerning intelligent manufacturing. The Government plans to build additive manufacturing innovation hubs to foster the development of related technologies, and has called for the application of additive manufacturing technologies in industrial production (State Council 2015a).

Nonetheless, additive manufacturing technologies are still in the early days of application in the manufacturing industry. The materials that can feed 3D printers are limited. The speed of printing is not comparable to conventional manufacturing. And 3D printers remain expensive for most enterprises (Forrest 2014). As a result, additive manufacturing technologies are still mainly used for creating prototypes and tooling, rather than for printing end parts (Molitch-Hou 2017). A recent application of 3D printing for end use production is Adidas's 3D-printed sneakers Futurecraft 4D released in 2018. It is not clear how many companies are involved in end use production, and it is generally agreed that additive manufacturing is a complement to conventional manufacturing methods such as injection moulding and CNC machining, rather than a competitor (Zahnd 2018).

Wohlers Associates, an association of preeminent 3D printer experts globally, estimates that the market value of the additive manufacturing industry, consisting of all additive manufacturing products and services worldwide, was US$7.3 billion in 2017 (excluding internal investments in Airbus, Adidas, Ford, Toyota, Stryker, and hundreds of other companies) (McCue 2018). The Industrial Association of Additive Manufacturing in China values the Chinese additive manufacturing industry in 2017 at 10 billion RMB (US$1.4–1.5 billion). Between 2015 and 2017, the average annual growth rate of the Chinese additive manufacturing industry in terms of market value was over 30 per cent, significantly higher than the global average. In 2017, China had over 500 companies engaging in additive manufacturing (Xia and Liu 2018).

The 3D printing industry includes the development and production of 3D printers (including desktop 3D printers for household use and industrial 3D printers), materials to feed printers, 3D modelling software, supporting services, and so on. Foreign brands dominate the high-end market of both desktop and industrial 3D printers in China. Chinese companies are good at producing cheap low-end desktop 3D printers of acceptable quality and selling them in large numbers both at home and overseas (Yu 2016). However, according to a WIPO report published in 2015, in the area of 3D printing and robotics, China filed more than a quarter of patents in the world between 2005 and 2015, the highest share among all countries.

The application of 3D printing technologies is not at present disrupting manufacturing in China and is unlikely to do so in the near future. According to fieldworkers who visited over 60 factories in Dongguan and Guangzhou between 2016 and 2018, most factories did not use 3D printing at all, while a few used it for prototyping.[14] In addition to manufacturing, news reports indicate that in China 3D printing technologies are also used in healthcare, construction, education, entertainment, and so forth (Qianzhannet 2016). *The Action Plan for the Development of the Additive Manufacturing Industry (2017–2020)* released by the Chinese Government sets the goal of breakthroughs in key 3D printing technologies, including materials for 3D printing, 3D printers and 3D modelling software. It is worth noting that the mass adoption of 3D printers in the production of end parts is off the action agenda of this plan (Ministry of Industry and Information Technology 2017).

2.2.4 Enterprise software

Enterprise software is software used by organizations for business activities. It is complementary to humans and can outperform them in business processes such as product design, manufacturing process monitoring, and customer services in terms of quality,

14 Interviews with Hui Xu, Yu Huang and Yunxue Deng by the author, November 2018. Yu Huang is a postdoctoral fellow based at the Hong Kong University of Science and Technology. Yunxue Deng is a postdoctoral fellow based at the Central South University in China. Both of them have researched the application of industrial robots in China.

quantity and costs. Enterprise software can be roughly divided into three categories: industrial design software (for example, computer-aided design software (CAD) and computer-aided engineering software (CAE)), production monitoring software (for example, manufacturing execution systems), and management software (for example, enterprise resource planning systems and customer relationship management systems). Overall, with regard to both development and adoption, Chinese enterprise software lags behind its foreign counterparts in advanced economies, but Chinese industrial design software is catching up in certain subfields and the MIC 2025 highlights the development of indigenous industrial design software in its agenda. Chinese companies have not developed a strong appetite for management software. But to boost the efficiency of domestic companies, the Chinese Government has offered subsidies to increase the popularity of enterprise software.

CAD and CAE are the most commonly used industrial design software packages in the world. Foreign companies dominate the Chinese market for both. The technological gap between Chinese and leading foreign software makers in CAD is smaller than that in CAE. In fact, in 2009, in response to the pressure from its Chinese competitors, Autodesk, a global leading CAD company, cut the price of its products by 80 per cent in China (Hong 2009). According to an interview with the chief executive officer of ZWSOFT (a Chinese CAD company) in 2015, the market share of ZWSOFT in the Chinese CAD market came second, after Autodesk (CAD Insider 2015).

Chinese companies are still at the early stage of adopting CAE; the Chinese CAE market has been almost monopolized by foreign companies (E-works 2015). Compared with developed economies, China also sees less penetration of management software. This kind of software tends to be less technologically sophisticated than industrial design software. Chinese vendors dominate the domestic market of management software because they know the needs of Chinese companies better than foreign vendors and their products and services are more affordable than foreign ones (Liang et al. 2004).

The MIC 2025 identifies industrial design software as a subfield of the new-generation information technology industry, one of the ten key fields listed in the initiative. The MIC 2025 expects to “make breakthroughs in tools related to intelligent design and simulation[15]… develop indigenous and controllable high-end industrial platform software and key applications … and foster the systematic development and application of indigenous industrial software” (State Council 2015a). With regard to less foreign-dominated management software, the Chinese Government has launched subsidy programmes to facilitate its application. To take Shenzhen for example, the municipal government provides subsidies for small and medium enterprises in deploying digital technologies

15 CAD and CAE are part and parcel of this kind of tool.

to streamline business processes, including but not limited to management software. The amount of subsidy is up to 30 per cent of the cost of the digital applications purchased or 750,000 RMB, whichever is higher (Bureau for Serving Small-and-Medium Enterprises, Shenzhen 2017).

2.2.5 Internet of Things (IoT)

The IoT uses technologies such as sensors to gather large volumes of data (big data) from physical devices and transmits the data to the "cloud". The cloud is a network of remote servers hosted on the Internet and shared by multiple users to store and process data (cloud computing). Big data in the cloud can be used to train machines to gain artificial intelligence (AI) so that intelligent machines can efficiently analyse new data and give feedback to physical devices to improve their operations. A survey by the BCG finds that managers in Germany and the United States associate the IoT with increased productivity, cost reduction and revenue growth (Mascarenhas 2016). With regard to the development of IoT, companies in advanced economies take the overall lead. Chinese companies come close to them. In the development and adoption of the 5G mobile network technology which is key to IoT, China is at the global frontier. Financial incentives have been provided by the Chinese Government to boost IoT adoption.

Regarding the key technologies that enable IoT, overall, China lags behind advanced economies, but not far behind. Sensors, the Radio Frequency Identification (RFID) technology, and the global navigation satellite system are key to capturing data from the physical environment. Chinese companies can make low-end chips but are still unable to make high-performance chips, including those used for high-end sensors and RFID devices. As a result, China relies exclusively on foreign enterprises for high-end sensors (Communications Industry Net 2018). It was reported in 2018 that Chinese companies accounted for less than 10 per cent of the domestic market for sensor chips (*Semiconductor Industry Observer* 2018). China can make low and high frequency RFID chips with comparable performance to those of the global industrial leaders, but relies on foreign enterprises for ultra-high frequency RFID chips. Chips are also the bottleneck that compromises the performance of the BeiDou system, which is China's counterpart to the United States' Global Positioning System (GPS). But the overall performance of the BeiDou system is comparable to that of the GPS in China and its neighbouring countries (Deng 2014; Chen et al. 2009).

When it comes to data transmission technologies, Chinese enterprises are able to provide short-distance communication solutions such as Wi-Fi and Bluetooth comparable to those of global leading companies (China Finance Information Net 2017). Cellular mobile communications technologies are key to long-distance data transmission in the IoT and have entered the era of its fifth generation (5G). With regard to the development of 5G technology, China has become the global leader (Fung 2019). Regarding 5G adoption, China is also at the global frontier. 5G requires more base stations than the fourth generation of cellular mobile communications technology. According to Deloitte, a consultancy, China had almost two million telecom network sites in early 2018, ten times the number in the United States: for every 10 square miles, China had 5.3 sites while the United States had 0.4 sites (Deloitte 2018a). Nonetheless, regarding readiness for the actual deployment and spectrum allocation that will affect the development and adoption of the global 5G standards, the United States is the global leader. By the end of 2019, the United States was on track to have 92 commercial 5G deployments, versus 48 in the Republic of Korea, 16 in the United Kingdom, and zero in China. The United States is also leading the world in the quantity of allocated low-band and high-band spectrum for 5G, surpassing China by a wide margin, but it is at the bottom of the list globally when it comes to allocated mid-band spectrum for 5G (Horwitz 2019).

Cloud infrastructure and cloud computing are key to storing and processing data. There are three main models of cloud service: infrastructure as a service (IaaS) refers to a cloud computing offering whereby a vendor provides users access to computing resources such as servers, storage and networking; platform as a service (PaaS) refers to an offering that provides users with a cloud environment in which they can develop, manage and deliver applications in addition to storage and other computing resources; and software as a service (SaaS) refers to an offering that provides users with access to a vendor's cloud-based software (IBM n. d.).

Overall, it is companies in the advanced economies that are spearheading the development of cloud computing, but Chinese companies come close; they dominate the domestic IaaS market (Sun 2020). Globally, it is reported that in 2018 Alibaba, a Chinese IaaS supplier, had surpassed IBM to become the world's fourth largest supplier of cloud infrastructure and related services (Singh 2018). General Electronic Company's Predix and Siemens' Mindsphere are the top two industrial PaaS platforms in the world. In 2017, the China Aerospace Science and Industry Corporation launched China's first industrial PaaS platform, the Industrial Internet Cloud Space (Central Broadcast Net 2017). Compared with the General Electronic Company, the China Aerospace Science and Industry Corporation invests significantly less in the development of industrial IoT platforms. The Industrial Internet Cloud Space supports far fewer algorithmic models and has fewer developers on it than Predix does (Chen 2017). The Chinese SaaS market is half closed to foreign companies. Many popular SaaS products in the West such as Dropbox and Gmail are either blocked or in danger of being blocked (Dickinson 2017). In both 2016 and 2017, Kingdee, a Chinese financial software vendor, took the lion's share in China's SaaS market (Wang 2018).

The MIC 2025 is going to sharpen China's ability to develop technologies related to IoT, which are part of the new-generation information technology industry, one of the ten key fields listed in the initiative. Moreover, in 2016, the Chinese Government launched the *Scientific and Technological Innovation 2030 Major Projects*, an update to the projects shortlisted in the *Outline of the National Mid-to-Long-Term Science and Technology Development Plan (2006–2020)* launched in 2006. The *Scientific and Technological Innovation 2030 Major Projects* provides the highest-level governmental support to projects that are deemed of top importance. So far, 16 projects have been shortlisted, including one on intelligent manufacturing and robots, one on big data, and one on the next generation of AI (*People's Daily* 2017).

With regard to the penetration of the IoT, according to a survey conducted by the BCG that polled more than 600 managers representing 300 German and US companies in 2016, 17 per cent of these manufacturers had already applied some predictive maintenance solutions (a major IoT application area in manufacturing) in their factories; more than 40 per cent of the German and 24 per cent of the American companies intended to do so within one or two years (Meola 2016). According to fieldworkers who visited over 60 factories in Dongguan and Guangzhou between 2016 and 2018, Chinese factories have begun to embrace enterprise software, but it is not clear whether they use cloud-based software services, namely SaaS platforms, or conventional software. Very few enterprises use IaaS or PaaS platforms.[16] The Chinese Government wants to change this situation. Not only the central Government, but also various provincial governments have issued guidance or action plans to encourage enterprises to use IoT services. The provincial government of Guangdong spearheads such efforts. According to *Several Support Policies to Facilitate Enterprises to Use Cloud Platforms and to Accelerate the Development of Industrial IoT in Guangdong (2018–2020)*, the provincial government would negotiate with the suppliers of public cloud services on behalf of enterprises in Guangdong for cost concessions of at least 30 per cent, and provide subsidies for enterprises' purchase of cloud services; the provincial government would also provide subsidies for R&D activities of IoT suppliers (Guangdong Government 2018).

2.2.6 Artificial intelligence (AI)

The potential of AI technologies to redefine the way human beings live and work goes far beyond its application in robots and IoT. Overall, the United States is leading the global AI race and China comes second. Compared with the US AI industry, the Chinese AI industry is smaller in scale and less advanced in technology. When it comes to AI application, China is more proactive than the United States.

16 Interview with Yu Huang and Yunxue Deng by the author, 18 December 2018.

Table 8 compares the development of AI between China and the United States. Between 1997 and 2017, China surpassed the United States regarding the number of AI research articles, the number of high-impact AI research articles, and the number of AI patents filed. However, in China, AI patents were mainly filed by research institutions and universities rather than by enterprises. As a result, in the list of the top ten organizations that filed the most AI patents in the world between 1997 and 2017, only one Chinese enterprise was shortlisted, that is, the State Grid Corporation of China (Tsinghua Science and Technology Policy Research Centre 2018).

Table 8 shows that during the same time frame the United States outperformed China by a wide margin in terms of the number of active AI skills, the percentage of top talent in the national active AI skill pool, the amount of aggregate investment in the AI industry, the number of staff in this industry, and the overall number and different types of companies in this industry. Moreover, Chinese AI companies were concentrated in the layer of application, rather than the technologically more sophisticated layers that lay the foundation for AI applications. In addition, according to the same data sources, the aggregate amount of investment in AI chips up to June 2017 in China was 1.3 billion RMB, some 4 per cent of that in the US chip companies (30.8 billion RMB). Capital is not a big constraint for Chinese AI start-ups. In fact, a report released by the Tencent Research Institute (2017a) found that on average, 69 per cent of Chinese AI start-ups received investment from venture capital as compared to 51 per cent of US AI start-ups; it took Chinese AI start-ups 9.7 months to obtain the first round of seed funding (investment in start-ups in exchange for an equity stake in the company) compared to 14.8 months for US AI start-ups. With strong support from the State and avid enthusiasm from venture capital, the development of AI in China will continue to closely follow the tech frontier led by the United States, if not surpass it.

Chinese companies are proactive adopters of AI technologies. According to a BCG report released in 2018, the percentage of Chinese companies that adopted AI in existing business processes or ran pilot AI initiatives exceeded that of other countries, including the United States (Duranton, Erlebach and Pauly 2018). The Chinese Government also takes advantage of AI technologies to streamline public services and to consolidate public security. Chinese financial companies use AI technologies throughout their business processes, from frontline customer services and precise marketing, to intelligent investment consulting, to proactive transaction security protection. Automobile companies use AI technologies to improve drivers' experience, and experiments of various kinds of unmanned vehicles are under way. In the field of healthcare, AI technologies help Chinese doctors to better analyse medical images and to manage the data of their patients. AI technologies are also overhauling the retail industry in the sense that they are recalibrating the management of supply chains, marketing, customer services, and so on.

Table 8. A comparison of the development of AI between China and the United States

	China	United States
Number of AI research articles, 1997-2017	369,588	327,034
Number of high-impact AI research articles, 1997-2017	2,349	2,241
Number of AI patents filed, 1997-2017	1st globally	2nd globally
Number of active AI talents	18,232 (8.9% of the global total)	28,536 (13.9% of the global total)
Percentage of top active AI talent in one country's overall active AI talent	5.4%	18.1%
Aggregate investment in the AI industry to June 2017, in billion RMB	63.5 (33.2% of the global total)	97.8 (50.1% of the global total)
Estimated number of staff in the AI industry in June 2017	39,000	78,000
Number of AI companies in June 2017:	592 (23% of the global total)	1,078 (42% of the global total)
AI chip companies	14	33
AI tech companies	273	586
AI application companies	304	488

- Notes: According to the data source, active AI talent here refers to people who published AI patents or AI research articles in English between 2007 and 2017; top active AI talent refers to active AI talent with the top 10 per cent highest h-index ranking in the world. H-index is the largest number h such that h publications have at least h citations. According to the data source, AI companies can be roughly divided into three groups according to their main businesses: chip/processor companies, tech companies working for solutions such as natural language processing and computer vision, and app companies that develop AI applications such as unmanned driving and drones.
- Sources: Data on patents, research articles and active AI talents from Tsinghua Science and Technology Policy Research Centre 2018; other data from Tencent Research Institute 2017b.

Despite all this, Chinese manufacturing has not made many efforts to unlock the potential of AI technologies. The Chinese branch of SAP, a German-based software solution supplier, analysed the top 300 biggest AI investment projects in China between 2015 and 2018 and found that 23.4 per cent of the investment was in commerce and retailing, 18.3 per cent in unmanned driving, and less than 1 per cent in manufacturing (Deloitte

2018b). But according to a survey which involves some 800 enterprises in Hangzhou, a second-tier city in China, 107 enterprises surveyed (12 per cent) used AI technologies in their operations, most of which were in the machinery, electronics and plastics industries; 597 enterprises had no plan to deploy AI applications in the coming three years from the survey time. With regard to the reasons given by the 107 enterprises for using AI technologies, 81 hoped to boost efficiency, 12 hoped to lower labour costs, another 12 hoped to enhance product quality, and two hoped to lower safety hazards in the workplace (Xiao et al. 2018).

2.3 Product upgrading

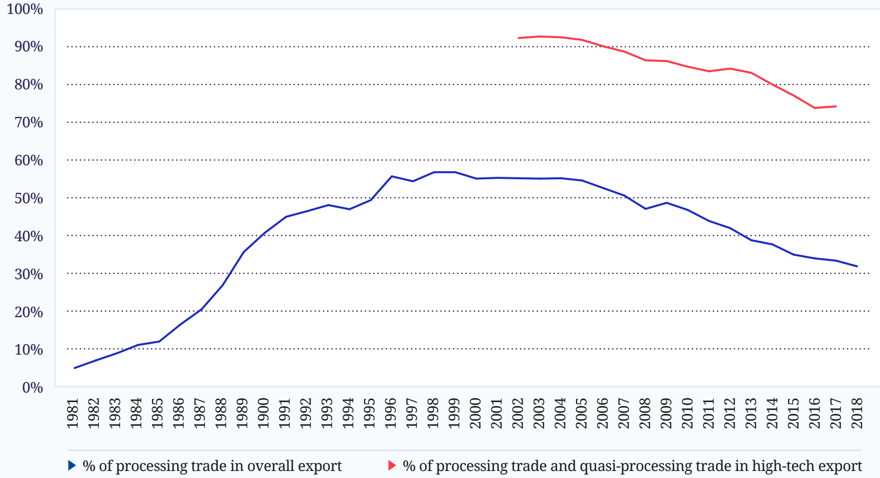
This section examines the extent to which China has achieved product upgrading. In GVC studies, industrial upgrading is dividing into several stages, entailing the shifting of the role of a certain economy from assembly, to original equipment manufacturing (OEM), to original design manufacturing (ODM), and finally to original brand manufacturing (OBM). OEM is a business model that focuses on manufacturing activities, particularly parts and components. ODM adds design capabilities to production. OBM focuses on branding and the sale of own-brand products (Fernandez-Stark, Frederick and Gereffi 2011). Given that product upgrading underpins the escalation of an economy's role in the GVCs, this section showcases the extent of China's product upgrading by focusing on China's shifting roles in GVCs.

As a result of the growing production of parts and components in China, while maintaining dominance as an assembly station in the GVCs China is emerging as an OEM supplier of parts and components. In major mass consumption industries, thanks to technological edge, price competitiveness, or a combination of the two, Chinese companies have increasingly engaged in OBM. Generally, Chinese brands tend to be at the lower end of the global market and are not as lucrative as the global leading brands. That said, in some niche markets such as telecoms equipment and electric cars, Chinese companies are likely to leapfrog their foreign competitors with regard to technological advancement, or have already done so. But the intensified tension between China and the United States is dampening the future of Chinese brands.

2.3.1 Moving up from assembly to OEM of parts and components

Over a decade ago, and to some extent up to the present, China has largely been perceived as the final assembly station in GVCs. An article published in the *New York Times* in 2006 suggests that instead of "made in China", "assembled in China" would be a more

▶ **Figure 16. China's reliance on processing trade, 1981–2018**



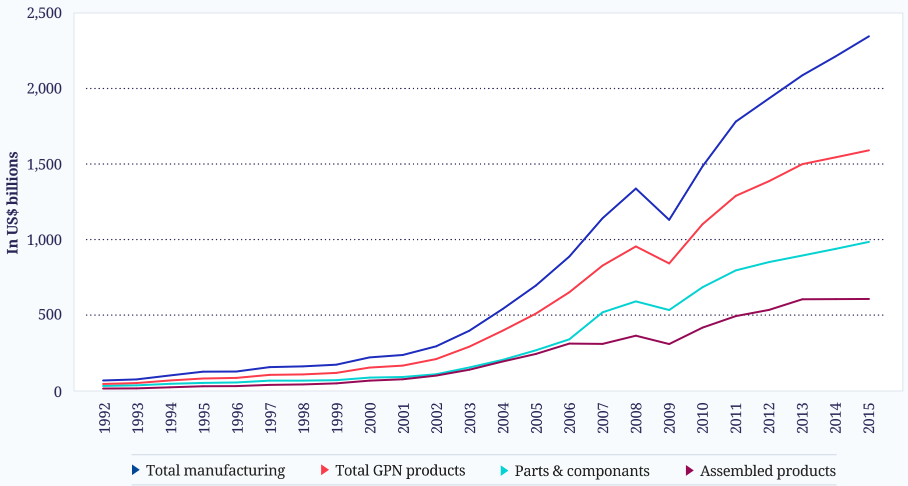
Sources: Data on the percentage of processing trade in overall export between 1981 and 2017 from National Bureau of Statistics 2018a; other data from Ministry of Science and Technology 2019.

apt label to characterize Chinese exports (Barboza 2006). The meagre value that China as an assembly station captures from GVCs is the root cause of China's poor working conditions in export sectors that employ tens of millions of people. The label "assembled in China" certainly held true in 2006. But while this label still holds to some extent, as China increasingly engages in the production of parts and components the relevance of the label "made in China" is increasing. China's changing role in the GVCs of global electronics and automobile illustrates this fact well.

Although China is the largest high-tech exporter in the world, this leading position is largely a myth because assembled high-tech products, made with imported key parts and components, account for the majority of these exports (Xing 2014). Nonetheless, Chinese enterprises are slowly moving away from assembly to OEM of parts and components in the high-tech sector. Figure 16 shows that the share of processing trade and quasi-processing trade[17] in high-tech exports dropped from 92.8 per cent in 2003 to 74.3 per cent in 2017. As shown in figure 17, the share of processing trade in China's overall exports

17 The report series on China's high-tech merchandise trade divides exports in the high-tech sector into three categories: export from processing trade, normal trade, or trade under special supervision from Chinese customs. This third category refers to export from free-trade zones and export processing zones, a high percentage of which is de facto processing trade. To reconcile the categorization of the report series with the reality, this report calls the third category quasi-processing trade.

Figure 17. China's manufacturing exports, 1992–2015



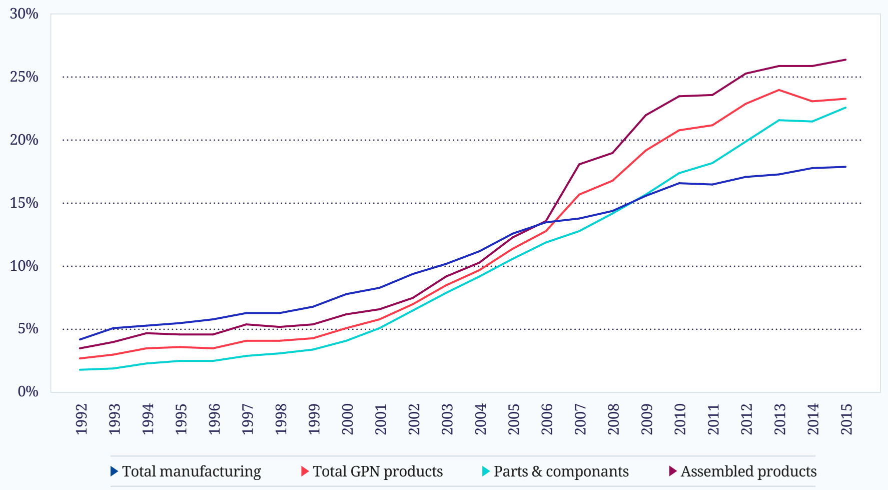
Note: Network products refer to products produced in GPNs. Trade in final assembly is estimated as the difference between the total trade of network products and the trade of parts and components.

Source: Compiled from United Nations Comtrade database, cited from Athukorala 2017.

rose from 5.1 per cent in 1981 to peak at 55.8 per cent in 1996, remained at over 50 per cent until 2008, but had dropped to 32.0 per cent by 2018.

A close look at the composition of China's exports more clearly reveals China's emerging role as an OEM supplier of parts and components. Between 1992 and 2015, exports of manufacturing products, GPN manufacturing products, parts and components, and assembled products, and their share in world manufacturing exports, all showed an upward trend (figures 17 and 18). China has been deeply integrated into the world economy. In those decades, 65–75 per cent of China's manufacturing exports were contributed by GPN products; China's share in world manufacturing exports rose from 4.1 to 17.8 per cent, while its share in world GPN manufacturing exports rose more impressively from 2.6 to 23.2 per cent. Its share in GPNs as a supplier of parts and components has been rising hand in hand with its increasing role in GPNs as an assembly station. Its share in world exports of parts and components rose from 1.7 to 22.5 per cent while its share in world exports of assembled products rose from 3.4 to 26.3 per cent. Although in GPNs its role as an assembly station still outshines its role as a supplier of parts and components, China has been shifting to the latter in the past two decades. With regard to its exports of GPN manufacturing products, the share of parts and components rose from 31.0 per cent in 1992 to peak at 48.5 per cent in 2004, before dropping to 38.1 per cent in 2015; meanwhile, the share of assembled products dropped from 69.0 per cent

▶ **Figure 18. China's share in world manufacturing exports, 1992–2015**



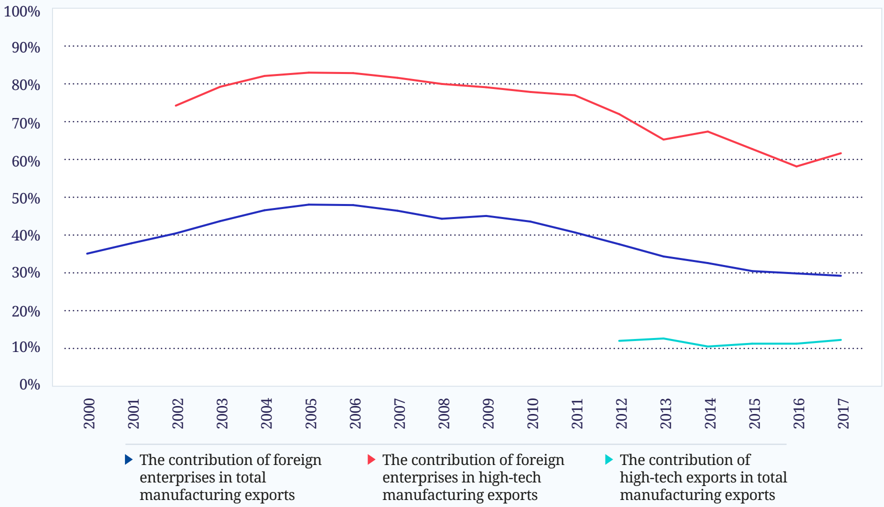
Source: Compiled from United Nations Comtrade database, cited from Athukorala 2017.

in 1992 to bottom at 51.5 per cent in 2004, before rising to 61.9 per cent in 2015. In addition, China's imports of parts and components as a percentage of its total exports of assembled products dropped to 63 per cent in 2015 from the peak level of 94 per cent in 2004 (Athukorala 2017).

It is unclear whether it is foreign or indigenous Chinese enterprises that play the major role in China's escalation to OEM. While foreign enterprises remain major exporters, their importance has been dwindling in recent years, including in high-tech exports. Figure 19 shows the contribution of foreign enterprises in China's manufacturing exports. Between 2012 and 2017, the share of high-tech exports in total manufacturing exports remained stable at some 30 per cent. During China's increasing integration into the world economy, as shown in figures 17 and 18, the contribution of foreign enterprises to China's total manufacturing exports grew from 47.9 per cent in 2000 to peak at 58.3 per cent in 2005, before dropping to 43.2 per cent in 2017. In the high-tech sector, the contribution of foreign enterprises to manufacturing exports grew from 79.3 per cent in 2002, to peak at 86.3 per cent in 2005, before dropping to 69.2 per cent in 2017.

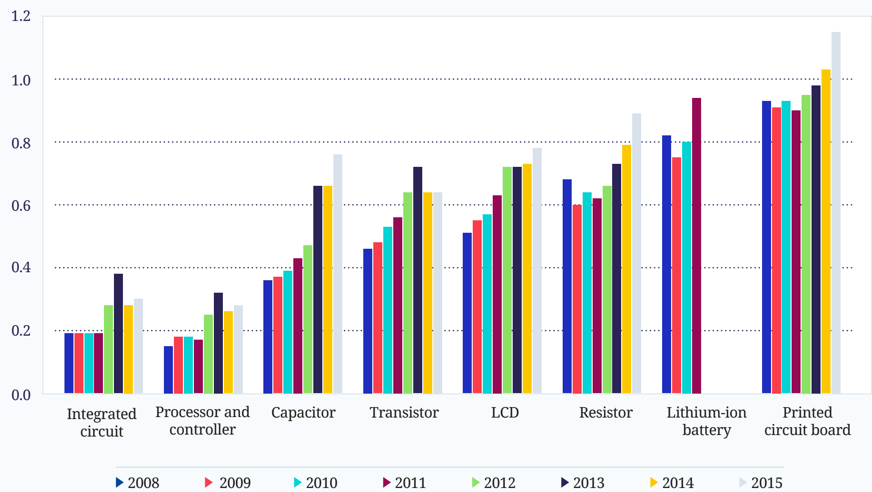
Electronic products, mainly including computer and communication devices, make up over two-thirds of China's high-tech exports (Ministry of Science and Technology 2019).

Figure 19. Contribution of foreign enterprises in China's manufacturing exports, 2000–2017



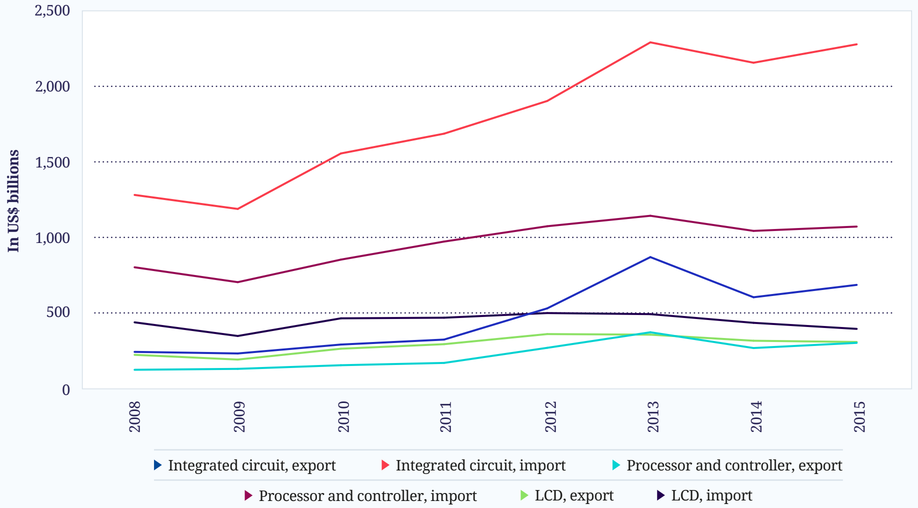
Sources: Ministry of Commerce 2018b; Ministry of Science and Technology 2019; National Bureau of Statistics 2019a.

Figure 20. Ratio of export/import of China's most import-dependent electronic parts and components, 2008–15



Source: Ministry of Industry and Information Technology 2009c-2016c.

▶ **Figure 21. Export and import values of China's most import-dependent electronic parts and components, 2008–15**



▶ Note: This figure omits capacitors and transistors because according to the data source, the import value of the two was far less than that of the three parts and components included in the figure.

▶ Source: Ministry of Industry and Information Technology 2009c-2016c

Thus, the changing role of enterprises in China in the global electronics industry is a good example of China's moving up to OEM of parts and components in GVCs. Between 2005 and 2016 the share of processing trade in China's electronics exports dropped by 30.0 per cent, from 89.2 to 59.2 per cent (Ministry of Industry and Information Technology 2009c–2016c). Figure 20 gives information about all electronic parts and components whose export/import ratio was less than one in 2008. Clearly, between 2008 and 2015, the export/import ratio of all these parts and components showed an upward trend. It is worth noting that the export/import ratio of processors and controllers, the most sophisticated forms of integrated circuit, jumped from 0.15 in 2008 to 0.28 in 2015. Figure 21 shows that between 2008 and 2015, although the import value of integrated circuit processors and controllers, and liquid-crystal displays (LCDs), still far exceeded their export value, the export value also showed an upward trend.

The changing composition of Apple's suppliers better illustrates China's developing role in global electronics. In terms of sales, in 2017 Apple was the largest tech company and the largest consumer electronics supplier in the world (Stoller 2017). In 2012, for the first time, it released its list of top suppliers, consisting of 156 suppliers that represented at least 97 per cent of Apple's expenditures for materials, manufacturing and assembly of its products worldwide in 2011 (Evertiq 2013). The 2019 edition of Apple's supplier list includes 200 suppliers that represent at least 98 per cent of the same expenditures in 2018 (Apple 2019). The key parts and components of consumer electronics can be roughly categorized into six groups: display devices (usually the most expensive part in smartphones), cameras, semiconductor devices such as memory and processors, passive parts and components such as resistors and capacitors, power and skeleton parts and components such as battery and metal frames, and miscellaneous supporting parts and components such as audio parts and components. In Apple's 2012 supplier list, only eight Chinese indigenous enterprises were shortlisted and they provided two categories of components – skeleton and miscellaneous supporting components, which are less valuable than the other categories. In the 2019 supplier list, 27 Chinese enterprises were shortlisted and their footprints covered five categories of key parts and components of consumer electronics (except for passive components) (Ning 2018a).

In fact, it was reported in 2018 that BOE, a Chinese display device maker, accounted for the lion's share in four segments of the world display market: smartphone LCDs, tablet personal computer (PC) displays, notebook computer displays, and monitor displays (*China Daily* 2018). Moreover, although Korean brands such as Samsung and LG continued to dominate the global organic light-emitting diode display (OLED)[18] market, BOE entered the OLED display supplier lists for Huawei's premium smartphone model Mate 20 Pro (Valiyathara 2018). Chip design were once monopolized by players in the developed world. Now the monopoly has been broken by Chinese companies. For example, while the vast majority of chips in Huawei phones were still bought from foreign brands, in September 2018 Huawei released the first seven-nanometre smartphone chipset in the world. Chipset at this size is sought after by international giants, including the industry leader Qualcomm (Sin 2018).

China has also been moving towards OEM of parts and components in the automobile industry. Between 1998 and 2014 the ratio between export value and import value of auto parts in China increased from 0.6 in 1998 to peak at 2.4 in 2007, before dropping to 1.7 in 2016 (Chinese Association of the Automobile Industry 2017). It is not clear whether it is Chinese or foreign enterprises that dominate the export of auto parts. According to a survey that covered over 55,000 of some 100,000 auto parts companies in China, in 2017 indigenous auto parts companies contributed 72 per cent of the industrial revenue and took 53 per cent of the industrial profit, while joint ventures and foreign companies in China contributed 28 per cent of the industrial revenue and took 47 per cent of the industrial profit in the Chinese market (Wan 2018). In other words, indigenous companies are at the lower end of the auto parts market in China.

18 OLED displays are thinner and more efficient than LCDs.

2.3.2 Towards OBM

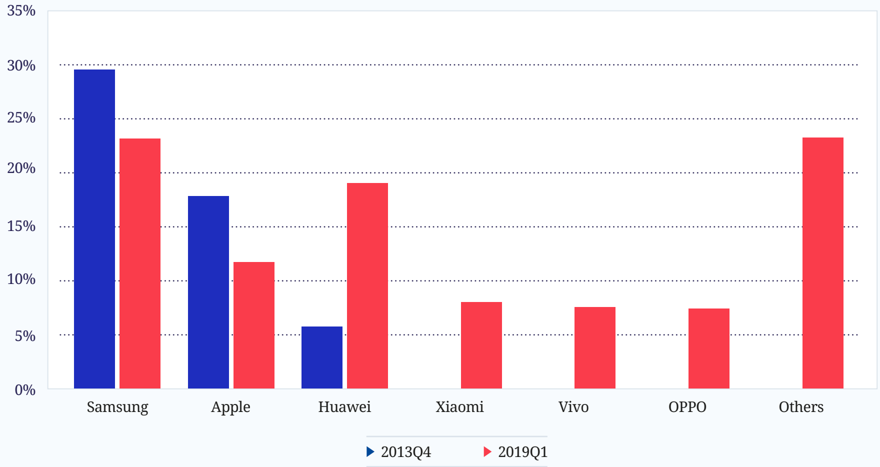
In several industries of mass consumer goods, some Chinese companies have moved beyond OEM and successfully engaged in OBM. The rise of Chinese brands in these industries on the one hand supplants their foreign counterparts in the domestic market, and on the other hand manages to establish a foothold in the global market. Nonetheless, owing to the fact that Chinese-brand products are still at the lower end of the world market, their expansion in world market share fails to lead to comparable growth in profit share. Home appliances, consumer electronics and automobiles are three major durable mass consumption industries. It is reported that in terms of market share, 2016 was the seventh year Chinese brand Haier topped the global home appliance market (Haier 2016).

This section focuses on the performance of Chinese brands in ICT equipment and automobiles. Their performance in these industries represents two different levels of product upgrading. Leading Chinese ICT equipment companies have managed not only to capture market share from foreign brands in the domestic market, but also to establish a foothold in the global market; their products have entered the global premium market, albeit in the lower price range. In contrast, gasoline automobiles still dominate the global automobile market, but leading Chinese gasoline automobile companies only manage to enlarge their domestic market share by the edge of price competitiveness and are far from penetrating into the global market; Chinese-brand gasoline automobiles are concentrated at the lower end of the domestic market. Nonetheless, in the niche market of electric cars, Chinese makers not only dominate the domestic market but also rival their foreign counterparts in the global market, and are likely to leapfrog them in the future. The intensified tension between China and the United States has overshadowed the prospects of China's top brands by creating barriers to their international penetration and disturbing their supply chains. The excessive reliance on foreign suppliers for key technologies has rendered Chinese high-tech brands vulnerable amidst the Sino-US trade war. It remains unclear whether this ongoing tension will be a catalyst or hindrance for indigenous innovation in China.

The ICT equipment industry

This section examines the rise of Chinese brands in the world market in the case of smartphones, PCs and telecoms equipment. In terms of shipped units, Chinese smartphone brands are gaining ground in the world market and even more so in the domestic market. In the fourth quarter of 2013, the top five smartphone brands that had the largest market share in the world were Samsung, Apple, Huawei, Lenovo (a Chinese brand), and LG electronics (Gartner 2014). Figure 22 shows the market share of the global top six smartphone brands in the first quarter of 2019. Of these, four were Chinese brands,

▶ Figure 22. World smartphone market share, by shipped units, 2013Q4 and 2019Q1

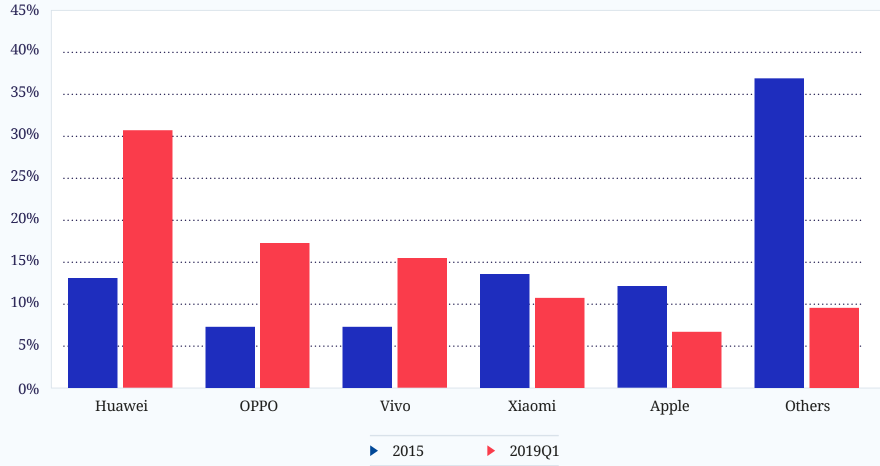


- Note: 2013Q4 refers to the fourth quarter of 2013.
- Sources: Data on 2013Q4 from Gartner 2014; data on 2019Q1 from IDC 2019.

including Huawei, Xiaomi, Vivo and OPPO. Between the fourth quarter of 2013 and the first quarter of 2019, the market share of the Korean brand Samsung dropped from 29.5 to 23.1 per cent while the market share of Apple plunged from 17.8 to 11.7 per cent; in contrast, the market share of Huawei soared from 5.7 to 19.0 per cent; Xiaomi, Vivo, and OPPO (not even shortlisted among the top smartphone vendors in the fourth quarter of 2013) ranked fourth, fifth, and sixth in the new list, with 7 to 8 per cent of world market share. In the Western European smartphone market in the third quarter of 2018, Huawei was the second most popular brand after Samsung (Savov 2018); in the Indian smartphone market in 2018, Xiaomi was the most popular brand (Counterpoint 2020a). As shown in figure 23, the global top two smartphone brands Samsung and Apple are marginalized in the Chinese market thanks to the rise of domestic brands. In the first quarter of 2019, the market share of Huawei in China stood at an staggering 34.0 per cent, well beyond its share in the world market; in contrast, the market share of Apple in China was merely 7.4 per cent, below its share in the world market; the world leader Samsung was not even shortlisted among the top five smartphone vendors in China.

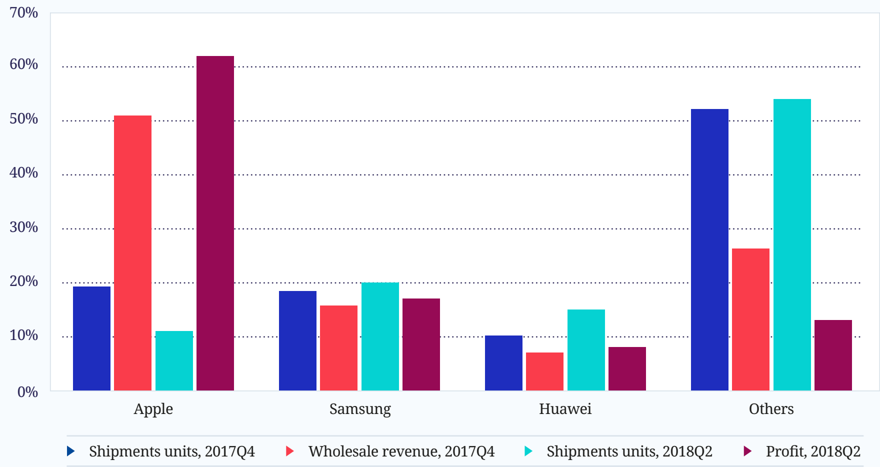
But in terms of the value captured from the global smartphone GVCs, Apple as the leader of the industry is far from being challenged. Despite its shrinking market share, Apple continues to scoop the lion's share from the global smartphone profit pool. It is calculated that between 2013 and 2017, Apple's share in profit from the global smartphone industry

Figure 23. Chinese smartphone market share, by shipped units, 2015 and 2019Q1



Sources: Data on 2015 from Guan, Tang and Xu 2016; data on 2019Q1 from Canalys 2019.

Figure 24. World smartphone market and profit share, Apple, Samsung and Huawei, 2017Q4 and 2018Q2



Sources: Data on 2017Q4 from Jones 2018.; data on market share in 2018Q2 from Counterpoint 2020b; data on profit share in 2018Q2 from Counterpoint 2018a.

remained above 60 per cent and reached a staggering 90 per cent in 2015 (Jones 2018). In both in the fourth quarter of 2017 and the second quarter of 2018, Apple remained the only smartphone brand in the world whose revenue and profit share was higher than its market share (figure 24). The discrepancies between revenue, profit and market shares for Huawei were larger than those for Samsung, but smaller than other miscellaneous brands. Table 9 partly explains the landscape of figure 24. The premium segment of the global smartphone market refers to smartphones sold at over US$400 per unit. In the second quarter of 2018, the premium smartphone segment contributed some 20 per cent of global smartphone sales by volume. Table 9 shows the distribution of different brands in different price segments of the global premium smartphone market in the second quarter of 2018. It is clear that the higher the price segment, the bigger the market share of Apple. In contrast, Chinese brands, including OnePlus, occupied the lower end of the global premium smartphone market.

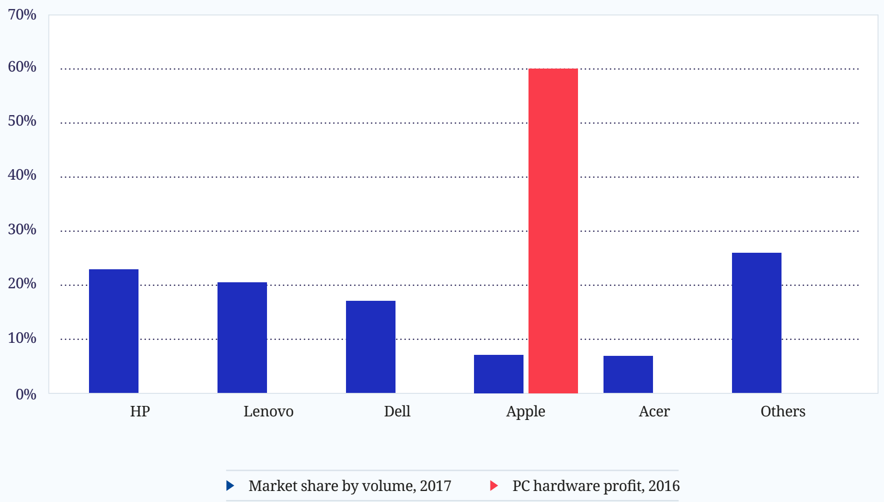
Similarly, Chinese-brand PCs also have a large market share and a smaller profit share in the global PC industry. As figure 25 shows, in 2017 the Chinese brand Lenovo had the second largest market share in the global PC market, only slightly lower than that of HP.

▶ Table 9. World premium smartphone market share, by price segment, 2018Q2

<table>
<tr><th>Price segment (US$) and sales share by volume in the premium market</th><th colspan="7">Brands and their market share (by volume)</th></tr>
<tr><td rowspan="2">>800, 20%</td><td colspan="4">Apple</td><td colspan="3">Other</td></tr>
<tr><td colspan="4">88%</td><td colspan="3">12%</td></tr>
<tr><td rowspan="2">600-800,35%</td><td colspan="2">Apple</td><td colspan="2">Samsung</td><td colspan="3">Other</td></tr>
<tr><td>44%</td><td>41%</td><td></td><td></td><td colspan="3">15%</td></tr>
<tr><td rowspan="2">400-600, 45%</td><td>Apple</td><td>OPPO</td><td>Samsung</td><td>Huawei</td><td>Xiaomi</td><td>OnePlus</td><td>Other</td></tr>
<tr><td>22%</td><td>22%</td><td>16%</td><td>14%</td><td>6%</td><td>5%</td><td>15%</td></tr>
<tr><td>Total premium market</td><td>43%</td><td>10%</td><td>24%</td><td>9%</td><td>3%</td><td>2%</td><td>9%</td></tr>
</table>

▶ Source: Counterpoint 2018b.

▶ Figure 25. World PC market and profit shares, 2016 and 2017



Source: Data on the market share from IDC 2018; data on the profit share of Apple from Dediu 2016.

▶ Figure 26. World telecoms equipment market share, by revenue, 2015–18

Note: Data on 2018 refer to 2018Q1-2018Q3.

Source: Yu 2018.

Apple accounted for only 7.1 per cent of the global market share in 2017. In 2016, Apple had a similar market share and captured over 60 per cent of the global PC hardware profit. Thus, Lenovo's profit share was highly likely to be lower than its market share.

In recent years, Chinese brands have managed to achieve the lion's share in the global telecoms equipment market. Between 2015 and 2018, Huawei was the only major telecoms equipment maker that gained market share (figure 26). In addition to Huawei, Chinese vendor ZTE was also among the top five vendors in the global telecoms equipment industry. Huawei is not only the world's biggest telecoms equipment maker but also its most advanced (Kynge and Fildes 2020).

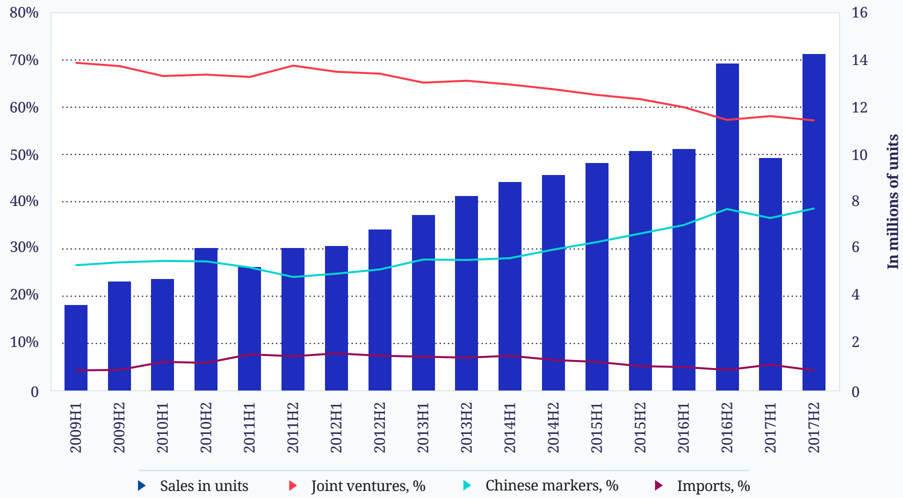
The automobile industry

When it comes to brand-building, Chinese automobile enterprises have not been as successful as ICT equipment enterprises. So far, Chinese indigenous gasoline carmakers have largely failed to penetrate the world market or to dominate the domestic market, although in recent years they have managed to enlarge their share in the domestic market. With regard to electric cars, thanks to their strength in battery technologies, Chinese makers not only dominate the domestic market but also rival their foreign counterparts in the world market. It is worth noting that foreign automakers that want to make cars in China have had to do so through a 50-50 joint venture with a Chinese car company; this requirement was cancelled in early 2018 for limited types of cars, including new energy cars, and is to be entirely phased out by 2022 (Bradsher 2018b).

Overall, Chinese carmakers are small and rely on the domestic market. According to JATO, a market consultancy specialized in the automobile industry, of the top 25 most popular brands of passenger cars and light commercial vehicles in the world, only one wholly Chinese-owned brand was shortlisted in 2017: Geely ranked 19th with sales in units accounting for 15.9 per cent of the brand ranked first, Toyota. Another two Sino-foreign joint ventures were shortlisted and ranked 22th and 25th respectively. Most of their sales were in the Chinese domestic market, which has grown to be the world's largest car market (Demandt 2017). With this expansion, the market share of Chinese brands in the domestic market increased from 26.5 per cent in the first half of 2009 to 38.5 per cent in the second half of 2017, squeezing the market share of joint ventures by 12 per cent (figure 27). Nonetheless, Chinese indigenous carmakers are at the lower end of the domestic market. As shown in table 10, the lower the price segment, the higher the market share of Chinese-brand cars.

New energy cars are celebrated by some people as the future of motoring (McCarthy 2019). This sector is also listed in the MIC 2025 as one of the ten key fields that receive prior support from the Chinese Government (State Council 2015a). While Chinese makers lag behind their foreign counterparts in delivering traditional gasoline cars, they take

Figure 27. The Chinese market for passenger cars and light commercial vehicles, by type of manufacturer, 2009–17



Note: 2009H1 refers to the first half of 2009.

Source: DaaS-Auto 2018.

the lead in the global niche market of new energy cars. It is calculated that in Canada, China, Europe, Japan and the United States combined, the sales of battery-electric vehicles and plug-in hybrids as a proportion of total vehicle sales rose from 1.1 per cent in 2016 to 1.7 per cent in 2017, much lower than that in China alone which stood at 2.3 per cent in January 2018 (Scutt 2018). In 2017, over 1.8 million new energy cars (including battery-electric vehicles, plug-in hybrids, and fuel cell vehicles) were used in China, over half the global stock. In the same year, 46.7 per cent of world sales of new energy cars (by volume) was contributed by China (Feng and Wan 2018). The strong demand from the Chinese market has fuelled the rise of Chinese indigenous new energy carmakers. In 2017, of the top 20 most popular electric car models in the world, nine bore Chinese brand names and three of them were shortlisted in the top ten, including the first place. In the same year, of the top 20 most popular electric car brands in the world, nine were Chinese brands, including BYD that ranked first on the list (Yang 2018). In 2018, Chinese new energy carmakers held over 90 per cent of the domestic market (*Workers' Daily* 2018.). The tiny premium market for new energy cars in China, however, is dominated by European, Japanese and US brands (*People's Daily Online*, 2018).

Chinese-brand electric business cars have also established a foothold in the world market. Thanks to its advanced battery technologies, BYD is the global leader in the

Table 10. Chinese market for passenger cars and light commercial vehicles, by price segment, 2017 (January–July)

Price segment per unit (RMB)	Chinese brands (%)	German brands (%)	Japanese brands (%)	US brands (%)
≥800,000		67.0	8.8	6.3
720,000≤TP<800,000		85.6	4.3	3.9
640,000≤TP<720,000		73.9	5.2	7.4
560,000≤TP<640,000		71.5	7.8	7.4
480,000≤TP<560,000		65.2	18.4	11.8
400,000≤TP<480,000		76.6	7.5	8.4
320,000≤TP<400,000	0.1	57.5	11.0	18.6
240,000≤TP<320,000	3.8	45.0	27.6	21.1
160,000≤TP<240,000	10.3	28.3	30.8	21.9
80,000≤TP<160,000	40.8	16.2	21.6	11.9
50,000≤TP<80,000	70.0	11.1	7.7	5.1
TP<50,000	98.5		1.5	
Overall	39.3	21.9	18.7	12.1

- Note: TP= total price (before tax). Sino-foreign automobile joint ventures mostly produce cars bearing foreign brands.
- Source: DaaS-Auto, 2017.

battery-electric bus industry with over 35,000 buses in service in more than 200 cities in some 50 countries (BYD 2018). It was reported in early 2018 that BYD had provided some 50 per cent of the pure electric buses in the United Kingdom and 90 per cent of the pure electric buses in London (Shea 2018). BYD also exports or leases electric buses to Canada, Chile, Japan and the United States, among others. In fact, BYD has production facilities for electric buses in France and Hungary (Xinhuanet 2017). In addition, BYD, together with other Chinese electric carmakers such as Geely, has provided electric taxis to continental Europe and the United Kingdom (BYD 2014; *Global Construction Review* 2017).

BYD's leading position in the global new energy car industry is likely to be further strengthened by its progress in battery technologies. On 29 March 2020, BYD released its all-new Blade Battery. Currently, electric cars are mainly powered by two types of batteries, either the ternary lithium battery or the lithium ferrophosphate/lithium iron phosphate (LFP) battery. The ternary lithium battery has long been favoured because it beats the latter in energy density, thus allowing greater cruising range. However, it has an underlying downside: when it is damaged it may catch fire. In contrast, the conventional LFP battery has lower energy density, but is also less susceptible to catching fire. The Blade Battery is a new kind of LFP battery. It is much safer than both ternary lithium batteries and conventional LFP batteries. It also has a comparable cruising range to that of the most advanced ternary lithium battery so far. Equipped with this battery, the Han EV, BYD's flagship sedan model launched in June 2020, is said to have a cruising range of 605 kilometres (BYD 2020). In comparison, Model S, Tesla's signature and longest-range model which uses ternary lithium batteries and is BYD's biggest competitor, was reported to have a cruising range of 370 miles (approximately 595 kilometres) in April, 2019 (Tesla 2019).

The vulnerability of Chinese brands amidst geopolitical tensions

The intensified tension between China and the United States is dampening the future of Chinese brands, by creating barriers for their penetration into international markets and disturbing their supply chains. After the Sino-US trade war was ignited in early 2018, by mid-May 2019 the US Government had imposed a tariff of 25 per cent on US$250 billion worth of Chinese goods and had threatened tariffs on $325 billion more; the Chinese Government had imposed tariffs of 5 to 25 per cent on US$110 billion worth of US goods. The trade war then went back and forth several times. On 15 January 2020, the United States and China signed the phase one trade deal (US-China Economic and Trade Agreement). This deal cancelled the United States's 15 per cent tariffs originally set to take effect on 15 December 2019 that would have affected Chinese-made imports worth US$160 billion; the deal also halved the 1 September 2019 tariff from 15 per cent to 7.5 per cent on US$120 billion worth of Chinese products. In return, China agreed to purchase an additional US$200 billion worth of US goods and services over the next two years, from a baseline of US$186 billion worth of purchases in 2017. The remaining tariffs include the 25 per cent US tariffs on US$250 billion worth of Chinese products, and China's 5 to 25 per cent tariffs on US$110 billion worth of US goods (Wong, Cyrill and Zhang 2020; Wong and Koty 2020). Given that the US is not only a big market for Chinese brands but also where Chinese manufacturers source key parts and components, the escalating tariffs will hurt Chinese brands and their Chinese contract manufacturers badly. Moreover, asserting that Chinese companies could be linked with the Chinese Government and may be employed by the latter in espionage, the US Government has banned or has been considering banning multiple Chinese companies from selling in the United States or acquiring parts and components and software from US companies.

With regard to telecoms equipment, in 2014 the US Government banned Huawei from bidding for government contracts (Yueh 2014). Under pressure from the United States, in 2018 Australia and New Zealand announced they would exclude Huawei from building their 5G networks (BBC 2019a); Japan announced that Huawei and ZTE would be excluded from government procurement of cellular networking hardware (Tao 2018). In April 2018, the US Government banned ZTE from obtaining critical parts and components, and software, from US companies. The ban was lifted three months later after ZTE replaced its board, paid a US$1 billion fine, and put another $400 million in escrow (Kastrenakes 2018). On 16 May 2019, the US Government repeated the same tactics with Huawei, banning it from purchasing parts and components from US companies (Bureau of Industry and Security 2019); on 20 May the US Government postponed the ban to 19 August 2019 (Barrett 2019). In addition, it was reported in late May 2019 that the US Government was considering barring Hikvision and Dahua, two Chinese companies that controlled one-third of the global market for video surveillance and had multiple high-profile clients in both Europe and the United States, from purchasing US technology (Carville and Kahn 2019). Also in May 2019, the US Government issued an alert warning that Chinese-made drones (with DJI as the industrial leader, which had a market share of 74 per cent globally and 79 per cent in the US and Canada in 2018 (Shortell 2019)) could pose a cyber-espionage risk to their users (BBC 2019b).

The predicament of ZTE and Huawei when facing these trade bans highlights the vulnerability of high-tech Chinese brands with their reliance on foreign companies for key technologies. In a globalized world, brands or their contract manufacturers source parts and components from all over the world and Chinese companies are no exception. For example, the smartphones of both Apple and Huawei use chips designed by Qualcomm and manufactured by TSMC, a Taiwanese company (Lee and Tung 2019). That said, when it comes to the most technologically sophisticated parts and components and software, as latecomers in the global ICT industry Chinese brands tend to rely more on external suppliers than their competitors in advanced economies do. And these external suppliers tend to be foreign companies rather than indigenous Chinese companies. To take Huawei, for example: Huawei has invested heavily in R&D. In 2017/18, the company spent US$13.1 billion in R&D, making it the fifth largest R&D investor in the world, after Samsung (US$15.5 billion), Alphabet (Google's parent company, 15.4 billion), Volkswagen (15.1 billion), and Microsoft (14.1 billion). In fact, when it comes to R&D intensity (R&D expenditure as a percentage of sales), Huawei overtook all the above four companies with a R&D intensity of 14.7 per cent, though this percentage is not as high as that of some companies that spent a smaller size of investment on R&D such as Intel (European Commission 2019). As a result, on the one hand, as mentioned earlier, Huawei has made inroads into chipset design, one of the most sophisticated technologies in the ICT industry. On the other hand, Huawei's reliance on foreign suppliers for key technologies is fundamentally unchanged. In November 2018 Huawei released for the first time a list of 92 suppliers that it considered to be core among its large numbers of suppliers, including 33 US companies, 25 mainland China companies, 11 from Japan, 10 from Taiwan, and 13 from Germany, Hong Kong (China), Republic of Korea, and other countries and regions. Among the 33 US companies were Qualcomm, Intel and Microsoft (Zhang 2018b).

After the US Government banned Huawei from purchasing from US suppliers on 16 May 2019, Google was the first to react, suspending business with Huawei a few days later on 20 May. While current Huawei phones were unaffected, future Huawei phones would lose access to Google's proprietary Android operating system (but still can access open-source Android), Google's updates to Android, the Google Play Store, Chrome, Gmail and YouTube, among others, which could effectively hobble Huawei's smartphone business outside China (Moon 2019). It was reported on 20–21 May that Intel, Qualcomm, Xilinx and Broadcom, all US companies and among the world's leading chip designers, had cut off dealings with Huawei (King, Bergen and Brody 2019). It was reported on 22 May that ARM, a chip designer headquartered in the United Kingdom and owned by Japanese telecoms giant Softbank, had suspended business with Huawei. ARM's technology describes how the chips' transistors should be arranged, and so far all Huawei's released and in-process chips have been based on ARM technology; in addition, Huawei has obtained a permanent licence over key ARM technology. While this ban does not affect Huawei's existing chips, it prevents Huawei from turning to ARM for future updates (Cook 2019; Lee 2019).

It remains unclear whether the intensified tension between the United States and China will be a catalyst or a hindrance to indigenous innovation. What we do know is that in response to the ban by Google, Huawei announced that since 2012 it has been developing its own operating system called Hongmeng for smartphones and computers (Li 2020).

3 Social upgrading amidst technological upgrading in China

Has the ongoing technological upgrading led to social upgrading in China? This chapter examines this question by looking at how the current technological upgrading has affected workers in China and how workers have been affected differently. The first section provides an overview of the changing employment landscape in China in terms of both the quantity and quality of employment. The second and third sections examine how process and product upgrading have affected workers in China respectively.

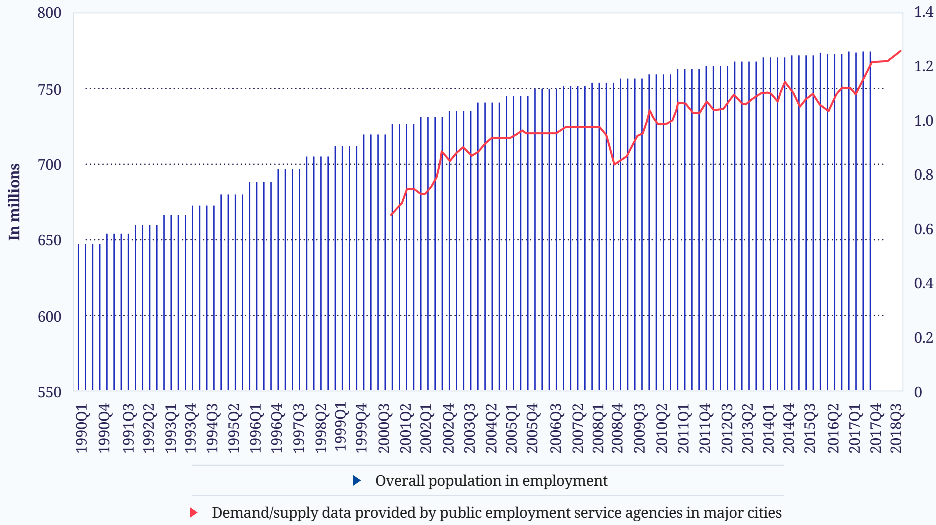
It is worth noting that owing to the limitation of data, this chapter largely omits the price and demand effect and the profit and reinvestment effect of technological upgrading, as well as the impacts of technological upgrading in advanced economies on China's role in the GVCs, which certainly have ramifications for the working population in China. Rather, the chapter focuses on the substitution, complementation, and productivity and distribution effect of technological upgrading on workers. The chapter also cannot examine the labour implications of the whole range of technological upgrading mapped in Chapter 2, while in reality all such upgrading affects working conditions to some extent.

3.1 The changing employment landscape: An overview

This section provides the necessary context to evaluate the labour impacts of technological upgrading in present-day China, which also reflects the effects of multiple transformative factors in the Chinese labour market, including technological transformation. Between 1991 and 2017 the population in employment gradually increased by 20 per cent, from 647.5 million to 776.4 million (figure 28); according to serial data provided by public employment service agencies in some 100 major cities in China, between 2001 and 2018 the Chinese labour market increasingly tightened: before 2010, in these cities jobseekers outnumbered openings while after 2010 this situation was reversed; in 2018, on average, for each jobseeker there were over 1.2 jobs. That said, given the continual slowdown of the Chinese economy, which was further decelerated by the coronavirus disease that struck China in late 2019 (COVID-19), it is difficult to be optimistic about the current employment prospects of Chinese workers.

Many factors have contributed to the changing employment landscape in China. Apart from technological upgrading, demographic transition is a prominent one. It is reported that in 2011 for the first time in decades the working-age population in China dropped

▶ **Figure 28. The changing labour market in China, 1990–2018**



Note: Data on population in employment are on an annual basis; data on demand/supply are on a quarterly basis.

Sources: National Bureau of Statistics 2019a; MOHRSS 2019.

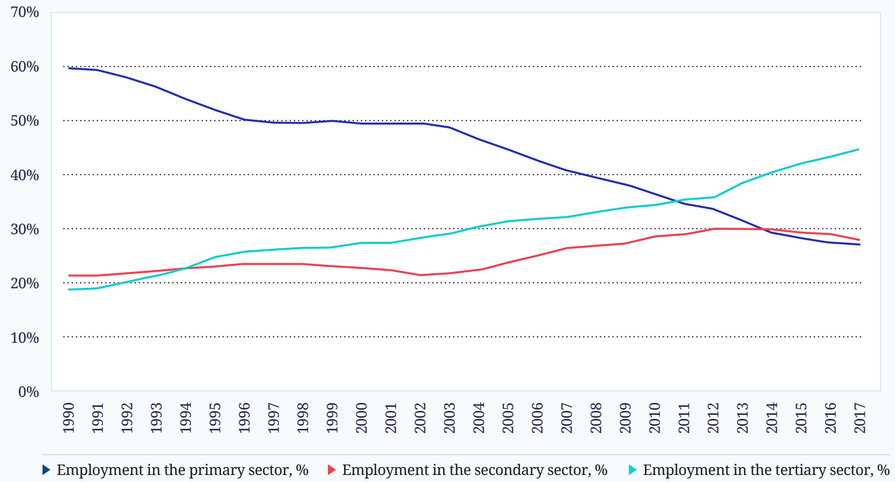
(Cai 2014). Moreover, according to the World Bank, in 2017, two years after China abolished the one-child policy, the fertility rate (births per woman) of China was 1.6, well below the replacement-level fertility rate of 2.1 (World Bank 2019e). It is reported that the two-child policy has been ignored by potential parents (Kuo and Wang 2019). According to a sample survey of 1 per cent of Chinese population conducted by China's National Bureau of Statistics in 2015, the then fertility rate was merely 1.047. There is no consensus on the present real fertility rate in China (Wang and Jiang 2019).

This section is organized into two parts which examine the changing employment structure and working conditions respectively.

3.1.1 The changing employment structure

In recent decades the employment structure in China has undergone dramatic transformations. In the early 1990s the primary sector accounted for most employment; in present-day China the tertiary sector provides the lion's share. Skilled workers remain a small fraction of Chinese employment. Professionals and technical staff have seen improved gender balance over the years, while the primary sector has witnessed feminization and the secondary sector has witnessed masculinization. Thanks to technological upgrading,

Figure 29. The changing employment structure in China, by sector, 1990–2017

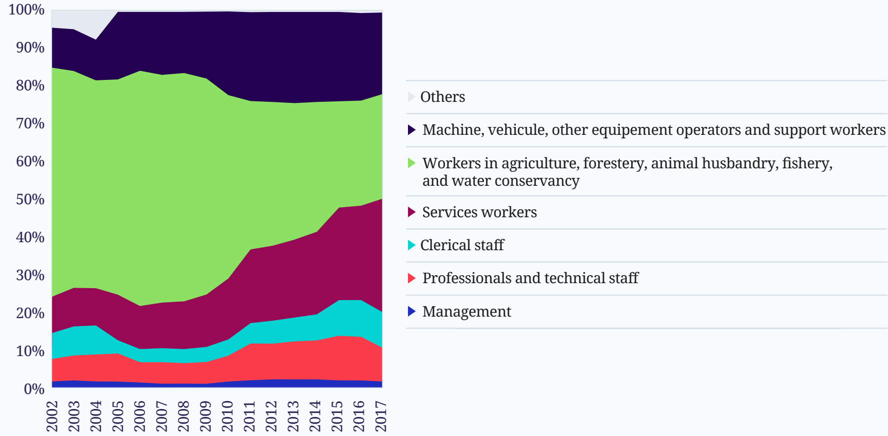


Source: National Bureau of Statistics 2019a.

employment in the high-tech sector has grown rapidly. Present-day China is experiencing a shortage of skilled labour, particularly low-skilled labour in the secondary sector (mainly manufacturing and construction), and more so in the tertiary sector. Eastern China is likely to experience a more severe labour shortage than the other parts of China. Engineering graduates increasingly seek jobs outside manufacturing. Peasant workers, the backbone of low-skilled workers in China, have been opting out of manufacturing and going into services. Nonetheless, structural unemployment always exists and the cooling economy may bring new unemployment pressures. It is important to be aware of the co-existence of the shortages of both skilled and low-skilled labour in manufacturing, workers' opting out of manufacturing in preference for services, persistent structural unemployment, and looming unemployment pressure in China when evaluating the impacts of technological upgrading on Chinese workers and stakeholders' response to these impacts.

Between 1990 and 2017 the proportion of employment in the primary sector dropped significantly from over 60 to 27 per cent, in the secondary sector it rose slightly from 21.4 to 28.1 per cent, while the tertiary sector saw a dramatic rise from 18.5 to 44.9 per cent (figure 29). The proportion of workers in the tertiary sector exceeded that in the secondary sector by 1994 and that in the primary sector by 2010. As shown later in this section, this scenario is partly due to workers' fleeing from manufacturing towards services.

Figure 30. The changing employment structure in China, by profession, 2002–17

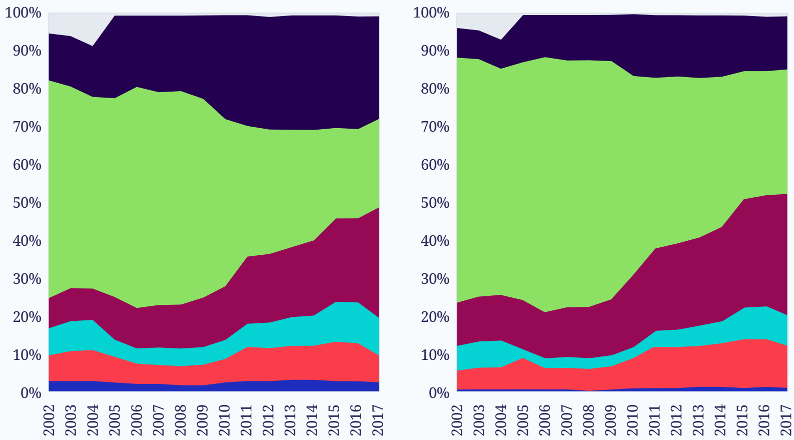


Source: National Bureau of Statistics 2003c–2018c.

The changing employment structure by profession better reflects the changing technological content of economic activities and thereby the labour implications of technological upgrading. Figure 30 shows that between 2002 and 2017 the proportion of professionals and technical staff in overall employment rose from 6.0 per cent in 2002 to peak at 11.7 per cent in 2015 before dropping slightly. During the same time frame, the proportion of workers in agriculture, forestry, animal husbandry, fisheries and water conservancy in overall employment dropped sharply from 60.8 to 27.6 per cent; the proportion of all low-skilled staff in manufacturing and services rose dramatically from 27.2 to 61.1 per cent.

The employment structure in China is gendered. Owing to the lack of data on the gender structure of overall employment in China and the facts that men have a higher social labour participation rate than women and that China has continually produced significantly more male children than female ones, it would be hasty to compare the left and right parts of figure 31 and jump to the conclusion that a certain sex is more represented in a certain profession. Nonetheless, this comparison does indicate trends. First, between 2002 and 2017 professionals and technical staff achieved better gender balance: the proportion of professionals and technical staff among male workers in China rose from 6.9 per cent in 2002 to 10.7 per cent in 2015 while among female workers it rose from 5.0 per cent in 2002 to 13.0 per cent in 2015. In contrast, machine, vehicle,

▶ Figure 31. The changing employment structure in China, by profession and sex, 2002–2017



▶ Note: Male: left, female: right. The legends shown in figure 30 also apply to this figure.

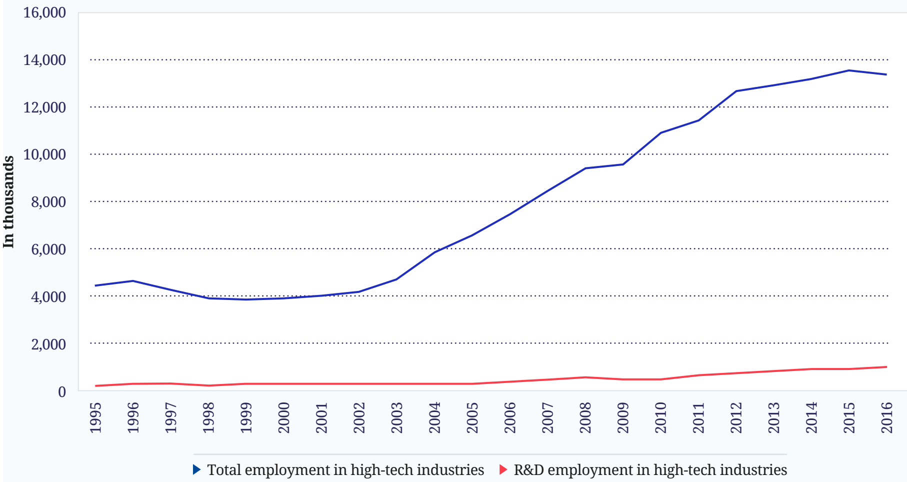
▶ Source: National Bureau of Statistics 2003c–2018c.

other equipment operators and support workers experienced masculinization: during the same time span, the proportion of workers in these positions among male workers rose from 12.9 per cent in 2002 to 30.4 per cent in 2013 before dropping to 27.3 per cent in 2017 while among female workers it only rose from 7.8 per cent in 2002 to 16.7 per cent in 2011 before dropping to 14.4 per cent in 2017. However, the primary sector witnessed feminization: between 2002 and 2017, the proportion of these workers among female workers dropped from 65.1 to 32.9 per cent while among male workers it dropped from 57.2 to 23.5 per cent.

Technological upgrading has powered the expansion of employment in the high-tech sector.[19] Figure 32 shows the rapid increase in this sector since the early 2000s. Nonetheless, the sector remains quite small in scale. In 2016, it provided jobs for 13.4 million people, or 2.4 per cent of the combined employment in the secondary and tertiary sector. Moreover, as shown in figure 32, between 1995 and 2016 the number of R&D staff in China's high-tech sector grew only slightly.

19 The high-tech sector in the series of the *Chinese Yearbook of High-tech Industries* refers to pharmaceuticals, medical devices, precision measuring tools, aviation, astronautics, communication devices, electronics and office equipment.

Figure 32. Employment in high-tech industries in China, 1995–2016

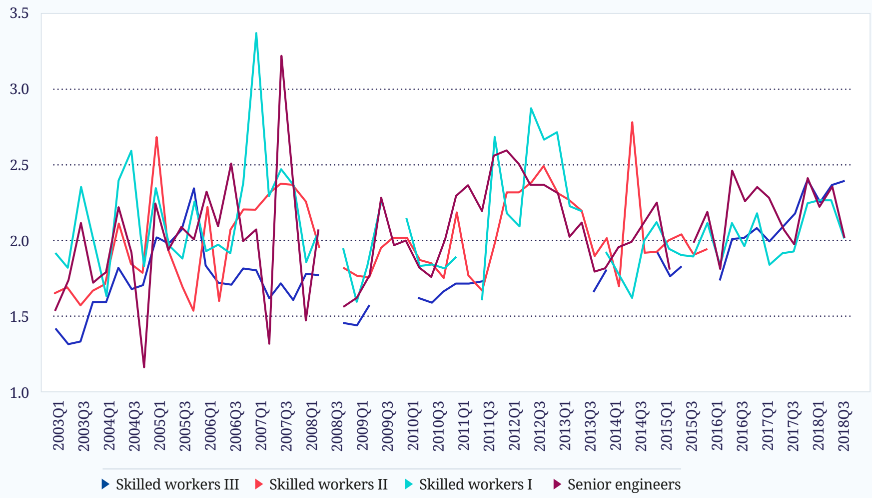


Source: National Bureau of Statistics 2003d–2017d.

Technological upgrading has contributed to the chronic skilled labour shortage in China. Figure 33 shows the demand/supply ratio of the top three or four categories of skilled workers that suffered the most severe labour shortages between 2003 and 2018. During this time frame, the demand for skilled workers in all categories constantly exceeded supply; moreover, roughly, the higher the skill qualification was, the higher the demand/supply ratio. According to Manpower, a leading global human resource solution supplier, 13 per cent of employers surveyed in China reported a skills shortage in 2018, up from 10 per cent in 2016; of the top ten categories of positions that suffered from the largest labour shortages, the top six (except for the top one, that is, sales representatives) and the ninth were for skilled applicants (Manpower 2018). Table 11 shows the estimated labour shortages in the ten key fields listed in the MIC 2025. Of these, new-generation ICT, equipment for electricity generation and distribution, high-end machine tools and robots and new materials will witness a skills gap on a scale of millions in the near future; and this gap will enlarge between 2020 and 2025.

That said, particularly given the huge media (and also academia) attention to the labour displacement potential of technological advances, it is worth noting that present-day China also has a shortage of low-skilled labour, especially in services, in its large cities that are traditional recipients of migrant labour. Table 12 gives a concrete flavour of

▶ **Figure 33. Ratio of demand/supply of skilled workforce in China, 2003–18**



▶ Note: Skilled workers here refers to all skilled workers in non-engineering fields. Skilled workers I: workers with the highest skills in this category. Skilled workers II: workers with medium skills in this category. Except in this figure, the term “skilled workers” in this report refers to any workers with specialized job-related skills.

▶ Source: MOHRSS 2019a.

the most wanted workers in China’s major cities. Clearly, most openings in these cities are in the tertiary sector and the most wanted jobseekers are low-skilled workers in services, whose demand/supply ratio is often higher than that of skilled workers (see figure 33). In fact, news reports about labour shortage in China’s economic hubs first appeared in 2003 and have been recurrent headlines ever since (Lei, Wang and Li 2011). Given the co-existence of reports on labour shortages in urban China and labour surplus in rural China, it is debatable whether China as a whole has run out of surplus labour; but it is plausible that the Chinese labour market has been tightening (Knight, Deng and Li 2011).

It is unclear whether this trend will continue in the near future. In 2019 the Chinese GDP growth rate registered a record low in almost three decades at 6.1 per cent (People’s Daily 2020). Owing to the spread of the coronavirus both at home and abroad in 2020, the downward trend of China’s GDP growth rate may continue, which will weigh on employment. It is reported that as a result of the COVID-19 pandemic, tens of thousands

Table 11. Estimated skills gap in the ten key fields of the MIC 2025 (in 10,000s)

	Stock of skilled workers, 2015	Estimated stock of skilled workers, 2020	Estimated skills gap, 2020	Estimated Stock of skilled workers, 2025	Estimated skills gap, 2025
New-generation information technology	1,050	1,800	750	2,000	950
Equipment for electricity generation and distribution	822	1,233	411	1,731	909
High-end machine tools and robots	450	750	300	900	450
New materials	600	900	300	1,000	400
Energy-saving and new energy automobiles	17	85	68	120	103
Aeronautical and astronautic equipment	49.1	68.9	19.8	96.6	47.5
Bioengineering and high-performance medical equipment	55	80	25	100	45
Agricultural machinery	28.3	45.2	16.9	72.3	44
Maritime engineering equipment and high-tech watercraft	102.2	118.6	16.4	128.8	26.6
Advanced rail transit equipment	32.4	38.4	6	43	10.6

Source: Ministry of Education 2017d.

▶ **Table 12. Labour demand in China's major cities, 2018Q3**

Cities	Demand in the secondary sector, %	Demand in the tertiary sector, %	Top three job categories with the largest labour shortages	Demand/ Supply
Shanghai	7.2	92.7	Banking professionals	3
			Real estate professionals	3
			Shop assistants, cashiers	3
Chongqing	44.1	54	Marketing workers	3
			Manual workers	3
			Management	8
Shenyang	22	74.5	Marketing workers	2
			Mechanics	3
			Customer service workers	3
Shijiazhuang	22.2	77.8	Marketing workers	2
			Clerks	2
			Manual workers	2
Zhengzhou	16.4	82.6	Marketing workers	3
			Manual workers	3
			Shop assistants, cashiers	3
Nanjing	34.2	61.8	Shop assistants, cashiers	3
			Marketing workers	5
			Security guards	3
Xian	20.0	77.3	Marketing workers	5
			Catering workers	4
			Sanitation workers	6

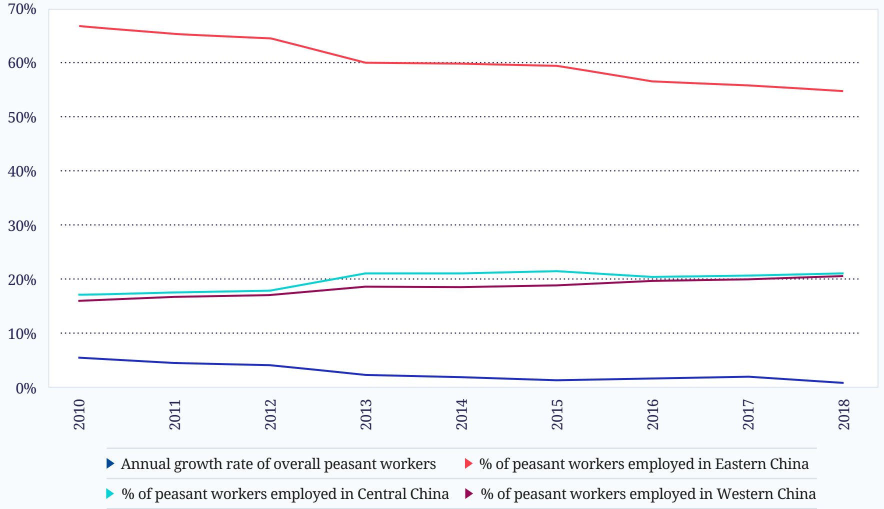
Cities	Demand in the secondary sector, %	Demand in the tertiary sector, %	Top three job categories with the largest labour shortages	Demand/Supply
Fuzhou	55.7	44.1	Manual workers	2
			Electronic workers	2
			Garment workers	2
Chengdu	27.1	72.1	Manual workers	7
			Customer service workers	9
			Security guards	9
Kunming	16.6	80.4	Catering workers	4
			Childcare domestic workers	4
			Sanitation workers	4

- Note: Low-skilled positions are shadowed.
- Source: MOHRSS 2018a.

of businesses in China, particularly small and medium-sized ones, had their cash flow disrupted or went bankrupt; export-oriented factories suffered from dramatic order cancellations from overseas buyers and had to stop production and lay off workers (Sina Caijing 2020).

Eastern China is likely to suffer more severe labour shortages than the other parts of China; it is home to the majority of the country's manufacturing enterprises. The Yangtze River Delta and the Pearl River Delta are the top two manufacturing hubs and are both in Eastern China. Peasant workers make up the majority of the low-skilled workforce in China's manufacturing. Between 2010 and 2018 the annual growth rate of peasant workers kept decreasing; the percentage of peasant workers employed in Eastern China dropped from 66.9 to 54.8 per cent, while the percentage of peasant workers employed in both Central and Western China increased by approximately 5 per cent (figure 34). Despite the ongoing relocation of manufacturing from Eastern China to Central and Western China, the dominance of Eastern China in Chinese manufacturing is far from being challenged. Thus, the salient relocation of peasant workers' employment from Eastern China to other

▶ **Figure 34. Changing regional distribution of the employment of peasant workers in China, 2010–18**



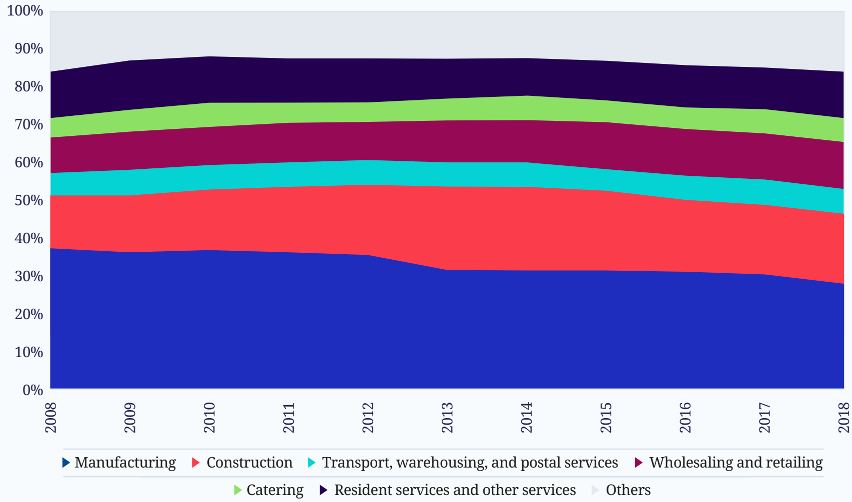
Note: Peasant workers employed in Northeast China made up a small fraction of all peasant workers and are therefore omitted in this figure.

Source: National Bureau of Statistics 2012b–2019b.

parts of China will aggravate the labour shortage in Eastern China, provinces in which, as mentioned in Chapter 2, happen to be the most avid robot adopters.

In addition, both prospective skilled and low-skilled workers are fleeing from manufacturing towards services. The diminishing interests of both college students and peasant workers in manufacturing may aggravate the labour shortage in manufacturing, compromise efforts to build a skilled manufacturing workforce, and cripple the implementation of the MIC 2025. According to MyCOS (2018), an education consultancy, among all engineering undergraduates in China the percentage of those employed in manufacturing dropped steadily from 42.0 per cent in 2012 to 32.3 per cent in 2016. The relatively low pay and low social status of engineers compared to those majoring in finance, economics and management in higher education, and the less satisfactory quality of engineering programmes in China, are blamed for this leakage of engineering talent (Zhang 2014). Figure 35 shows the industrial distribution of peasant workers in China between 2008 and 2018. During this time frame, the percentage of those working in manufacturing dropped from 37.2 to 27.9 per cent while those in all walks of services increased from 33.1 to 37.6 per cent.

Figure 35. Changing industrial distribution of peasant workers in China, 2008–18



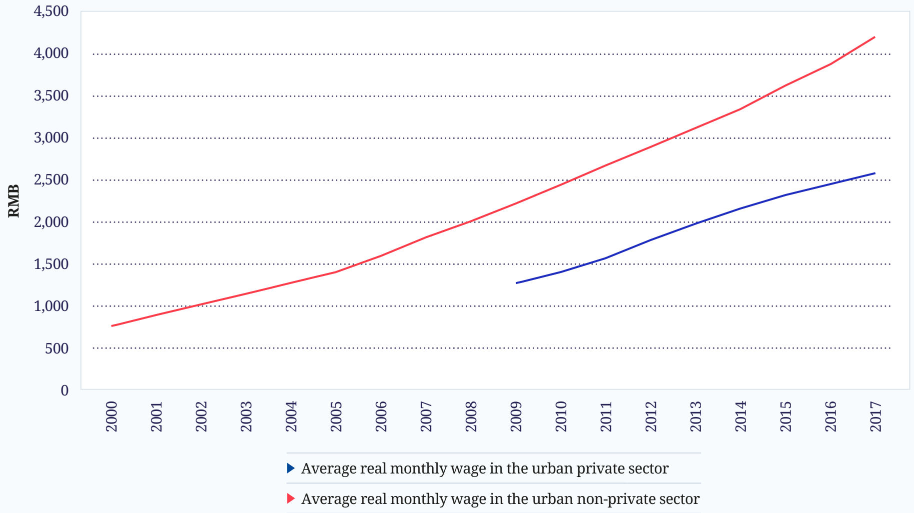
- Note: The category "others" refers to the difference between all peasant workers and those who cannot be identified with an industrial affiliation.
- Source: National Bureau of Statistics 2012b–2019b.

3.1.2 Changing working conditions

Working conditions in China have changed, too, albeit less dramatically than changes in the employment structure. Wages have increased rapidly in recent years and the increase rates have been above the global average. The wage growth of skilled workers outshines that of low-skilled workers. Average working hours have decreased. Peasant workers, while still working for longer hours than urban citizens, have also witnessed more significant working hour reductions than urban citizens. While technological upgrading is certainly not responsible for all progress in working conditions, it definitely has contributed to it. Owing to the unavailability of related data, this section is unable to examine the full range of working conditions.

Between 2000 and 2017 the average real monthly wages in urban China rose steadily (figure 36). According to the ILO's *Global Wage Report 2018/19* (2018), in recent years, wages in China, while remaining lower than wages in developed economies, have risen significantly faster than the global average. Between 2013 and 2018 the wages of professionals and technical staff were second only to those of management, and were significantly higher than those of low-skilled workers; moreover, the wages of professionals and technical staff also rose more quickly than those of low-skilled workers (figure 37).

Figure 36. Average real monthly wages in China's urban sector, 2000–2017

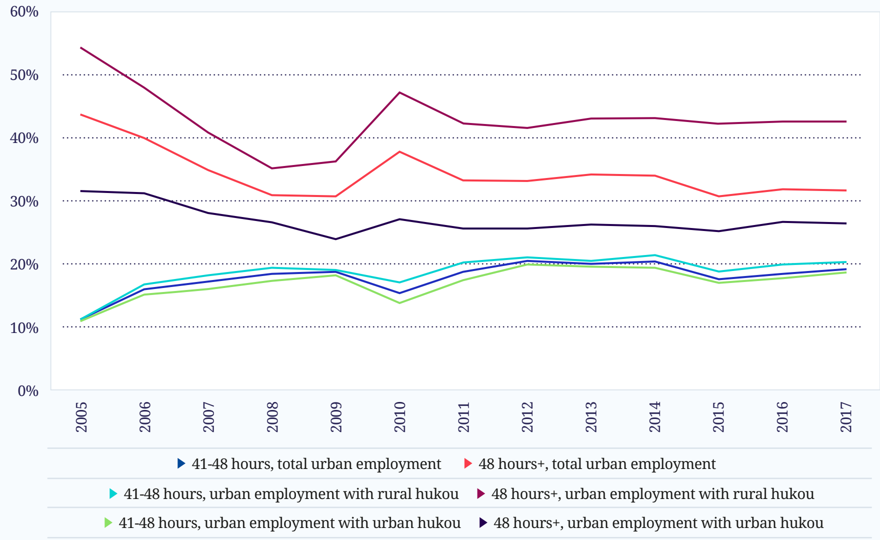


Note: Real wages are calculated based on the wage of the urban non-private sector in 2000.
Source: National Bureau of Statistics 2019a.

Figure 37. Average nominal monthly wages in China's enterprises above the designated size, by profession, 2013–18

Note: Management includes only middle-level and senior managers.
Source: National Bureau of Statistics 2014e–2019e.

Figure 38. Distribution of working hours per week, by groups of workers in urban China, 2005–17



Source: National Bureau of Statistics 2006c–2018c.

Alongside the wage growth, working hours have also been reduced. As shown in figure 38, between 2005 and 2016 in urban China the percentage of workers working for over 48 hours per week dropped by some 5 to 12 per cent, while the percentage of workers working for 41–48 hours per week increased by 6–8 per cent; compared with workers with urban *hukou* (household registration status), workers with rural *hukou* had a higher percentage working long hours, but these workers also enjoyed more significant working time reduction than workers with urban *hukou*. Despite this decrease, the working hours remained long: in 2016, 49.9 per cent of workers in urban China worked over 40 hours per week, including 31.5 per cent working for over 48 hours per week and 18.4 per cent working for 41 to 48 hours per week; for workers with urban *hukou*, 44.2 per cent worked for over 40 hours per week, including 26.5 per cent working for over 48 hours per week and 17.7 per cent working for 41 to 48 hours per week; for workers with rural *hukou*, 62.0 per cent worked for over 40 hours per week, including 42.3 per cent working for over 48 hours per week and 19.7 per cent working for 41 to 48 hours per week.

3.2 Impacts of process upgrading on social upgrading

As explained in Chapter 1, the R&D, manufacturing and operation of process technologies create employment while the adoption of these technologies often displace workers. The technological advances can also affect wages and other dimensions of working conditions by altering the demand and supply of the labour market. This section examines these effects of the process technologies mapped in Chapter 2. Overall, process upgrading in China does lead to increased demand for skilled workers and decreased demand for low-skilled workers. In the short term, in a context of dual shortage of both skilled and low-skilled workers and limited rolling-out of new process technologies, process upgrading aggravates the shortage of skilled workers and reduces the shortage of low-skilled workers.

3.2.1 Robots and other automatic equipment

It is unclear how many workers are employed in China's automatic equipment manufacturing industry. As shown in table 11 above, the skills gap in the field of high-end machine tools and robots in China is expected to reach three million in 2020 and 4.5 million in 2025. Chinese enterprises mainly use robots (the key content of the "replacing humans with machines" strategy that has been implemented in many places of China) and other automatic equipment to alleviate labour shortages and lower labour costs. Against this background, at least in present-day China, the deployment of robots and other automatic equipment has been welcomed by most workers.

Automation enhances the competence of enterprises, thus entailing potential benefits for workers. It also reduces the demand for low-skilled workers and boosts the demand for workers with related skills, which as a result reduces the shortage of low-skilled workers rather than leading to the bifurcation of the workforce. Automation deskills workers and does not necessarily open up opportunities to upskill. Existing studies indicate that automation has failed to significantly increase workers' wages or shorten working hours. Automation enhances the bargaining power of a few robot-related skilled workers but curtails the bargaining power of other skilled and low-skilled workers by deskilling them. Automation reduces workers' control over the labour process, and reduces work-related injuries as well. In the face of automation, low-skilled, elderly and female workers tend to be more vulnerable than skilled, young and male workers. At present, when automation is only taking place on a small scale, it has not caused mass unemployment. Automation-induced dismissals are rare. Employers mainly rely on natural workforce turnover for automation-induced redundancy.

Why companies embrace automation largely defines how it will affect workers. Compiled from survey data, table 13 lists the reasons why employers in China are using or considering using robots and other automatic equipment. Zhejiang, Jiangsu and Guangdong, all in Eastern China, are among the most developed provinces and have actively engaged in process upgrading. It is clear from these surveys that labour shortages and high labour costs (which are closely intertwined) were pervasive concerns for employers; to lower labour costs and to alleviate labour shortages were the most cited reasons for the adoption of automatic equipment. In addition, employers also used or were considering using automatic equipment to boost the performance of their enterprises by increasing labour productivity, improving product quality, lowering operating costs, stabilizing production, facilitating mass customization and reducing the risk of labour protests. In addition to the performance of enterprises, environmental concerns also fuelled the popularity of automatic equipment, as some employers adopted the equipment to reduce energy consumption and pollution. The third bundle of reasons involved the welfare of workers: to lower work intensity and to enhance workplace safety.

Against this background, Chinese workers overall welcome the adoption of automatic equipment. He and Han (2019) conducted a survey that involved 444 workers in manufacturing enterprises in Foshan, Guangdong. They found that most surveyed workers had a positive attitude towards replacing humans with machines. These workers believed that automatic equipment could lower work intensity and pressure, improve the workplace environment, and create opportunities for learning new skills and for promotion. According to a survey conducted in the textile sector of Jiangsu, 90 per cent of workers surveyed welcomed the adoption of automatic equipment in their factories. They cited boosting labour productivity as the primary reason. They also appreciated the role of automatic equipment in lowering work intensity and labour costs (Zhang 2019). According to a survey conducted in the auto parts sector of Guangdong, 71.5 per cent of workers surveyed thought that it was reasonable to replace humans with machines because machines represented progress (Yang 2019). The approval attitude towards automation and the notion of progress was shared by workers interviewed by Huang (2019a).

Automation affects Chinese workers in two ways. Indirectly, it can enhance the competence of their employer factories, thus mitigating the desire of these factories to leave China and also enabling them to climb up the GVCs. Directly, employees bear the brunt of their employers' adoption of automatic equipment. With regard to the indirect effects, by comparing table 13 and table 14 we find that automatic equipment has succeeded in delivering many of the enterprises' expectations. Table 14 shows that the deployment of automatic equipment has helped enterprises to reduce operating costs, reduce the number of low-skilled workers, increase labour productivity (thus alleviating labour shortages and lowering labour costs), improve product quality, increase the proportion of premium products, shorten the production cycle and reduce energy consumption. These improvements will enhance the competence of these enterprises in the global market. With refined competence, on the one hand, these enterprises are less likely to relocate to places with lower labour costs than China such as Southeast Asia where many Chinese factories have moved; on the other hand, improved product quality enables these enterprises to capture premium orders that were previously out of reach (Ning 2018b; Zhang 2019). In this sense, automation helps China to retain jobs and capture more value from the GVCs, which has the potential to benefit workers.

The deployment of automatic equipment has mixed direct effects on workers. In this regard, case studies and surveys have similar findings. First, automation reduces the demand for low-skilled workers and boosts the demand for workers with related skills. Table 14 strongly confirms the existence of these effects. But in an era of labour shortages of both skilled and low-skilled workers, this kind of recalibration of employers' labour demand contributes more to the alleviation of the shortage of low-skilled workers than to the bifurcation of the workforce. When it comes to case studies, based on fieldwork investigations in 2010–2011 in textile and garment factories in Dongguan, Butollo (2013) found that the introduction of CNC knitting machines at the companies surveyed significantly reduced the knitting workforce. The research by Butollo and Lüthje (2017) on two home appliance companies in China reiterates the labour displacement effect of automation. Based on fieldwork in multiple factories in China between 2015 and 2018, Xu (2019) found that the introduction of robots did displace low-skilled workers, but also generated new positions, for example in robot programming, communication between different automatic devices, and the design and maintenance of automatic production lines.

Second, automation deskills workers and does not necessarily open up opportunities for upskilling. Butollo (2013) found that in textile and garment factories in Dongguan automation deskilled machine operators without generating new demand for upskilling. Butollo and Lüthje (2017) reiterate the limited upskilling opportunities brought by automation. Based on fieldwork research in 2015–16 in Dongguan, Sharif and Huang (2019) found that in addition to displacing workers, automation also deskilled skilled workers; but in some cases, the deployment of robots required the upskilling of operators.

Third, automation fails to significantly increase workers' wages or shorten working hours, suggesting that workers fail to share the gains employers harvest from automation. Automation either has no significant impacts on workers' wages or decreases wages. As with Butollo (2013) who found that the introduction of CNC knitting machines had no salient impacts on the wages of operators, Yang (2019) found that for most workers, automation had no significant impacts on their wages or working hours; but for some workers, automation decreased their wages (see further details in table 14). Huang (2019a) found that skilled workers whose jobs were automated suffered from wage cuts. Based on a case study in Dongguan, Guangdong, Zhou and Jiang (2016) found that in contrast to the dramatic increase in labour productivity enabled by automation, the increase in workers' wages appeared meagre.

Fourth, automation enhances the bargaining power of a few robot-related skilled workers but curtails the bargaining power of other skilled and low-skilled workers by deskilling them. Consistent with Xu's (2019) finding that automation-invoked labour shortages inevitably boosted certain workers' bargaining power with employers, Yang (2019) found that in the auto parts sector, while automation enhanced the bargaining power of senior engineers in the positions of robot programming, robot-related R&D and robot adjustment, most other workers were exposed to the deskilling risk posed by automation and saw their bargaining power diminished. In addition, Huang (2019a) found that by dictating the working pace, the mass deployment of automatic equipment on the shop floor reduced workers' control over the labour process: they had to keep pace with machines, which largely disconnected their morale and working experience with their performance. Last but not least, as shown in table 14, automation reduced work-related injuries.

It is worth noting that different workers feel the shock of automation differently. Table 14 shows that in the face of automation, other variables being the same, low-skilled workers were more vulnerable than skilled workers; elderly workers were more vulnerable than young workers. Moreover, Xu (2019) found that female workers, who were highly concentrated in the low-skilled workforce, were more likely than men to be displaced by robots and were less likely to be reskilled and upskilled for new positions, rendering them (particularly those aged over 40) more vulnerable than their male counterparts amidst the mass deployment of robots. Based on a questionnaire survey in Guangdong in 2018, Deng and Xu (2019) found that at the firm level the introduction of automation equipment had been accompanied by more training about machine operation; nonetheless, compared to their male counterparts, female workers were less likely to receive such training.

What happens to workers who are made redundant by automation? It is safe to speculate that at least in the short term when automation still takes place on a relatively small scale, it will not lead to mass unemployment in China. What will happen in the long run remains to be seen. Consistent with table 13 which indicates that many enterprises embracing automation suffered from labour shortages, table 14 shows that automation-induced dismissals did happen, but not on a large scale. According to Zhou and Jiang (2016) who carried out multiple interviews in Guangdong, natural turnover was the most common way for enterprises embracing automation to let go of redundant labour.

The job turnover among China's peasant workers has traditionally been quite high. In 2011 the average duration of the first job for Chinese peasant workers born in the 1990s,

Table 13. Survey data on why employers use automatic equipment, 2013–19

Year	Region	Survey conductor	No. of surveyed enterprises, sectors	Labour shortages and labour costs	Reasons for using or considering using automatic equipment	Source
2013	Zhejiang	Provincial government of Zhejiang	515, M	77.7%-with labour shortage 30%-with LSR of 10-20% 7.3%-with LSR of 20-30% 25.7%-with shortage of low-skilled labour 74.3%-with shortage of skilled labour Average annual wage growth rate at 10-15%	75.7%-lower labour costs as the primary reason 68.5%-improve product quality 30.1%-boost energy efficiency and reduce pollution 28.7%-government subsidies 4%-increase labour productivity and enhance workplace safety	Jia, Lin and Yi 2013
2013	Hangzhou, Zhejiang	Local government of Hangzhou	84 enterprises above the designated size, M	84.5%-with labour shortage	Labour shortage	Zhejiang Daily 2014
2015/16	Taizhou, Zhejiang	Zhejiang branch of the NBS	325 enterprises above the designated size, M	54.5%-with high workforce turnover	36.8%-lower labour costs as the major reason 76.7%-improve product quality 49.5%-boost energy efficiency and reduce pollution	Zhejiang branch of the NBS 2016
2016	Changzhou, Jiangsu	Changzhou branch of the NBS	48, M	66.7%-with shortage of low-skilled labour 29.2%-with shortage of skilled labour	45.8%-used automatic equipment in the past three years	Changzhou Daily 2016

Year	Region	Survey conductor	No. of surveyed enterprises, sectors	Labour shortages and labour costs	Reasons for using or considering using automatic equipment	Source
2018	Nanjing, Jiangsu	Nanjing branch of the NBS	114 micro and small enterprises	32.5%-with labour shortage	Labour shortage (some used automatic equipment to cope)	Liu and Li 2018
2017	Guangdong	University academics	Multiple, auto parts	Labour shortage is not a concern because of relatively high wages	Lower labour costs Lower the risk of labour protests	Yang 2019
2017	Huizhou, Guangdong	Huizhou branch of the NBS	31 micro and small enteprises, M, services	45.2%-with labour shortage (average LSR was 10.8%) 62.5%-rising labour costs as the primary reason of rising operating costs Average wage growth rate last year at 12.4%	Labour shortage (only one used automatic equipment to cope)	Zhou and Yang 2017
2017	Foshan, Guangdong	Local government of Foshan	173*, M	Average annual wage growth rate at 10-15% in Foshan between 2005 and 2015	71.1%-increase labour productivity as the primary reason 46.8%-improve product quality 33.0%-lower labour costs 16.8%-alleviate labour shortage Reduce energy consumption Facilitate mass customization	Jinyangnet 2017

Year	Region	Survey conductor	No. of surveyed enterprises, sectors	Labour shortages and labour costs	Reasons for using or considering using automatic equipment	Source
2017/18	Beijing	University academics	6*, M		Lower labour costs Reduce work intensity Enhance workplace safety Lower operating costs	Zhang 2018a
2017/18	Jiangxi	Jiangxi branch of the NBS	60, M	Average LSR at 10.2% Over 20%-with LSR over 20% Average wage growth rate in 2018 at 8.1%	43.3%-lower labour costs 33.3%-alleviate labour shortage Others-increase labour productivity, improve product quality and production stability	Zheng, Chen and Zhu 2018
2018	Jiangsu	Jiangsu trade union of textiles	Multiple enterprises, textiles		Alleviate labour shortage as the primary reason Lower operating costs	Zhang 2019
2018/19	Multiple provinces	A related national trade union	Multiple enterprises, textiles		Lower labour costs and alleviate labour shortage as the primary reason	National Trade Union of the Finance, Trade, Textiles, and Tobacco Sector 2019

- Notes: In column 4, numbers refer to the number of surveyed enterprises that responded to the survey; numbers with and asterisk indicate that all surveyed enterprises were confirmed to have used automatic equipment at the time of survey. LSR=Labour shortage rate=Labour gap/the number of incumbent staff. NBS=National Bureau of Statistics; M=Manufacturing.
- Sources: As indicated in the table.

Table 14. Survey data on the effects of automatic equipment on enterprises and workers, 2013–19

Year, region	No. of surveyed enterprises, sectors	Effects on enterprise performance and working conditions	Source
2013, Zhejiang	515, M	68.9%-cut operating costs by over 5% 27.3%-increase labour productivity by over 30% 16.6%-increase labour productivity by over 20-30% 29%- increase labour productivity by 10-20% 51.7%-shorten production cycle by over 10% 24.8%-increase the proportion of premium products by over 20% 86.3%-reduce energy consumption	Jia, Lin and Yi 2013
		61.5%-reduce rank-and-file workforce by over 10% Nearly 20%- reduce work-related injuries	
2015/16, Taizhou, Zhejiang	103 enterprises above the designated size, M	42.7%-cut operating costs by 5-10% 50.6%-cut operating costs by over 10% 9.7%-increase labour productivity by over 30% 15.5%-increase labour productivity by 20-30% 24.2%-increase labour productivity by 10-20% 58.2%-shorten production cycle by over 20% 31.1%-increase the proportion of premium products by over 20% 73.9%-reduce energy consumption	Zhejiang branch of the NBS 2016
		72.8%-reduce rank-and-file workforce by over 10% Reduce work-related injuries	
2013/14, Suqian, Jiangsu	Nearly 300	Reduce operating costs by over 5% Nearly 30%-increase labour productivity by over 30% Nearly 50%-increase the proportion of premium products by over 15% Over 90%-reduce energy consumption	*Xinhua Daily* 2014
		On average, reduce workforce by over 10%	

Year, region	No. of surveyed enterprises, sectors	Effects on enterprise performance and working conditions	Source
n.d., Kunshan, Jiangsu		On average, reduce frontline operatives by 19%, boost demand for skilled workers by 18%	Huang 2018
2014–16, Dongguan, Guangdong		Significantly increase labour productivity Lower average costs per unit of product Lower product defect rate	*Daily Economic News* 2016b; *21st Century Business Herald* 2016
		Reduce 87,000 workers when 1,485 related programmes (applied between September 2014 and October 2016) were completed	
2017, Foshan, Guangdong	173, M	8.8%-increase labour productivity by over 50% 67.3%-increase labour productivity by 10-30% 93.6%-improve product quality	Jinyangnet 2017
		52.1%-reduce workforce by 10-30%	
2017, Guangdong	Multiple, auto parts	88.6% of interviewed workers reported no significant change in wages 5.7% of interviewed workers reported wage decrease 91.2% of interviewed workers who received related training reported no wage increase No significant change in long working hours Make workers replaceable and diminish their bargaining power against employers	Yang 2019
2017/18, Beijing	6, M	Reduce low-skilled manual and routine cognitive jobs Layoffs, but on small scale Increase demand for skilled workers Lower work intensity Reduce work-related injuries	Zhang 2018a

Year, region	No. of surveyed enterprises, sectors	Effects on enterprise performance and working conditions	Source
2018, Heze, Shandong	20	30%-increase labour productivity by over 20% 55%-lower labour costs by over 10% 15%-improve product quality 60%-increase the proportion of premium products by over 20% 60%-shorten the production cycle by over 20% Average profit margins increase at 10%	Zhu 2019
		30%-create jobs for the development, operation and maintenance of automatic equipment Reduce jobs for low-skilled workers	
2018, Five provinces	1,882	Displace low-skilled workers Create jobs for high-skilled workers	Cheng, Chen and Li 2018
2018/19, Multiple provinces	Multiple, textiles	No concern of mass layoffs Greater demand for skilled workers to operate and maintain automatic equipment Old, lower-skilled workers were more vulnerable than young, skilled workers	National Trade Union of the Finance, Trade, Textiles, and Tobacco Sector 2019

- Notes: In column 2, numbers refer to the number of surveyed enterprises that responded to the survey, mostly enterprises that had adopted automatic equipment. Unless otherwise specified, the percentages in column 3 refer to the percentages of surveyed enterprises that experienced certain effects. NBS=National Bureau of Statistics; M=Manufacturing.
- Sources: As indicated in the table.

in the 1980s, and before 1980 were estimated to be less than one year, 18 months, and 50 months respectively (Department of Sociology 2013). Between 2013 and 2017, those born in and after 1980 made up roughly half of China's peasant workers (National Bureau of Statistics 2018b). The intensified shortage of low-skilled workers in recent years can only have encouraged higher turnover. Yang (2019) found that in the auto parts sector robot-induced dismissals were very rare: some employers took advantage of the high turnover of China's peasant workers and relied on natural turnover to let go of redundant labour, while others opened new lines to reposition redundant workers. Zhang (2018) found that in the six enterprises surveyed, those with different kinds of ownership and at different stages of development treated redundancies brought by automation differently: state-owned and fast-growing enterprises tended to reposition redundant workers, while foreign, domestic private and mature enterprises tended to lay them off. According to a report released by Meituan (a Chinese group buying company for locally found delivery services, and which used over 2.7 million part-time and full-time delivery workers in 2018), approximately one-third of its delivery workers in 2018 were manufacturing workers immediately before they worked for Meituan (Meituan 2019). This fact on the one hand reflects low-skilled workers' option out of manufacturing into services, and on the other hand reflects the potential of services to absorb unemployment in manufacturing.

3.2.2 3D printing

On the one hand, 3D printers have hardly displaced any workers on China's shop floor, and will remain unable to do so in the near future. On the other hand, the manufacturing of 3D printers in China has created jobs, although the number of jobs created is underwhelming and most of them are likely to be low-skilled.

As shown in Chapter 2, 3D printing tends to complement rather than supplant conventional manufacturing, which limits its potential for labour displacement; moreover, owing to technological bottlenecks, the use of 3D printers in printing end parts is very limited, even in the most advanced economies. Chinese enterprises mainly use 3D printing for prototyping; the mass deployment of 3D printers in end part printing is off the near-future policy agenda of the Chinese Government. Thus, 3D printing has limited impacts on manufacturing in China and thereby workers in China.

It is reported by the Chinese Government that the number of workers in the 3D printing industry in China increased from 13,000 in 2012 to 24,100 in 2014 (Lu, Wang and Zhao 2017). Given that Chinese 3D printer suppliers are at the lower end of the market, it is safe to assume that most of these jobs were low-skilled. The year 2013/14 was a watershed for the global 3D printing industry. Since then, the stock price of the global leaders in this industry such as 3D systems, Stratasys and ExOne has dropped sharply (Ausick 2019). According to Wohlers Associates (2015), the compound annual growth rate of additive manufacturing dropped from over 30 per cent in the early 2010s to 17.4 per cent in 2016, and 21.0 per cent in 2017 (Laforest 2018). In China, owing to the launch of the MIC 2025 that highlights 3D printing, venture capital flooded into this industry in 2015, which would surely boost employment. However, the over-heated bubble burst before long. In 2016 and 2017, many 3D printing companies in China went bankrupt. Owing to the various bottlenecks that prevented the large-scale use of 3D printers both in manufacturing and in daily life, the demand for 3D printers in China, after expanding for a while, appeared distressed (Lu 2018). Thus, it is unrealistic to expect a dramatic job increase in China's 3D printing industry.

3.2.3 Digitalization

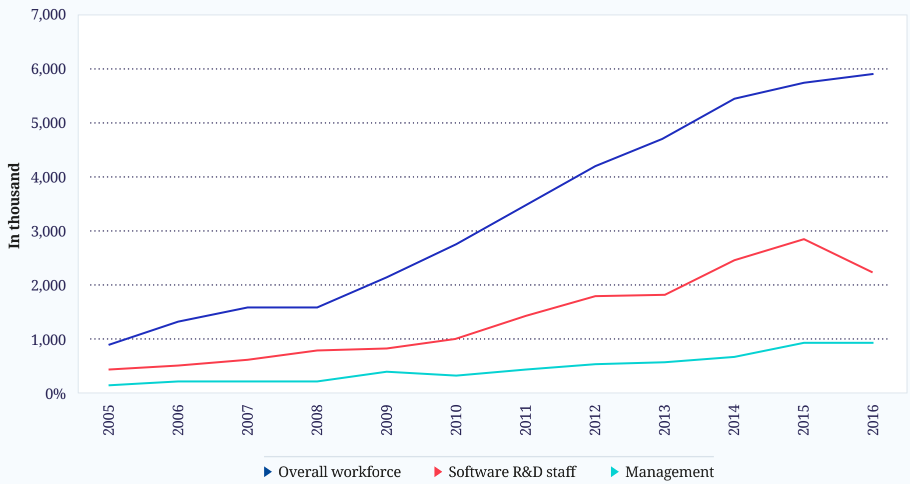
Enterprise software, IoT, and AI are all vehicles of digitalization and products of the software and ICT services industry. This section first gives an overview of the employment and working conditions in China's software and ICT services industry. It then focuses on special labour implications of management software and AI.[20]

The software and ICT services industry in general

The rise of the software and ICT services industry in China has created millions of relatively well-paid and skilled jobs. Generally, workers in this industry are well-educated but find their work repetitive, stressful and precarious and have to work unlawfully long hours. They are more likely to become agency workers than their counterparts in most other industries. Female skilled workers are under-represented in the technical workforce in this industry and are often penalized in compensation because of their gender.

Figure 39 shows that between 2005 and 2016 employment in China's software and ICT services industry jumped from 0.9 to 5.9 million. Over half the jobs in this industry were

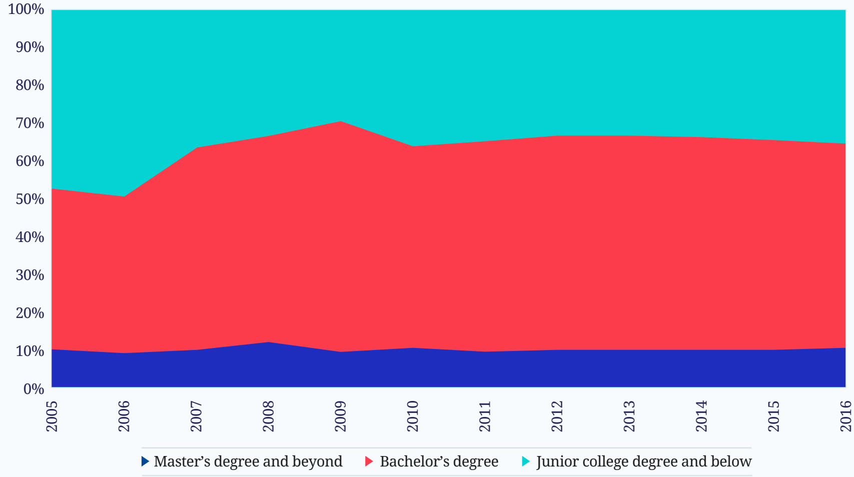
Figure 39. Employment in China's software and ICT services industry, 2005–16



Source: Ministry of Industry and Information Technology 2006d–2017d.

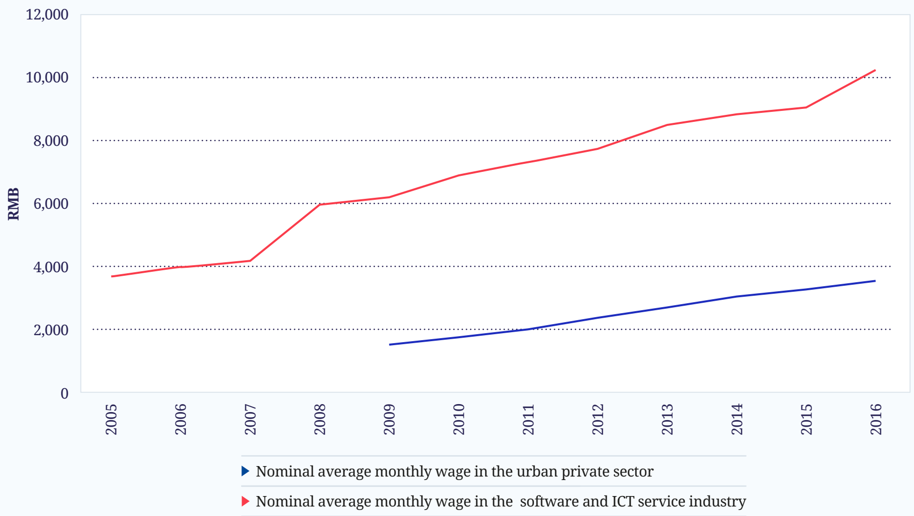
20 This section omits the labour implications of the Internet of Things (IoT) because IoT is in fact a combination of various technologies; this chapter examines the impacts of IoT technologies such as SaaS software and AI separately.

Figure 40. Levels of education in China's software and ICT services industry, 2005–16



Source: Ministry of Industry and Information Technology 2006d–2017d.

Figure 41. Average wage of workers in China's software and ICT services industry, 2005–16



Source: Ministry of Industry and Information Technology 2006d–2017d, figure 36.

either for R&D activities or for management. The proportion of R&D staff (mainly programmers) and management peaked in 2015 at 65.0 per cent. Most staff in this industry were well educated. Figure 40 shows that between 2005 and 2016, the proportion of staff with a bachelor's degree or beyond jumped from 52.9 to 64.3 per cent. Jobs were generally well-paid. Most of the software and ICT service companies in China are private, and as shown in figure 41, between 2009 and 2016 the wage of workers in this industry tripled or even quadrupled the average wage of the urban private sector.

Despite the fact that programmers are relatively well-educated and well-paid in China, according to an ethnography survey conducted in 2015 and 2016 in Shenzhen, a leading ICT innovation hub in China, programmers there considered themselves to be coding peasants (*manong* in Chinese), an identity in sharp contrast to the image of highly regarded knowledge workers. Very often programmers found their work more repetitive than creative. Entry-level jobs were at a low threshold. After short-term training at vocational schools or private training institutions, workers without any IT background could find entry-level jobs earning some 3,000 RMB per month in 2015 and 2016. Working in the industry was also stressful. In such a fast-developing industry, programmers had to keep learning new things; the rapid pace and high intensity of work made this industry half closed to people older than 30. Many IT companies were small-scale or start-ups, rendering related jobs highly precarious (Sun 2016). Moreover, amidst the recent economic slowdown, IT giants in China have carried out rounds of layoffs. According to news reports, in December 2018, Zhihu, a Quora-like question-and-answer platform in China, had fired 400 people, or one quarter of its workforce; in early 2019, Didi, the largest ride-sharing company in China, planned to let go of approximately 2,000 people, or 15 per cent of its workforce (Huang 2019a); meanwhile, JD, one of China's biggest e-commerce companies, was reported to be planning to dismiss up to 8 per cent of its 178,000 full-time workforce. JD said the number was incorrect but did not disclose the correct number (Horwitz and Goh 2019). In addition, workers in this industry are more vulnerable to informal employment arrangements than workers in most other industries in China. According to a survey conducted by the All-China Federation of Trade Unions (ACFTU) in 25 cities in 2010 and 2011, 60 per cent of firms surveyed f in the software and ICT services industry in China used agency workers; on average 17.9 per cent of workers in these firms were agency workers; and both percentages were higher than those in most other industries (ACFTU 2012).

Working time in China's software and ICT services industry is notoriously long. The *Labour Contract Law* of China stipulates that generally the working time per day shall not exceed eight hours; the working time per week shall not exceed 44 hours; under circumstances in which overtime is needed, overtime per day shall not exceed three hours and total overtime per month shall not exceed 36 hours; employers shall pay for overtime work; overtime pay for workdays, weekends, and official holidays is 150, 200 and 300 per cent of the normal wage rate respectively. However, the default working time for many companies in China's software and ICT services industry is "996": working from 9 a.m. to 9 p.m., six days per week. In 2016, Didi compiled a report on the "off-work time" (the time of day when staff leave work) in China's ICT giants according to its customer riding records. JD topped the off-work time list with 11.16 p.m. being the average time that its recorded staff left work in 2016. In the same list, the average off-work times at China's famous ICT companies such as Tencent, Sohu, Sina and Baidu were all after 8 p.m. (Fulihui 2016). In the same year, Gaode Map (an online map and navigation company whose application is very popular in China), the Chinese Ministry of Transport and Tsinghua University co-conducted an investigation and found that Huawei topped the list of working hours among ICT manufacturing and software companies with an average of 3.96 hours of overtime per day; on average its staff left work at approximately 10 p.m.; Huawei was followed by Tencent (3.92 hours of overtime per day), Alibaba (3.89 hours), NetEase (3.86 hours), and JD (3.86 hours), all ICT giants in China (Quicktech 2017). It is worth noting that overtime work in China's ICT industry is usually unpaid (Beijing Youth 2016). It is reported that under the 996 work schedule, workers in this industry have "no sleep, no sex and no life" (Huang 2019b). Death from overtime work is also not uncommon in this industry, either (Fulihui 2016).

In the face of the economic slowdown, some ICT companies in China have exploited the widely-held "hard-work-leads-to-success" doctrine and reinforced the overwork culture. In February 2019, Youzan, an e-commerce company in China, announced that it would implement 996 and suggested that married staff who could not balance work and life should divorce (Kong 2019). In March 2019 an online campaign against the 996 work schedule began to solicit reports and compiled an ever-updating list of companies that implemented 996 or similar long-hour work schedules such as 10-10-6, 9-11-6, two days off per month, among others. By early May 2019 approximately 150 companies, predominately ICT companies, had appeared on the list, including integrated IT solution giants such as Alibaba, Tencent and Baidu, e-commerce giants such as JD and Pinduoduo, ICT equipment giants Huawei, Xiaomi and Vivo, household appliance giants Haier and Midea, and also the drone maker DJI (996.ICU. 2019a).

Jobs in China's software and ICT services industry are gendered. Compared with male programmers, female programmers are small in numbers, earn less, and are more likely to work in less technologically demanding positions. According to Girls Who Code, a NGO seeking to inspire, educate and equip girls with computing skills, the proportion of women holding computing jobs in the United States stood steady at 24 per cent between 2011 and 2016 but is likely to drop to 22 per cent by 2025 if no gender balance efforts are made. The gender gap starts in college: the share of women in computer science majors in the United States dropped from 34 per cent in 1984 to 18 per cent in 2016 (Bagri 2016). Two reports based on convenience sampling reveal the gender imbalance in China's software and ICT services industry. One report finds that in 2014 women made up 20 per cent of programmers in China (CodeForge 2014). Another report investigating 13,342 programmers on a jobseeking online platform in 2015 and 2016 found that only 20 per cent of programmers registered on the website were female; overall, compared with male programmers registered on this website, their female counterparts were 7 per cent less likely to get a job invitation, and would be offered a 10 per cent smaller compensation package for the same position; and the gender pay gap enlarged with seniority (Lin 2016). An interview with an industry insider shows that female programmers in China are more likely to work in testing positions, while male programmers dominate the more technologically sophisticated developer positions (100offer. com. 2016).

Management software

The management software market in China is rapidly expanding. In January 2015 Alibaba released its management software DingTalk; the number of its employer users reached one million at the end of 2015, three million at the end of 2016, and five million in September 2017. In late December 2017 DingTalk announced that the number of its registered individual users exceeded 100 million. DingTalk's rival WeChat for Enterprises, an enterprise management application developed by Tencent, had some 1.5 million enterprise users and 30 million individual users in early 2017 (Zhang 2017). In 2018 DingTalk was the most popular mobile management software in China, with its market share exceeding the sum of the market share of all the other top ten most popular management software in China (Sohu Tech. 2018).

Management software may facilitate the work of employees, but more often amplifies the power of management and reduces the discretion of workers in the workplace. In addition to functions that are common to communication applications such as address book, instant messaging, message read notification, and video conference, DingTalk has management functions such as attendance recording, process approvals, and daily reports that require workers to list complete tasks on a daily basis. DingTalk is GPS-activated, thus enabling employers to monitor employees' whereabouts (Koetse 2017). The signature feature of DingTalk is "ding", which allows employers to bombard message recipients who have not read the message or who have read but do not reply with repeated text messages and phone calls, both during and beyond working hours. As a result, thanks to DingTalk, employees are largely forced to delegate their discretion of when to do what and where to go to employers, which has fuelled a backlash by employees ranging from complaints to resignation (Chen and Shepherd 2018). Another case of GPS-activated management software was reported in 2019: some street cleaners in Nanjing, Jiangsu were required to wear GPS-tracking watches while on duty, which would send out an audio alert if the wearer stopped moving for more than 20 minutes. Facing intense public criticism, the related sanitation company removed the alarm feature of the watch (Cheng 2019).

Artificial intelligence (AI)

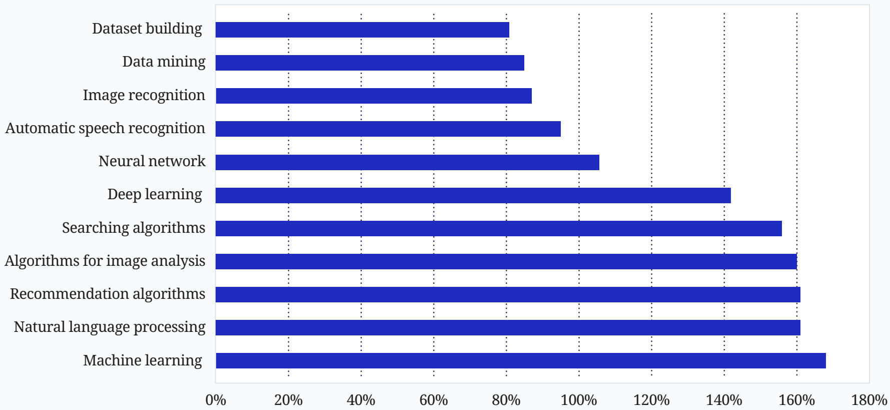
On the one hand, the booming AI industry in China has created jobs (both white-collar and blue-collar ones) and there are labour shortages in this industry. On the other hand, AI technologies have reduced labour demand in the industries it has penetrated. Male workers overwhelmingly dominate the global AI industry and there is no evidence indicating that the Chinese AI industry is an exception.

Table 8 in section 2.2.6 showed that in 2017 the AI industry in China accommodated some 39,000 staff. Investment data indicate that the Chinese AI industry took off in 2013 and has been dramatically expanding ever since (Chinese Academy of Information and Communication Technology 2018). As a result, as shown in figure 42, job demands in the subfields of AI have increased rapidly. With regard to pay, AI jobs appear to be premium jobs in the ICT industry. Data from recruitment websites show that in 2017 the average monthly wage for AI jobs in China was 25,800 RMB, significantly higher than the average wage in the software and ICT services industry; nearly 80 per cent of AI openings offered a monthly wage over 20,000 RMB; some 50 per cent of AI openings offered a monthly wage over 30,000 RMB; and in addition to wages, nearly 50 per cent of AI openings offered stock options as well. Moreover, AI skilled workers see more rapid salary growth than other workers in the ICT industry (Tencent Research Institute 2017c).

The booming AI industry also generates new blue-collar jobs such as data labellers who label objects on photos according to the specifications of clients to facilitate machine learning. Generally, ICT companies headquartered in China's first-tier cities outsource data labelling, the most labour-intensive part of their business processes, to companies in lower-tier cities. Guiyang, the capital city of Guizhou, one of China's least developed provinces, is a hub of data-labelling companies. Insiders estimate that in 2018 full-time data labellers in China totalled approximately 100,000, and part-time workers might total one million, including many with hearing and speech impairments. On average, in 2018 full-time data labellers earned 4,000–5,000 RMB per month, significantly lower than that of AI engineers. Data-labelling companies often face great cost pressure from contract issuers and do not buy social insurance for their employees (Jazzyear 2018).

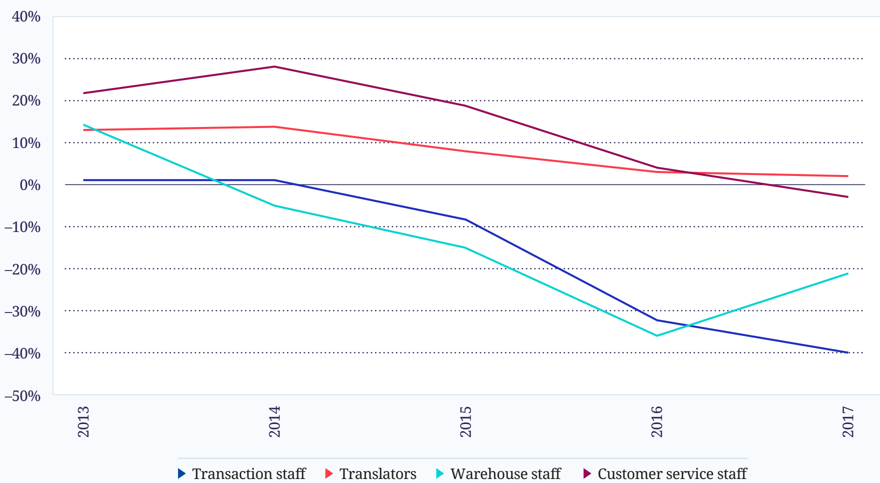
Male workers dominate the global AI industry. Among the academics who published over 30 papers in top international AI conferences in the world between 2006 and 2017, the male-to-female ratio was 7 to 1. In 2017 the majority of the heads of AI companies (both

Figure 42. Compound annual growth rates of job demand in China’s AI industry, 2015–17



Source: Tencent Research Institute 2017c.

Figure 43. Job demand growth rates of several AI-penetrated professions in China, 2013–17



Source: Tencent Research Institute 2017c.

well-established ones and start-ups) in the world were male; some 90 per cent of the heads of enterprise laboratories in the global leading AI companies were male. In China, owing to the labour shortages and high compensation in the AI industry, large numbers of workers in the conventional ICT industry have switched to AI jobs (Tencent Research Institute 2017c). Given the gender imbalance already existing in China's conventional ICT industry, such professional mobility will contribute to increased under-representation of females in China's AI industry.

Despite the recurrent media excitement about how many workers will be displaced by AI technologies, in China, as mentioned in Chapter 2, where employers actively embrace AI technology there are very few news reports about dismissals induced by the adoption of these applications. As mentioned earlier in this chapter, there has been a chronic dearth of low-skilled labour in China's economic hubs since the early 2000s and the turnover of China's low-skilled workforce is quite high. Thus, as in enterprises that have introduced automatic equipment, what seems to have happened so far is that the redundancy created by the deployment of AI applications has been offset by the natural labour turnover. As a result, at such an early stage of AI adoption, AI-induced dismissals are rare. But AI has reduced employer demand for new recruits in positions supplanted by AI. Based on data from job search websites, figure 43 shows the job growth rates of several professions into which AI has penetrated between 2013 and 2017. All witnessed significant slowdown of job growth, if not the shrinkage of labour demand. It is unclear to what extent the dwindling growth rates of these positions are due to the economic slowdown.

Since the Chinese AI industry took off quite recently, further implications of AI applications on Chinese workers remain to be seen. Based on interviews with financial and AI experts, a report co-compiled by BCG and the China Development Research Foundation predicts that some 23 per cent of jobs in China's financial services industry will have been struck by AI applications by 2027: these jobs will either disappear or have their major content altered. Specifically, between 2017 and 2027 the number of jobs in China's banking, insurance and capital market services will decrease by 22, 25 and 16 per cent respectively (He et al. 2018). Using the method developed by Frey and Osborne (2017), Chen and Xu (2018) estimate that in the coming 20 years, 76.8 per cent of total employment, or 65.6 per cent of non-agricultural employment in China, will be exposed to the risk of AI-enabled labour displacement.

3.3 Impacts of product upgrading on social upgrading

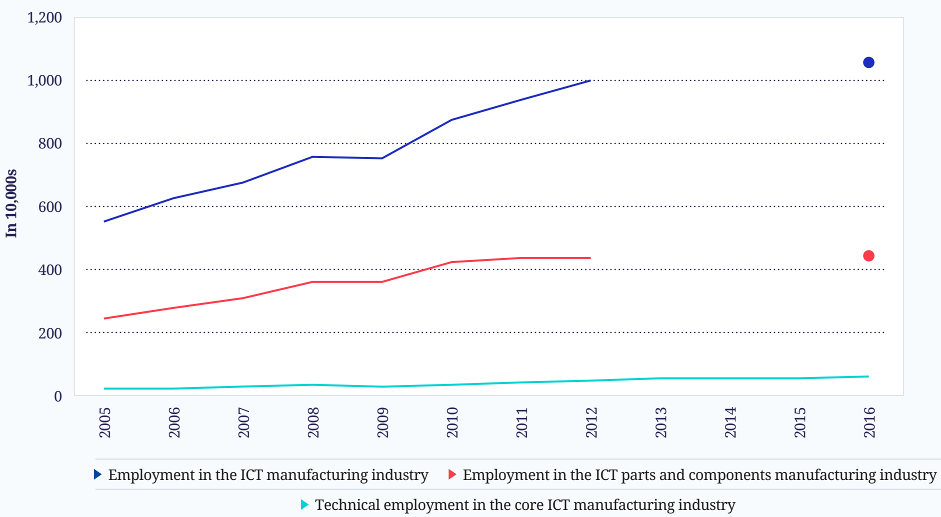
This section examines how the product upgrading mapped in Chapter 2 has affected social upgrading. Owing to limitation of data, it consists mainly of case studies on the ICT manufacturing and automobile industries in China, and the leading indigenous companies in these two industries.

3.3.1 At the industrial level

China's escalation from an assembler to an OEM of parts and components and even OBM supplier has taken place in multiple industries. The changing employment structure in the ICT manufacturing and automobile industries well illustrates the labour implications of this shift.

The shift has been accompanied by the expansion of overall employment in these two industries, the expansion of employment in ICT parts and components manufacturing, and in auto parts, and the expansion of technical employment in both industries. As shown in figure 44, between 2005 and 2016 total employment in China's ICT manufacturing industry almost doubled (from 5.5 to 10.6 million); employment in the ICT parts

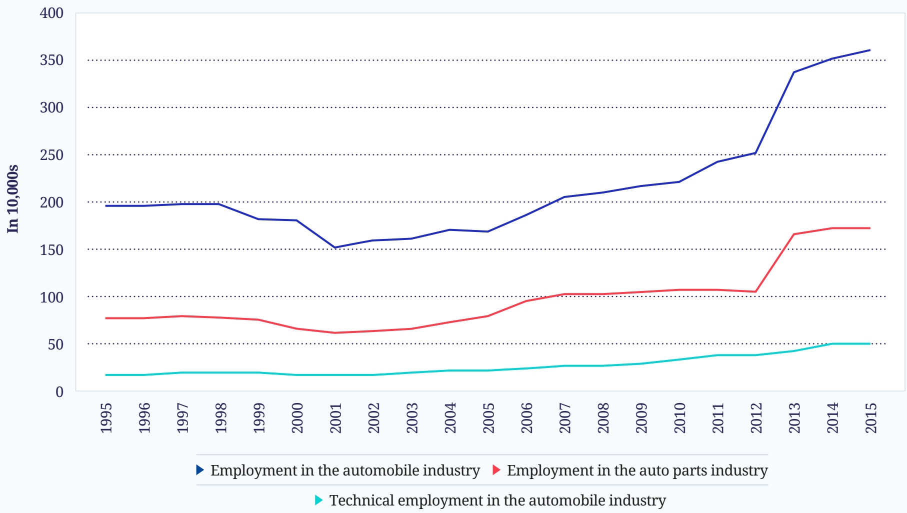
Figure 44. Employment in China's ICT manufacturing industry, 2005–16



Notes: According to the categorization of the data source, the ICT manufacturing industry includes the core ICT manufacturing industry (manufacturing of electronic and communication equipment, computers and office equipment) and manufacturing of radar, broadcast equipment. Data on employment in ICT manufacturing and ICT parts and components manufacturing only include employment in enterprises above the designated size. These enterprises made up the majority of employment in this industry (82.1 per cent in 2005, according to the same data source). Data on technical employment include all enterprises in this industry.

Sources: Ministry of Industry and Information Technology 2009c–2016c; National Bureau of Statistics 2006d–2017d.

▶ **Figure 45. Employment in China's automobile industry, 1995–2015**



Source: Chinese Association of the Automobile Industry 2016.

and components manufacturing industry almost doubled too (from approximately 2.4 to 4.4 million); and technical employment in the core ICT manufacturing industry tripled (from approximately 0.2 to 0.6 million). In terms of percentage, between 2005 and 2016 the share of electronic parts and components employment in overall employment in the ICT manufacturing industry fluctuated at around 40 per cent, peaking at 48.2 per cent in 2010 and falling to 41.9 per cent in 2016. Employment in the automobile industry shows similar trends. Figure 45 shows that total employment in China's automobile industry was approximately 2.0 million in 1995, dived to 1.5 million in 2001 and gradually increased to 3.6 million in 2015; employment in the auto parts industry increased from approximately 0.8 to 1.7 million while technical employment almost tripled from 0.17 to 0.49 million. In terms of percentage, between 1995 and 2015 the share of auto parts employment in overall employment of the automobile industry rose steadily from 39.4 to 47.5 per cent while the share of technical staff in overall automobile employment increased from 8.5 to 13.7 per cent.

3.3.2 At the enterprise level

Generally, although enterprises do not necessarily offer decent working conditions to the extent that their financial capabilities would permit, leading enterprises are in a better position than follower enterprises in this regard. Certainly, the generalizability of the working conditions in leading enterprises to the working conditions of the whole industry and of the whole country now and in the near future is questionable. That said, in a fast-changing economy as in the case of China, the working conditions in leading enterprises can largely be a harbinger of the working conditions in the follower enterprises now and in the near future.

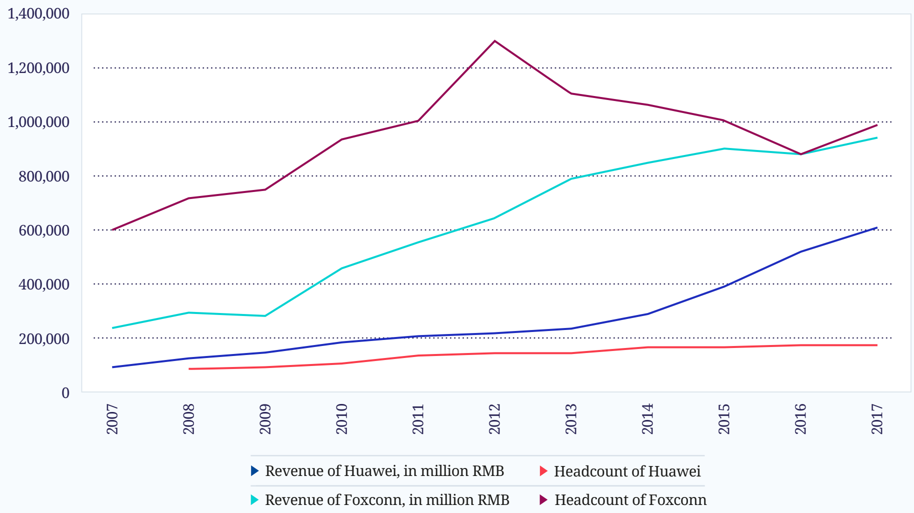
In light of this, this section uses two cases of leading enterprises in the ICT equipment industry and the automobile industry to illustrate the changing working conditions in China enabled by product upgrading. The performance of Chinese brands in these two industries represents two different levels of product upgrading and therefore two levels of impact on working conditions. At Huawei, which has managed to build a global brand and whose products have entered the global premium market, product upgrading is associated with upskilling, high compensation and masculinization of the workforce, but has not led to a reduction in working hours or significant improvement in job security and trade union representation. At Geely, which has only managed to build a domestic brand image and whose products remain concentrated at the lower-end market, the above Huawei effects are less pronounced.

Working conditions at Huawei

Huawei started its business in 1987 as a retail franchisee of telecoms equipment made in Hong Kong (China). The company began to engage in telecoms OEM in 1990 and in mobile phone OEM in the 2000s (Huawei 2019). Huawei does not assemble products for other brands. In fact, the Taiwanese company Foxconn is a contract manufacturer for Huawei (Ni and Luo 2019). Both Huawei and Foxconn have global presence but the majority of their facilities are in mainland China. As stated in Chapter 2, present-day Huawei well represents Chinese enterprises that successfully build their own brands. In contrast, Foxconn is a good example of an enterprise in China whose preoccupation is assembly. Foxconn has been the largest assembler of smartphones and tablet computers in the world for many years; in 2016, it accounted for 39.5 per cent of the total revenue of the global electronic manufacturing services industry (Foxconn 2018a). Thus, the comparison between Huawei and Foxconn is apt to illustrate the impacts of product upgrading on working conditions.

Before focusing in more detail on the working conditions at these two companies, figures 46 and 47 provide further information to set the scene for comparison. Between 2007 and 2017, the revenue of both Foxconn and Huawei grew steadily and Foxconn continuously ran a bigger revenue than Huawei. It also had far more workers than Huawei: between 2008 and 2017 the number of workers at Huawei increased gradually from 87,502 to 180,000 while that of Foxconn increased from 603,000 in 2007 to peak at 1,300,000 in

Figure 46. Revenue and headcount at Huawei and Foxconn, 2007–17

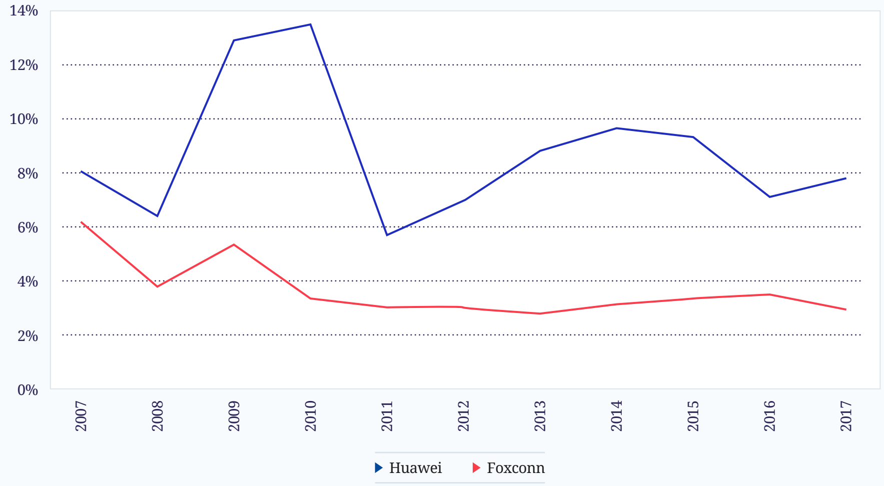


- Notes: Data on the headcount at Huawei between 2011 and 2018 are estimates. The headcount at Foxconn here includes the number of formal workers and excludes the number of agency workers and student interns. According to the data source, formal workers generally make up at least 95 per cent of the workforce at Foxconn. Huawei uses agency workers and outsourced workers. It is not clear whether the data on the headcount of Huawei include agency workers or outsourced workers. As shown in figure 48, some 40-50 per cent of Huawei staff engage in R&D. And according to a researcher who studied working conditions at Huawei between 2015 and 2017, the majority of Huawei R&D staff are formal workers (interview with the researcher, February 2019). This note applies to all the figures below that concerning the headcount of Huawei directly or indirectly.The original revenue figures for Foxconn are in New Taiwan dollars (NTWD). The exchange rate used in this report is 1 NTWD=0.2 RMB.
- Sources: Huawei 2018a, 2018b; Foxconn 2018a, 2018b.

2012 before dropping to 988,000 in 2017. In 2017, Huawei earned 64.1 per cent of what Foxconn earned with a headcount making up only 18.2 per cent of that of Foxconn. In other words, Huawei workers are more productive than Foxconn workers. Huawei also enjoys higher net profit margins than Foxconn. Figure 47 shows that between 2007 and 2017 the Foxconn's net profit margins showed a downward trend, dropping from 6.3 per cent in 2007 to 2.9 per cent in 2017; the profit margin of Huawei fluctuated wildly during this period, peaking at 13.5 per cent in 2010 and bottoming at 5.7 per cent in 2011, but remained constantly higher than Foxconn's.

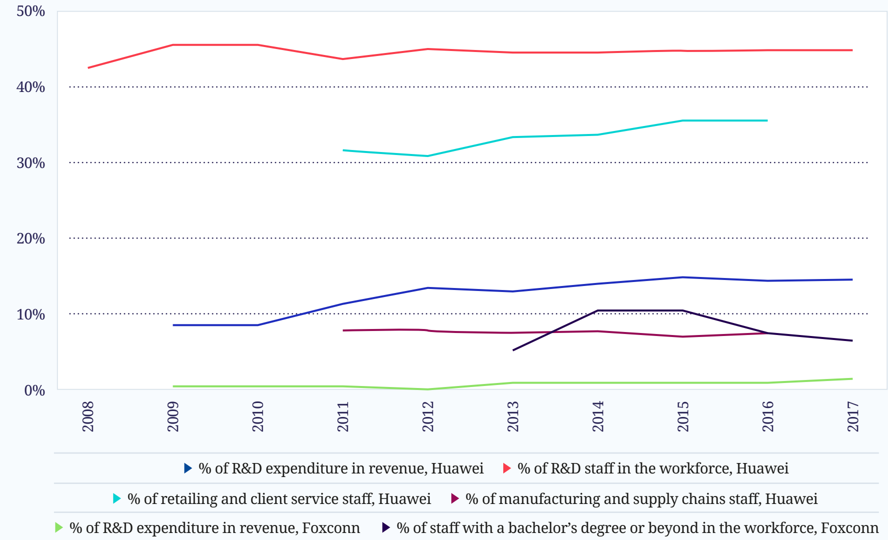
Compared with Foxconn, Huawei invests a higher percentage of revenue in R&D and has a higher percentage of R&D staff in its workforce. As shown in figure 48, between 2009 and 2017 the percentage of R&D expenditure in revenue at Huawei gradually increased from around 9 to 15 per cent; in contrast, this percentage of Foxconn increased from some 0.5 to around 1.5 per cent. As a result, between 2008 and 2017 R&D staff at Huawei

▶ Figure 47. Net profit margins at Huawei and Foxconn, 2007–17



Source: Huawei 2018a; Foxconn 2018a.

▶ Figure 48. R&D expenditure and workforce composition at Huawei and Foxconn, 2007–17



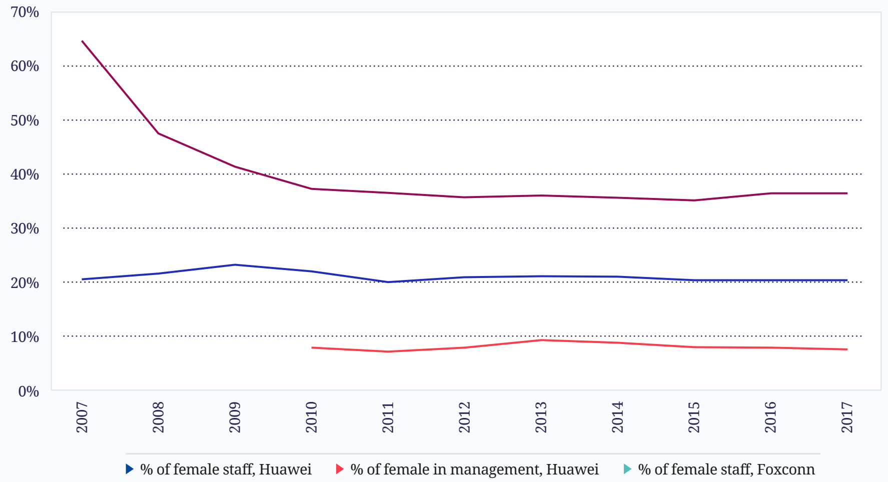
Sources: Huawei 2018a, 2018b; Foxconn 2018a, 2018b.

maintained a level of approximately 45 per cent. We do not have the data on R&D staff at Foxconn. But between 2013 and 2017 the percentage of staff with a bachelor's degree or beyond in its workforce (not all of them engaged in R&D) was significantly lower than the percentage of R&D staff in Huawei's workforce. Within Huawei, R&D staff were the largest share of the workforce, followed by around 30 per cent in retail and client service staff, and less than 10 per cent of manufacturing and supply chain staff thanks to mass outsourcing to factories such as Foxconn (Huawei 2018b).

Huawei has a more masculinized workforce than Foxconn. Figure 49 shows that between 2007 and 2017, despite Foxconn's preference for female workers, and owing to the facts that the majority of Foxconn workers were workers from rural areas among whom more males migrated into cities than females, and that the number of female migrants was falling (Feng 2017), the percentage of female staff at Foxconn dropped from 64.1 to 36.0 per cent; in comparison, at Huawei the percentage of female staff stagnated at 20 per cent with the percentage of females in management around 7 to 9 per cent.

Huawei workers receive a larger share from the revenue than Foxconn workers; on average their compensation package is seven to ten times of that of the latter. Figure 50 shows that between 2010 and 2017 the share of labour costs in revenue at Huawei in-

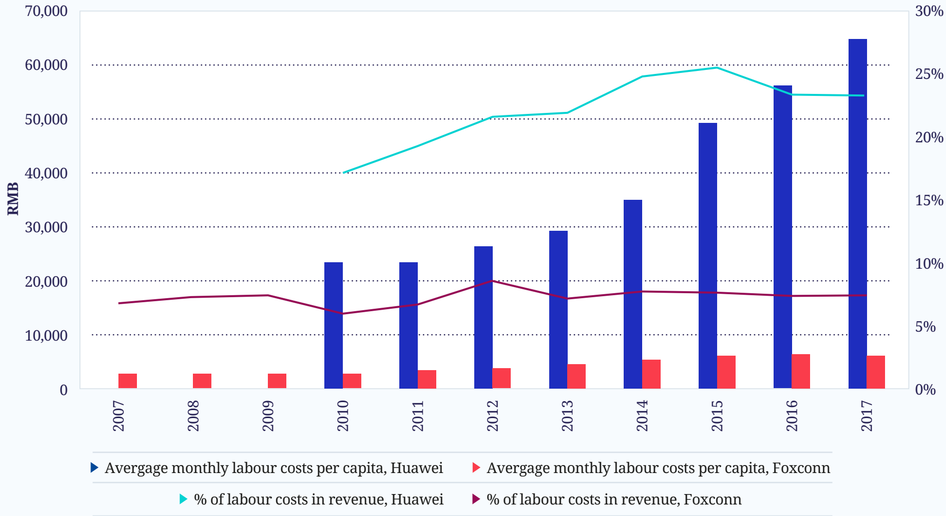
▶ Figure 49. Female staff at Huawei and Foxconn, 2007–17



Note: Data on female management at Huawei between 2010 and 2012 refer to the percentage of females in middle and senior levels of management; data for 2013–17 refer to the percentage of females at all levels of management.

Sources: Huawei 2018b; Foxconn 2018b.

▶ Figure 50. Labour costs at Huawei and Foxconn, 2007–17



▶ Note: Labour costs here include all costs for staff wages and benefits, including rank-and-file workers (production workers, marketing workers, and others) and management, incumbent and retired staff.

▶ Sources: Huawei 2018a, 2018b; Foxconn 2018a, 2018b.

creased from 17.2 to 23.2 per cent while at Foxconn it was around 7 per cent between 2007 and 2017.[21] Between 2010 and 2017 the average monthly labour costs per capita at Huawei increased from 23,329 to 64,947 RMB; between 2007 and 2017, such costs at Foxconn increased from 2,310 to 5,723 RMB.

Working hours at Huawei are notoriously long. At Foxconn, it was reported in 2017 that student interns at the Zhengzhou branch worked 11 hours per day. There is no evidence showing that formal workers worked shorter hours than student interns during peak seasons (BBC 2017). At Huawei, as mentioned earlier, the average overtime per day per capita was 3.96 hours in 2016, amounting to an average working time per day of 11.96 hours. In a Zhihu thread, Huawei workers reported that there was no clear distinction between official working time and off-duty time, between workdays and weekends or national holidays; working hours were inhumanely long: single workers did not have time to find a partner or to maintain a relationship; married people did not have time to fulfil family obligations; some male workers were refused to have even one day off when their wives were giving birth. Moreover, Huawei did not pay for overtime during workdays (Zhihu 2019a).

21 In fact, the labour share of frontline workers in revenue at Foxconn significantly increased in the early 2000s (from 2.63 per cent in 2002 to 5.67 per cent in 2013). For more details, please refer to Feng 2017.

Jobs at Huawei are not secure in absolute terms, but Foxconn has higher turnover rates than Huawei. A research paper (Feng 2017) mentions that in 2014 the monthly turnover rate on Foxconn's shop floor was more than 20 per cent and the majority of the rank-and-file workforce was replaced almost every six months. Huawei's corporate social responsibility (CSR) reports show that between 2007 and 2010 the annual turnover rate was between 6 and 10 per cent. Many Foxconn workers rely on overtime to increase their overall wage. When Foxconn could not get enough orders to keep workers working overtime, these workers would leave the factory in search of better-paid jobs. Dismissals may happen, but voluntary resignations are more common.[22] With the slump of Apple sales in China in 2018, many Foxconn workers resigned (Qian 2018).

In comparison, Huawei workers tend to have fewer voluntary resignations and more dismissals. In 2007, to circumvent the provision concerning open-ended contracts[23] of the impending *Labour Contract Law* that would come into effect from the first day of 2008, Huawei forced all workers with an employment record of over eight years with Huawei to resign and then re-sign contracts of one to three years with it on a competitive basis (Beijing Youth 2007). Since then, the mass media repeatedly report that Huawei dismisses staff who are over 35 years old. While Huawei always negates these news reports, the online postings of those who have been dismissed confirms the existence of these dismissals. It is just unclear how many are involved. The latest news report of this kind came out in late 2018 and continued to swirl around in 2019. It was reported in January 2019 that the founder of Huawei mentioned in an internal circular that dismissals were inevitable in the face of soaring labour costs and the boycott of Huawei telecoms equipment in some of the US's ally countries (Lu 2019). Whether dismissals of staff over 35 years old take place on a small or large scale, the total headcount of Huawei has been growing and the workforce at Huawei is ageing rapidly. According to the CSR reports on Huawei, between 2011 and 2017 the proportion of staff in the 30-or-younger age group dropped from 51 to 27.6 per cent, while the proportion of those in the 30–50 age group increased from 48 to 70.7 per cent. Given that elderly workers are more likely to be in costly positions than young workers, the fast-ageing workforce at Huawei will certainly trigger accelerating growth in its labour costs, which lends some credibility to the news reports above.

In addition, Huawei uses agency workers and outsourced workers in large numbers, whose jobs are more insecure than those of formal workers. One of Huawei's outsourced workers was reported to have committed suicide at the workplace, and another was

22 Information from the author who used to work at Foxconn and did research on working conditions at that company between 2014 and 2016.

23 According to the *Labour Contract Law*, employers should sign open-ended contracts with employees once the latter have worked with the former for ten years or have signed two consecutive contracts with the former.

reported to have been found dead after working for extremely long hours for several months (Xinshengdai 2016).

Trade unions at both Foxconn and Huawei are not functioning well. In 2007, Foxconn established an enterprise-level trade union. According to an investigation carried out in 2013, only 24.6 per cent of Foxconn workers thought that they were union members; only about 20 per cent thought that the Foxconn trade union had helped to increase their wages or protect their rights; 94.7 per cent had never participated in union elections in any form; and 90.2 per cent knew nothing about the elections in Foxconn's factories in mainland China (Feng 2017).

The counterpart to Foxconn's trade union at Huawei is an agglomeration of the employees' congress owning Huawei stock and an enterprise-level trade union that is registered as a branch of the ACFTU. Huawei is not a publicly listed company, but the older generation of its employees were able to buy its privately issued stock. According to its 2011 CSR report, 65,596 of its estimated 140,000 staff owned Huawei stock. Stock ownership, however, while giving employee owners access to year-end dividends, does not allow them to engage in collective bargaining on labour rights with the management. Huawei employees need to apply to become members of its trade union. In 2019, the committee of the Huawei trade union had seven members, none of them directly elected by Huawei employees. Two were members of Huawei's supervisory board and the other five were departmental managers recommended by their departments. The trade union at Huawei has no influence on its operating decisions at all; its main function is to organize refreshment activities such as sports and photography (Jiang 2019).

Working conditions at Geely

As mentioned in Chapter 2, in 2017 Geely was the most popular brand for passenger cars and light business vehicles in China. Geely began to make cars in the 1990s. In 2017 the company sold 1,247,116 cars, over 99 per cent of them in China, in contrast to Huawei which has established a global foothold. In 2017 the average before-tax price of Geely cars was 73,550 RMB (Geely Auto 2019a). An average Geely car fell into the price range of 50,000–80,000 RMB (total including tax of 10 per cent) in which Chinese-brand cars made up 70 per cent of the domestic market share in the first seven months of 2017. Compared with Huawei, Geely's path towards OBM relies more on price competitiveness, which limits the possibilities for improvement in its working conditions amidst product upgrading.

Geely has created jobs, including lots of skilled jobs. Figure 51 shows that between 2008 and 2017, with unit sales sextupled, the number of employees increased from 9,945 to 41,600. It is reported that in 2017 Geely had some 12,000 staff engaged in R&D, that is,

Figure 51. Employee numbers and unit sales at Geely, 2008–17

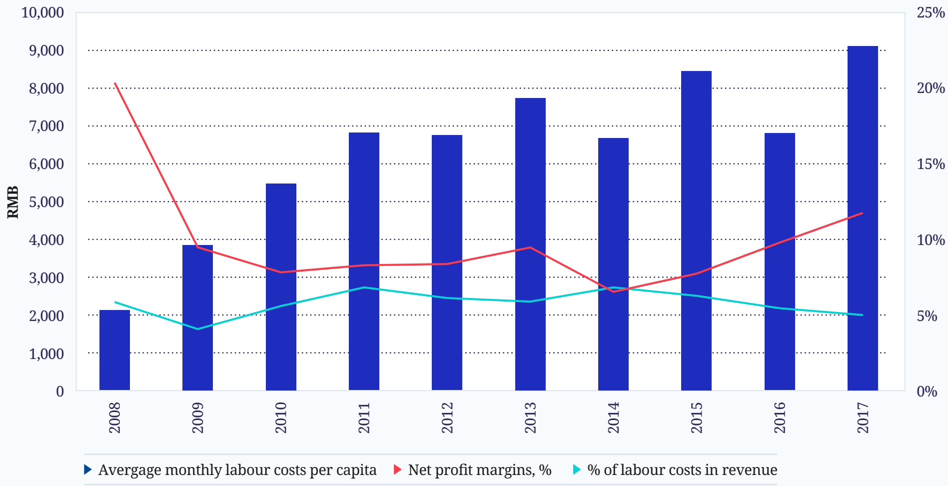
Note: The number of employees at Geely includes agency workers and interns.
Source: Geely Auto 2019a.

28.8 per cent (Auto Daily 2018). Its workforce is predominantly male; according to the CSR reports, between 2015 and 2017 the proportion of female staff in its workforce dropped from 14.7 to 12.4 per cent (Geely Auto, 2019b).

The low labour share of revenue at Geely reflects the impacts of a low-price-driven market share enlargement strategy on workers. After the 2008 global financial crisis, the net profit margins of Geely slumped to 6–7 per cent before rebounding to 11.6 per cent in 2017 (figure 52). At the same time, the labour share of revenue at Geely stagnated at 5–6 per cent. Nonetheless, the monthly labour costs per capita increased from 2,078 RMB in 2008 to 9,091 RMB in 2017.

Working hours at Geely are also long. Workers report that the common off-duty time is 8 p.m., both in the office and on the shop floor, and workers normally work six days a week. Jobs at Geely are hardly secure. According to the annual CSR reports, between 2015 and 2017 the annual staff turnover rate was 15–17 per cent; formal employees and interns made up some 80 and 20 per cent of the workforce respectively; and Geely also used a few agency workers (Geely Auto 2019b). The mass deployment of interns, mainly student interns, enables Geely to cut labour costs and maintain workforce flexibility at the same time. Student interns are mainly from vocational schools or junior colleges. Internships at factories, whether relevant or irrelevant to students' major fields of study,

▶ Figure 52. Labour costs at Geely, 2008–17



Source: Geely Auto 2019a.

are often used as a precondition for the conferral of diplomas by their schools. Albeit illegal, this kind of practice has been popular in China for many years (Smith and Chan 2015). Geely is reported to use this practice as well (Zhihu 2019b). In addition, Geely is often reported to dismiss workers when its sales go down temporarily. Geely's 2017 CSR report reveals that all staff were trade union members, but despite the recurring outpouring of grievances by Geely workers online, this report has no accounts of what the trade union did to safeguard workers' rights (Geely Auto 2019b).

4 Synchronizing technological and social upgrading in China: Challenges and efforts made

Chapter 1 of this report provides a toolkit on how to synchronize technological and social upgrading, which mainly includes education and training, better governance to harness the technological shock, and collective action of labour. As discussed in Chapter 3, technological upgrading in China, while creating jobs in the parts and components industry and in general, has been associated with displacement of low-skilled workers, shortage of certain skilled workers, poor job security, under-representation of and discrimination against women in the skilled workforce in certain industries, unlawfully prolonged working hours, and poor union representation. In addition, the penetration of management software into the workplace reduces workers' control over the labour process.

This chapter examines how the toolkit to synchronize technological and social upgrading has played out in the Chinese context, including efforts that various entities have made and challenges they have faced. It is worth noting that the Chinese State plays an overarching role in coordinating economic and social development, and it always pursues multiple policy agendas at the same time. This chapter includes policies that are not aimed at the synchronization of technological and social upgrading but have ramifications for it.

4.1 Education and training

Chapter 3 explains that the ongoing technological upgrading has suffered from a shortage of certain kinds of skilled workers and has reduced the demand for low-skilled workers in a context of dual shortage of both skilled and low-skilled workers. Education and training on the one hand can alleviate the shortage of skilled workers, and on the other hand helps to buffer the technological shock for low-skilled workers by reskilling them. This section first provides an overview of China's efforts in education to serve technological upgrading in general. It then narrows its focus to examine how China's education and training system has been tailored to cater for the skills needs of the MIC 2025.

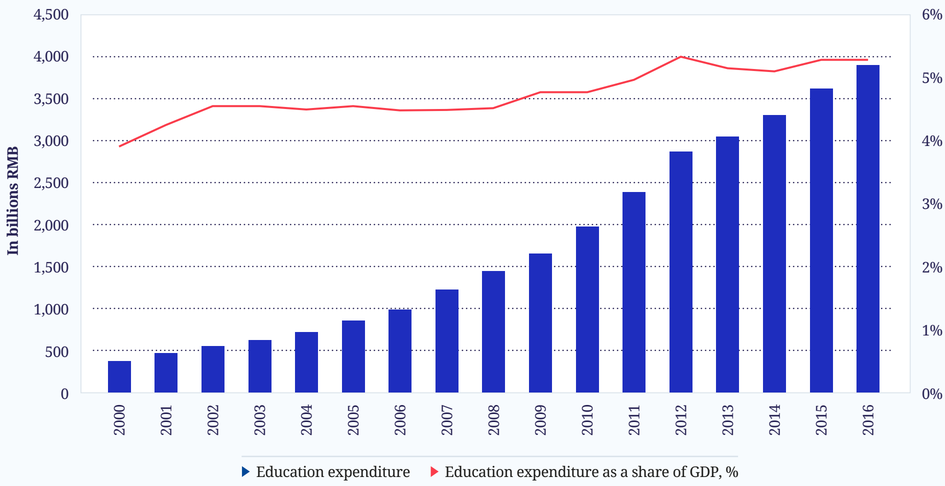
4.1.1 Education to serve technological upgrading in general

In China, most educational institutions are public; the role of private capital in the education sector is limited. Since the beginning of the new millennium, China has dramatically increased its investment in education. In retrospect, China's efforts to forge a skilled workforce to feed the technological upgrading has been uneven. At both the secondary and tertiary education level, priority has been put on academic over vocational education: academic educational institutions tend to get more funding per student and attract more students. On top of this, vocational education in China is of dubious quality. The long-lasting priority given to academic education can help to alleviate the shortage of white-collar skilled workers, but the relative lack of vocational education aggravates the shortage of much-needed blue-collar skilled labour. In addition, in recent years, women have gained ground in both secondary and tertiary academic educational institutions, and in tertiary vocational educational institutions, but have lost ground in secondary vocational educational institutions. This trend suggests improved representation of women in the white-collar skilled workforce and worsened female representation in the blue-collar skilled workforce.

In recent decades, China has seen ever-increasing expenditure on education. Figure 53 shows that expenditure in 2016 was almost ten times of that in 2000; between 2000 and 2016, the share of education expenditure in GDP gradually grew from 3.9 to 5.3 per cent. Public finance contributes most of education expenditure and this share has expanded in the past two decades. It can be calculated that between 2000 and 2016, the Government's contribution to education expenditure, though once dropping to a 61.3 per cent low in 2005, showed an overall upward trend: it grew from 66.6 per cent in 2000 to 80.7 per cent in 2016; by contrast, contributions from individuals dropped from 15.5 per cent in 2000 to 12.3 per cent in 2016; while the contribution by entities other than the State and individuals, including enterprises, dropped from 18.0 per cent in 2000 to 7.0 per cent in 2016 (Ministry of Education 2017a). The continuous financial input into the education system has improved the education levels of Chinese citizens. Since the beginning of the new millennium, higher educational institutions have produced ever-expanding numbers of graduates, in particular engineering graduates, whom the ongoing technological upgrading badly needs. It can be calculated that between 2002 and 2016 among all Chinese aged six and over, the proportion of junior college and college graduates increased from 4.7 to 13.9 per cent; the proportion of graduates from high schools or equivalents grew from 12.5 p to 17.6 per cent; and the percentage of those who never went to school and only went to primary schools dropped from 45.2 per cent to 30.5 per cent (National Bureau of Statistics 2019a).

At the level of tertiary education, the Government has constantly given priority to academic over vocational education. Compared with employment-oriented junior colleges,

▶ **Figure 53. Education expenditure in China, 2000–2016**

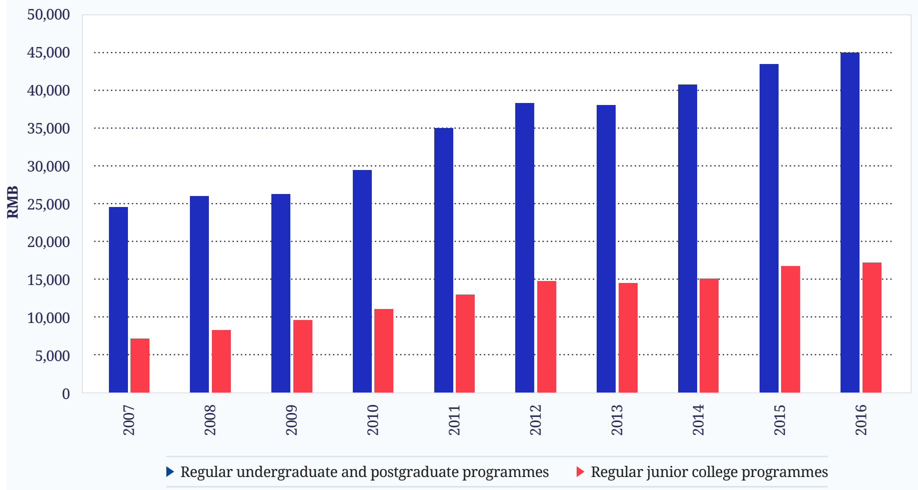


▶ Sources: Ministry of Education 2001a–2017a; National Bureau of Statistics 2019a.

universities get more funding from the Government per student and are authorized to take in more students. Figure 54 shows that between 2007 and 2016 average education expenditure per student both in regular undergraduate and postgraduate programmes and in regular junior college programmes increased steadily although it remained significantly higher in the former than in the latter. Nonetheless, the gap between the two was narrowed between 2007 and 2016: it can be calculated that educational expenditure per student in regular junior college programmes made up 28.3 per cent of that in regular undergraduate and postgraduate programmes in 2007, rising to 37.7 per cent in 2016. Meanwhile, between 2007 and 2016, after finishing secondary education, students were increasingly likely to be enrolled in undergraduate programmes rather than in junior college programmes. In 2007, 48.9 per cent of high-school graduates who continued education joined regular undergraduate programmes; in 2017, this proportion was 53.9 per cent (Ministry of Education 2008b, 2018b).

Secondary education in China is biased in the same way. It can be divided into two parts: academic education in high schools that tends to lead to tertiary education, and vocational education in secondary vocational schools that produces future cooks, clerical staff, tour guides, crane operators, automobile mechanics and the like. As shown in figure 55, between 2004 and 2017 enrolment in high schools stagnated while enrolment

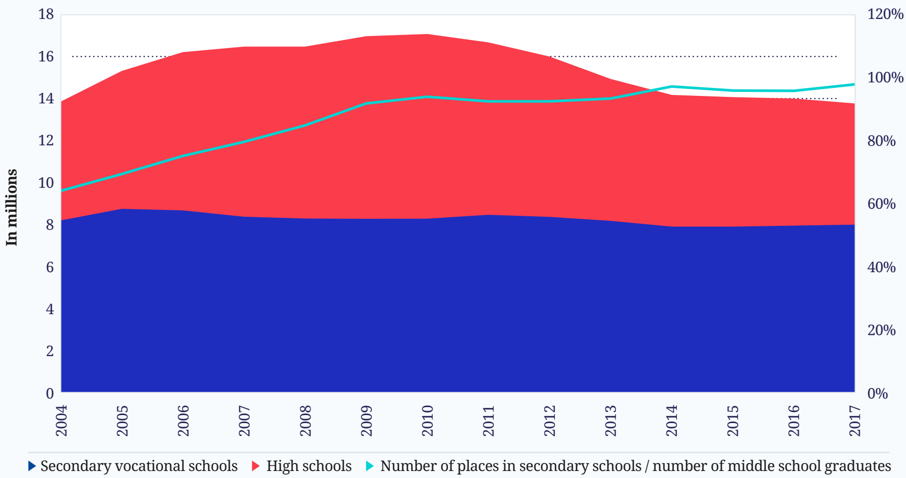
▶ Figure 54. Education expenditure per student in undergraduate, postgraduate, and junior college programmes, 2007–16



Source: Ministry of Education 2008a–2017a, 2008b–2017b.

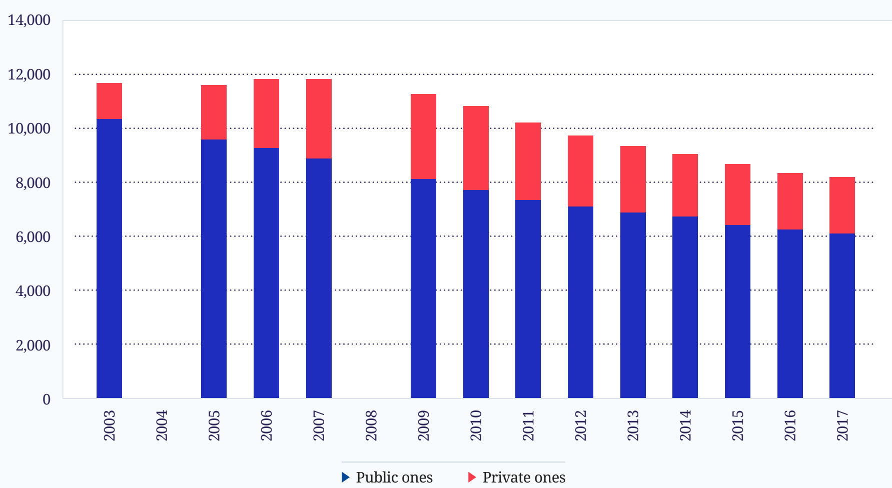
in secondary vocational schools significantly increased between 2004 and 2010 and then started to drop. It can be calculated that, at the peak level, in 2009, 51.1 per cent of enrolment in secondary education was in secondary vocational schools; however, in 2017, the percentage was merely 42.1 per cent. Behind the scenes lies the decrease in the number of secondary vocational schools: in recent years the Government has closed a number of poorly resourced secondary vocational schools (Li 2019). Figure 56 shows that between 2003 and 2017 the number of public secondary vocational schools shrank steadily; the number of private secondary vocational schools grew between 2003 and 2009 and dropped between 2010 and 2017. Moreover, according to the same data source, relative to the number of middle school graduates the number of places in high schools and secondary vocational schools increased rapidly. In 2004 the number of secondary-education places made up only 64.4 per cent of the number of middle school graduates; in 2017 the percentage was 98 per cent. In other words, the expansion of secondary education in China is reaching its limit, if has not already done so, given that many secondary vocational schools cannot fulfil the enrolment quota authorized by the Government (China Youth 2011).

▶ Figure 55. Distribution of enrolment between high schools and secondary vocational schools, 2004–17



- Note: Data on enrolment in secondary vocational schools include enrolment in adult institutions. Data on enrolment in adult high schools are unavailable. The available data show that the number of graduates in adult high schools each year is less than 10 per cent of the number of graduates in regular high schools.
- Source: Ministry of Education 2005b–2018b.

▶ Figure 56. Number of secondary vocational schools in China, 2003–17

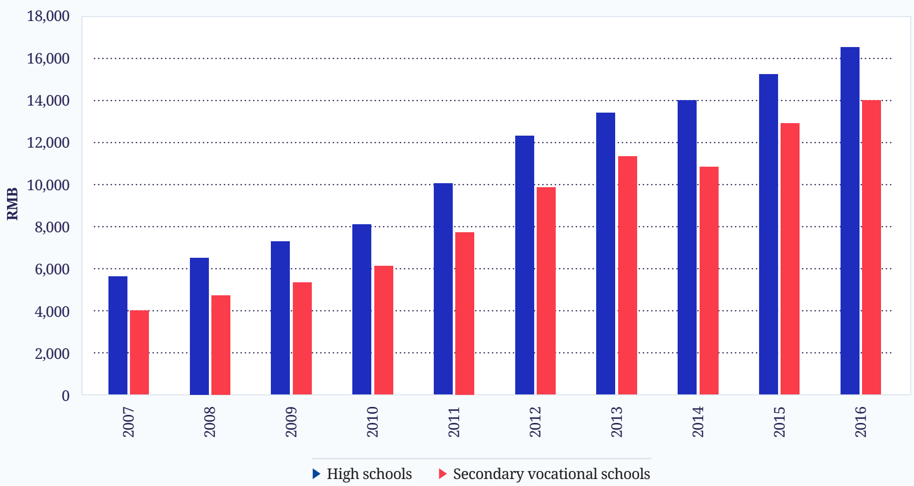


- Note: Owing to the limitation of data, this figure does not include skilled worker schools, which is one type of secondary vocational school in China.
- Source: Ministry of Education 2004b–2018b.

Moreover, as with the case of tertiary education, vocational education at the secondary level is poorly funded compared with academic education. Figure 57 shows that between 2007 and 2016 education expenditure per student in both high schools and secondary vocational schools steadily increased; but expenditure per student in high schools constantly remained higher than that in secondary vocational schools, although the gap was narrowed over the years. Consequently, the quality of secondary vocational schools in China is questionable. Based on participant observation in Nanning, Jiangsu in 2007 and 2008, Terry Woronov found that teachers in these schools often had low levels of commitment and little teaching experience because they were on short-term contracts or were teaching part-time; students tended to sleep during class and spent little energy learning (Woronov 2015). Other studies on vocational schools in China reveal the poor credentials of the teaching staff in these schools, the pervasive incongruity between the content of courses and the demand of related professions, and the incongruity between the major studies of vocational students and the compulsory internship programmes, among other problems (Lv 2018; Hu, Liu and Wu 2010; Chen 2018c).

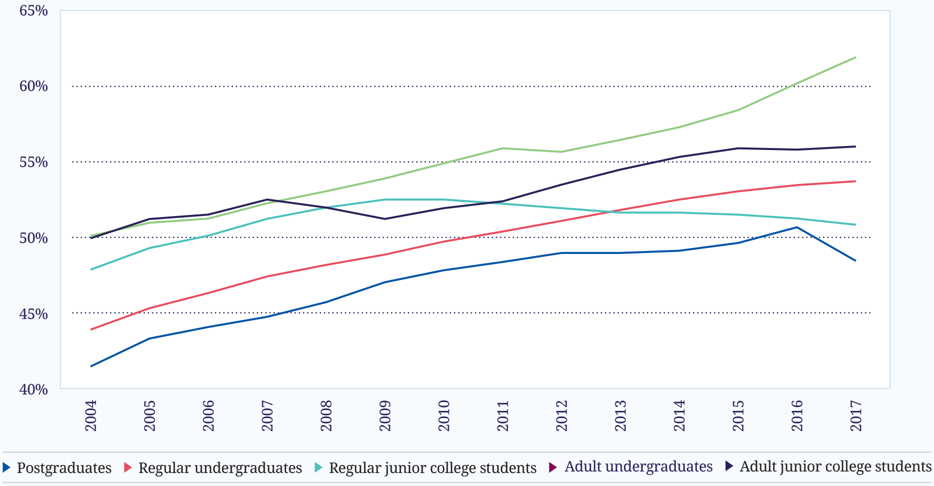
Female students are increasingly well or even over-represented at the college level (not necessarily in sciences and engineering majors though) and in high schools, but are losing representation in secondary vocational schools. Figure 58 shows that between 2004 and 2017 the proportion of female students among incumbent students in all categories of

Figure 57. Education expenditure per student in high schools and secondary vocational schools, 2007–16



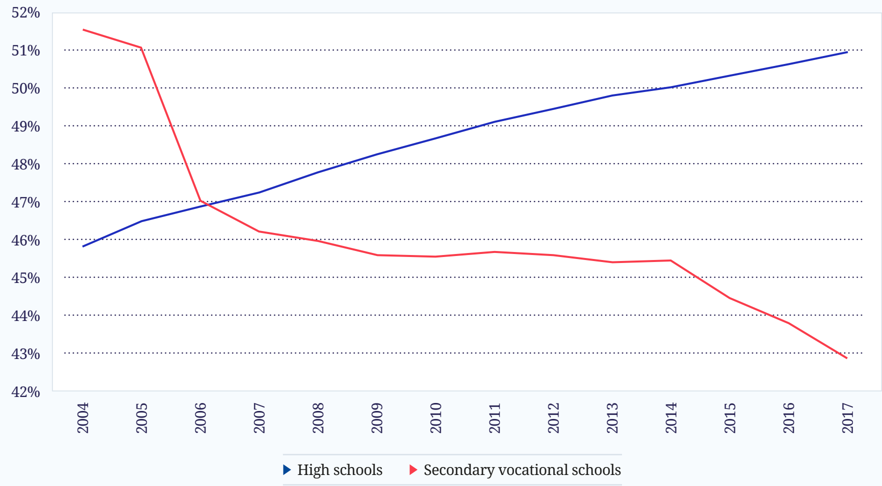
Source: Ministry of Education 2008a–2017a, 2008b–2017b.

Figure 58. Proportion of female students among incumbent students in higher educational institutions, 2004–17



Source: Ministry of Education 2005b–2018b.

Figure 59. Proportion of female students among incumbent students in secondary educational institutions, 2004–17



Note: Owing to the limitation of data, the calculation of the proportion of female students in secondary vocational schools in 2004 and 2005 does not cover skilled worker schools, which is one type of secondary vocational school in China.

Source: Ministry of Education 2005b–2018b.

tertiary education programmes showed an upward trend. In postgraduate programmes the percentage of female students rose from 41.6 per cent in 2004 to 50.6 per cent in 2016 before dropping; in regular undergraduate programmes this percentage increased from 43.9 to 53.7 per cent; in both adult undergraduate and junior college programmes females were already well represented in 2004 and were slightly over-represented in 2017. As shown in figure 59, in high schools female students were under-represented in 2004 and properly represented in 2017; however, in secondary vocational schools, between 2004 and 2017 the proportion of female students decreased dramatically.

4.1.2 Education and training to serve the MIC 2025

The Chinese Government is well aware that the shortage of skilled labour may stunt the implementation of the MIC 2025. Moreover, employers in China complain about the mismatch between the skills employees have and the skills they look for. According to a survey conducted with private enterprises in China in 2015, 30 per cent of employers surveyed said that "there are lots of jobseekers but few have the expected credentials"; and 70 per cent said that "the knowledge students acquired in college is not practical enough and employers have to re-train them" (Li and Yuan 2016). Against this background, in December 2016 the central government issued the *Guidance for the Development of Manufacturing Talent*, which is a supporting document to the MIC 2025 and a masterplan that aims to reform the education and training system to better serve the skills needs of the MIC 2025. The *Guidance* identifies the main problems associated with the current manufacturing workforce as the co-existence of structural labour surplus and shortage, the incongruity between the programmes of educational institutions and the needs of manufacturing enterprises, the lack of on-the-job training, and the low social status and compensation for skilled labour. Thus, according to the *Guidance*, the solution lies in reforming the education and training system, which concerns the programmes offered, the suppliers of education and training, the capabilities that graduates from manufacturing-related education and training programs are expected to have, and so on (Ministry of Education 2017d).

In retrospect, the Government has maintained its focus on academic education but has diverted more attention to vocational education and training. With regard to academic education, many universities have set up new programmes and expanded related programmes in the ten key fields listed in the MIC 2025. With regard to vocational education, the Government has planned to expand vocational education at both the secondary and tertiary levels, and has encouraged enterprises to play a larger role in the supply of training. The Government has also introduced policies to promote training for groups with low employability and the working population in general.

Academic education

So far, the most tangible progress in the education sector to serve the MIC 2025 has been the expanded offering of programmes, mainly at the level of higher education, in the ten key fields for technological upgrading listed in the MIC 2025. In fact, even before the introduction of the *Guidance*, in reaction to acute skilled labour shortages in several burgeoning fields some higher educational institutions have begun to offer or expand their offering of corresponding degree programmes. Such expansion has been uneven: while nine key fields listed in the MIC 2025 have seen enrolment expansion in related engineering disciplines in higher educational institutions, the field of agricultural machinery has witnessed enrolment decline in the discipline of Agricultural Engineering. The effectiveness of such expansion in alleviating certain labour shortages has also been compromised by the facts that engineering graduates increasingly seek jobs outside manufacturing (as mentioned in Chapter 3) and the dubious quality of some programmes.

Before we move further to details, basic knowledge of the system at China's higher educational institutions is necessary. There are 13 elementary disciplines in China, including engineering, science, literature, law, and so on. The elementary discipline of engineering is further categorized into over 20 secondary engineering disciplines such as mechanics, materials, computers, and the like. The secondary disciplines are further subdivided into tertiary disciplines. For example, the secondary engineering discipline Computer is divided into more specific disciplines such as software engineering, web engineering, and so on. This categorization is subject to updating as time goes by. Table 15 shows the major corresponding secondary engineering disciplines that each of the ten key fields listed in the MIC 2025 directly relies on. Changes in enrolment and the number of degree programmes in certain disciplines will reflect how the higher education system caters to the skills needs of technological upgrading in China.

Higher educational institutions have been responsive to the engineering skills needs of China's technological upgrading. Between 2003 and 2010, both in regular junior colleges and in regular undergraduate and postgraduate programmes, the enrolment of engineering students, the percentage of engineering enrolment in overall enrolment, and the enrolment of students in engineering disciplines underpinning the MIC 2025 all showed an upward trend (figure 60). Between 2012 and 2016, in regular undergraduate programs all the above three indicators also increased. It can be calculated from figure 60 that between 2003 and 2016 enrolment in engineering disciplines underpinning the MIC 2025 accounted for 70–80 per cent of overall engineering enrolment.

Considering table 11 (in section 3.1.1) and figure 60 together, we find that to a large extent the enlargement in enrolment for certain disciplines has been in tune with the severity of the skills shortages in certain fields, except for the discipline of Agriculture

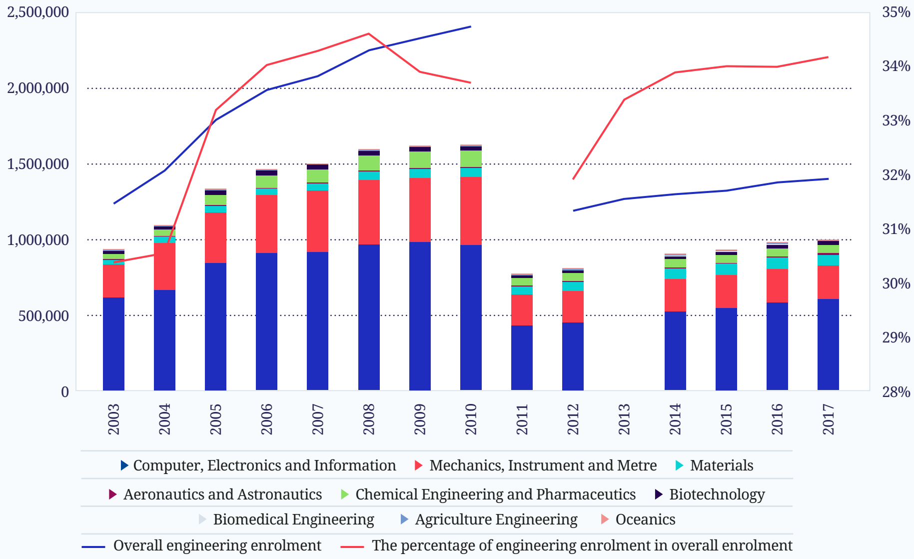
▶ Table 15. The ten key fields of MIC 2025 and their corresponding secondary engineering disciplines

Key fields	Major corresponding secondary engineering disciplines
New-generation information technology	Computer, Electronics and Information
Equipment for electricity generation and distribution	Electronics and Information, Mechanics, Instrument and Metre
High-end machine tools and robots	Automation, Mechanics, Instrument and Metre
New materials	Materials
Energy-saving and new energy automobiles	Mechanics, Instrument and Metre, Electronics and Information, Materials
Aeronautical and astronautic equipment	Aeronautics and Astronautics, Mechanics, Instrument and Metre
Biomedicine and high-performance medical equipment	Biotechnology, Biomedical Engineering, Chemical Engineering and Pharmaceutics, Materials, Mechanics, Instrument and Metre
Agricultural machinery	Agriculture Engineering, Mechanics, Instrument and Metre
Maritime engineering equipment and high-tech watercraft	Oceanics, Mechanics, Instrument and Metre
Advanced rail transit equipment	Mechanics, Instrument and Metre

- Note: The ten key fields are arranged in descending order according to the projected skills gap they will suffer from in 2020 and 2025. For more details see table 11 in section 3.1.1.
- Sources: Compiled from State Council 2015a and Ministry of Education 2017c.

Engineering and the field of agricultural machinery. According to table 11, the field of new-generation information technology is foreseen to experience the largest skill gap among the ten key fields in the MIC 2025 in the near future. According to figure 60, Computer, and Electronics and Information, two secondary engineering disciplines that prepare the workforce for the new-generation information technology industry, made up

▶ **Figure 60. Engineering enrolment in regular higher educational institutions, 2003–17**



▶ Note: Data on enrolment between 2003 and 2010 include enrolment in regular junior colleges and undergraduate and postgraduate programmes; while data on enrolment between 2011 and 2017 only include enrolment in regular undergraduate programs. Thus, in this figure, only data within individual time frames such as 2003–10 or 2011–17 are comparable.

▶ Source: Ministry of Education 2004b–2018b.

the lion's share (40–50 per cent) of engineering enrolment throughout 2003 to 2016; and the enrolment in these disciplines between 2003 and 2016 had both expanded.

Of the ten key fields in the MIC 2025, eight are related to equipment and vehicle manufacturing. Two secondary engineering disciplines – Mechanics, and Instrument and Metre – prepare skilled workers for these eight fields. Figure 60 shows that between 2003 and 2017 the combined enrolment in these two disciplines was the second largest enrolment in all secondary engineering disciplines underpinning the MIC 2025; these enrolments more than doubled between 2003 and 2010 but nearly stagnated between 2011 and 2017. According to table 11, with regard to the extent of projected skills shortages in the near future, the field of new materials ranked fourth. As shown in figure 60, between 2003 and 2010 enrolment in Materials grew less quickly than that in Chemical Engineering and Pharmaceutics; but between 2011 and 2017 enrolments in the former ranked third in all individual secondary engineering disciplines underpinning the MIC 2025. In addition, between 2011 and 2017 enrolment in Aeronautics and Astronautics, Chemical Engineering and Pharmaceutics, Biotechnology, Biomedical Engineering, and Oceanics all showed an upward trend, while enrolment in Agriculture Engineering made a U-turn, with enrolment in 2017 lower than in 2011.

Behind the scenes lies the increased number of engineering programmes. Colleges and universities need approval from the Education Ministry before they can offer new programmes. As shown in table 16, between 2010 and 2017, some 700–900 new undergraduate programs in engineering were authorized by the Government every year. Engineering programmes accounted for approximately 40 per cent of all newly authorized undergraduate programmes. This expansion outshone that of science programmes by a wide margin, reflecting the emphasis on practical and technical education rather than abstract and theoretical education.

Table 17 breaks down the number of newly authorized undergraduate programmes shown in table 16 into the ten key fields listed in the MIC 2025, thereby further explaining

▶ Table 16. Newly authorized undergraduate programmes in engineering and sciences in China's regular higher educational institutions, 2010–18

	Engineering, number	Engineering, %	Science, number	Science, %
2010	784	39.4	242	12.2
2011	761	41.1	204	11.0
2012	861	32.2	249	9.3
2013	657		177	
2014	690		148	
2015	856		213	
2016	786		227	
2017	907	39.2	299	12.9
2018	912		242	

▶ Note: In each year, the Ministry of Education also suspends some undergraduate programmes. But according to the data source, the number of newly suspended programmes is usually less than 5 per cent of the number of all newly authorized programmes. The newly authorized programmes are open for enrolment in the following year.

▶ Source: Ministry of Education 2019.

the dynamics of figure 60. Fields that are projected to expect a larger skill gap in 2020 and 2025 often have more newly authorized undergraduate programmes. The number of such programmes in the field of new-generation information technology outnumbered that of other fields by a wide margin. However, despite the foreseen labour shortages, the field of aeronautical and astronautic equipment witnessed only modest growth in the number of undergraduate programmes. In the field of agricultural machinery, such growth barely existed.

Table 17. Number of newly authorized undergraduate programmes in the ten key fields of MIC 2025, 2010–18

	2010	2011	2012	2013	2014	2015	2016	2017	2018
New-generation information technology	172	241	307	220	182	252	238	446	470
Equipment for electricity generation and distribution	21	35	27	20	24	21	26	17	14
High-end machine tools and robots	57	50	44	16	38	36	66	81	107
New materials	71	55	42	43	47	64	48	54	45
Energy-saving and new energy automobiles	23	31	49	25	45	47	29	22	14
Aeronautical and astronautic equipment	6	3	7	1	5	13	15	26	18
Biomedicine and high-performance medical equipment	68	63	91	45	59	74	66	58	55

	2010	2011	2012	2013	2014	2015	2016	2017	2018
Agricultural machinery	0	0	0	2	0	1	0	0	1
Maritime engineering equipment and high-tech watercraft	6	10	6	0	5	6	4	2	4
Advanced rail transit equipment / Mechanics, Instrument and Metre	106	94	143	82	109	108	117	64	35

Notes: This table covers programmes in tertiary disciplines that are related to the ten key fields in the MIC 2025. The scope is slightly larger than that of table 15, which covers only related secondary disciplines. Several tertiary disciplines not mentioned in table 15 are related to the MIC 2025, too. They have been chosen by comparing the MIC 2025 document and the 2012 and 2017 edition of the List of Disciplines at the Undergraduate Level in China issued by the Ministry of Education. This table only covers programmes in engineering and science.

The number of newly authorized undergraduate programmes in individual fields includes only programmes in disciplines that are peculiar to that field (except for the field of advanced rail transit equipment, which does not have special disciplines in China). The number of programmes in the field of advanced rail transit equipment is same as the number of programmes in the disciplines of Mechanics, and Instrument and Metre.

The ten key fields are arranged in descending order according to the projected skills gap they will suffer from in 2020 and 2025. For more details, see table 11 in section 3.1.1.

Sources: Ministry of Education 2019, 2012c, 2017c.

Higher educational institutions in China have paid particular attention to disciplines that underpin the burgeoning process technologies. As shown in table 18, after the launch of the MIC 2025 in 2015, new undergraduate programmes in Robotics Engineering, Data Science and Big Data Technology, AI, and Unmanned Driving came into being and expanded explosively; the number of undergraduate programmes in Intelligent Science and Technology grew slowly between 2010 and 2016 and rapidly in 2017 and 2018. The number of undergraduate programmes in IoT Engineering increased dramatically between 2011 and 2015 and continued to expand thereafter, though at a slower pace. Between 2010 and 2017, the number of undergraduate programmes in Software Engineering also grew fast.

None of the above rapidly expanding programmes was included in the 2010–15 list of undergraduate programmes with low employment rates in China (Gaokaobang 2017), which indicates that the expansion of these programmes contributes more to narrowing the skills gap than to creating new labour surplus. But expansion in the number of programmes offered does not necessarily mean improvement in the match between the

Table 18. Number of newly authorized undergraduate programmes in tertiary engineering disciplines concerning process technology

	2010	2011	2012	2013	2014	2015	2016	2017	2018
Robotics Engineering	0	0	0	0	0	1	25	60	102
Software Engineering	28	36	39	26	30	35	37	23	11
IoT Engineering	25	80	126	85	54	61	37	27	14
Data Science and Big Data Technology	0	0	0	0	0	3	32	250	203
AI	0	0	0	0	0	0	0	0	35
Intelligent Science and Technology	3	2	2	3	2	2	7	19	96
Unmanned Driving	0	0	0	0	0	0	1	3	9

Sources: Ministry of Education 2019, 2012c, 2017c.

education offered by universities and the needs at enterprises. For example, graduates from the explosively increased IoT programmes report that very few of them joined IoT enterprises after graduation; rather, their job choice did not differ much from students majoring in other branches of the secondary engineering discipline Computer (Zhihu 2019c).

Moreover, given that engineering graduates increasingly look for jobs outside manufacturing, as mentioned in Chapter 3, expanded enrolment in engineering programmes does not necessarily mean expanded supply of quality engineering talent to manufacturing. In addition, a survey involving over 500 enterprises, over 600 engineering teachers and over 10,000 engineering students finds that Chinese engineering graduates had decent performance in professional knowledge, logical thinking, research and professional morality but had poor records when it came to frontier knowledge, innovation, foreign language communication, and so on (*Chinese Education Newspaper* 2016).

Vocational education and training

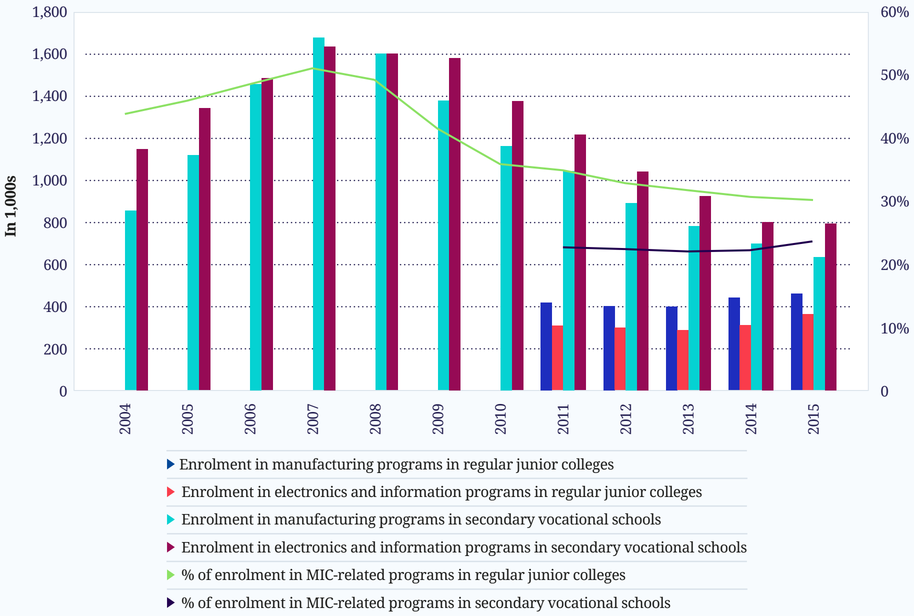
In recent years, enrolment in MIC 2025-related programmes in junior colleges has increased only slightly, while overall enrolment in secondary vocational schools has plummeted. The Government plans to dramatically expand the enrolment of tertiary vocational colleges[24] and to expand secondary vocational education as well, but is facing multiple challenges such as a shortage of students, teachers and teaching facilities. As in the case of universities, some tertiary vocational schools offer new programmes in the key fields listed in the MIC 2025 and have produced much-sought-after graduates. The Government encourages enterprises to play a more prominent role in the supply of vocational education and training by operating an apprenticeship system at enterprises, expanding on-the-job training, and investing in vocational educational institutions. In addition, the Government has introduced multiple policies to promote training for groups with relatively low employability and to encourage incumbent employees to receive training and obtain vocational qualification certificates.

Among all the programme offerings in vocational educational institutions in China, programmes in manufacturing and in electronics and information are the top two categories most related to the MIC 2025. Figure 61 shows that in junior colleges between 2011 and 2015, enrolment in these categories grew slightly; but the share of enrolment in these categories in the overall enrolment at junior colleges stagnated; in secondary vocational schools between 2004 and 2007, enrolment in manufacturing and in electronics and information programmes rose gradually and the proportion of enrolment in these two categories also increased; but in 2007, four years before overall enrolment at secondary vocational schools began to decline, the enrolment in these two programme categories began to drop; in addition, the proportion of enrolment in these categories also plummeted, which means that students in secondary vocational schools increasingly opted out of MIC 2025-related programmes. This is not good news for the severe shortage of blue-collar skilled labour that China is experiencing.

In October 2018, the MOHRSS (2018b) issued the *Implementation Plan to Build a Skilled Workforce (2018–2020)*. This plan lists what the central Government will do to counter the coexistence of structural unemployment and skilled labour shortage, including measures to reform the evaluation system for skilled workforce, to boost vocational education, to foster the development of skill contests, and so forth. In January 2019, the State Council (2019a) issued the *Implementation Plan of National Vocational Education Reform*. This plan emphasizes that vocational education is of the same importance as

24 There are two types of junior colleges in China: tertiary vocational colleges (gaozhi) that are more application-oriented, and tertiary specialized colleges (gaozhuan) that are less application-oriented. The former makes up the majority of junior colleges in China.

Figure 61. Enrolment in various MIC-related programmes in vocational educational institutions, 2004–15



Source: National Bureau of Statistics 2019a.

academic education and should be improved to power the ongoing industrial upgrading. This plan sets the goal, within five to ten years, of transforming the national vocational education system from one mostly operated by the Government to one concerted by the Government and operated by multiple social entities, in particular enterprises, and dramatically boosting the quality of vocational education in China. It details measures to optimize the structure of vocational education, to construct national standards for it, to further integration between education and industrial development, to encourage private capital to invest in vocational education and to increase funding for it, among others. It is not clear how these two guidance plans have been implemented.

At the level of higher education, parallel to the efforts to boost the supply of engineering talent via the expansion of academic education, as mentioned above, the Government has also attempted to strengthen application-oriented academic education and vocational education. The *Implementation Plan of National Vocational Education Reform* mentions that some universities should be more application-oriented and should experiment with vocational programmes at the undergraduate level. In March 2019 China's Premier Li Keqiang mentioned in a government work report that to alleviate both the unemployment pressure of low-skilled workers and the shortage of highly skilled workers, tertiary vocational colleges would enlarge enrolment by one million (approximately one quarter of its current enrolment) in 2019; and that in addition to high school graduates, others such as demobilized servicemen, dismissed workers and peasant workers should be mobilized to fulfil the enlarged quota (*China Education News* 2019). Given that peasant workers have been opting out of manufacturing for services, whether the enrolment expansion in vocational education will enlarge the supply of skilled workers in manufacturing is questionable.

Moreover, the chance that the enrolment expansion plan can be translated into reality is bleak. Tertiary vocational colleges are now facing problems of not only how to attract enough students, but also how to recruit enough teachers with decent credentials, and to secure enough facilities and equipment to cope with the expanded enrolment. In fact, even before the plan for enrolment enlargement was announced, some tertiary vocational colleges already found it difficult to fulfil the enrolment quota authorized by the Government. To be enrolled in tertiary vocational colleges, the groups mentioned by Premier Li (demobilized servicemen, dismissed workers and peasant workers) need to pass the same entrance examination as high school students do. Given that the majority of people in these groups have left schools many years ago, this plan is not realistic (Wang 2019).

To expand student enrolment implies a matching growth in the number of teachers. The Ministry of Education in China requires that the ratio between teachers and students at tertiary vocational colleges be 1:18. Accordingly, such colleges need to recruit at least another 55,000 teachers to accommodate a million extra students (Sun 2019). But before the Premier's announcement many tertiary vocational colleges were severely understaffed. For example, it is reported that in 2016 one tertiary vocational college in Foshan, Guangdong had 400 students and eight teachers in the major field of robotics; most of these teachers did not have an education background in robotics, but one in related disciplines; they had to learn the relevant knowledge by themselves before teaching their students; and the college could hardly compete with enterprises to recruit experts in this field (Xu 2018). Given that the vocational college entrance exam in 2019 took place only three months after Premier Li's announced plan, recruiting enough teachers seems like a mission impossible. If vocational colleges fail to match teacher recruitment with the enlargement in student enrolment, the already dubious quality of these colleges can only become worse.

In addition, to accommodate extra students, tertiary vocational colleges need not only extra classrooms, but also more teaching equipment, especially for students in engineering majors. Such equipment can be quite expensive. For example, in 2011 one vocational school in Guangzhou, Guangdong invested over 8t million RMB (including approximately one million from enterprises) for the first-phase construction of a robotics talent training centre; the second and third phase would cost another 2.6 million and 5 million RMB respectively (Xu 2018). It is unclear whether tertiary vocational schools could secure funding for such extra teaching facilities and equipment.

Besides enrolment expansion, many junior colleges have updated their programme offerings according to the MIC 2025, to train much-needed skilled workers. It is reported that in 2016 approximately 240 tertiary vocational colleges offered programmes in industrial robotics. For example, in 2010, the Guangzhou College of Mechanic and Electronic Workers began to run a programme; it had about a dozen students, most of them worked in robot-related positions after graduating in 2012. A small-scale survey conducted in 2016 with students majoring in robotics finds that after graduation 9 per cent of them engaged in the design of robotic systematic solutions while 63 per cent engaged in the installation and maintenance of robots (Xu 2018).

At the level of secondary vocational education, the *Implementation Plan of National Vocational Education Reform* mentions that secondary education should be further popularized particularly by expanding secondary vocational education, and that enrolment at the level of secondary education should be more or less evenly distributed between high schools and secondary vocational schools. However, in 2016 secondary vocational schools accounted for only 39.9 per cent of enrolment at this level of education; in 2017 the number of places offered by high schools and secondary vocational schools combined made up 94.9 per cent of the number of middle school graduates, leaving little room for the expansion of secondary vocational education. Again, the Plan suggests that secondary vocational schools should attract demobilized servicemen, retired athletes, dismissed workers and returning peasant workers. It is unclear, however, whether these groups would like to attend these schools. With regard to the quality of secondary vocational education, the Plan mentions that local governments should take into consideration the scale, costs and quality of these schools when allocating funding for them, and that per student funding for vocational schools can exceed that of high schools (State Council 2019a).

With regard to the supply of vocational education and training, the Government encourages employers and private capital to play a larger role. In 2015 the MOHRSS began to experiment with an apprenticeship system in several regions. Owing to the success of this experiment, in October 2018 the MOHRSS issued the *Opinion on Implementing the New Enterprise Apprenticeship System Nationwide*. The main elements of this new enterprise apprenticeship system are the following: the goal is to produce workers with intermediate or advanced levels of skills that enterprises need; enterprises lead this apprenticeship system with the help of vocational educational or training institutions; enterprises select apprentices from its new employees or employees to be repositioned; both enterprises and collaborative educational and training institutions provide supervisors for apprentices; the training should be flexibly scheduled to accommodate the production plan of enterprises and the working time of apprentices; the training should normally last one to two years and can be extended to three years in exceptional cases; enterprises shall pay apprentices no less than the local minimum wage and pay training fees to external training collaborators. To motivate enterprises to adopt this apprenticeship system, the Government subsidizes at least 4,000 RMB per apprentice per year under this system. The Government hopes to have rolled out the system and trained at least 500,000 apprentices by the end of 2020 and to train approximately 500,000 apprentices every year thereafter (MOHRSS 2018c).

The Government also encourages enterprises to provide more on-the job training. In May 2018 the State Council issued the *Opinion on Implementing the Lifelong Vocational Skill Training System*, which states that local governments should encourage enterprises above the designated size to provide training, both for the enterprises themselves and for other small and medium-sized enterprises. This Opinion does not specify how to motivate enterprises to do so (State Council 2018a). In practice, in order to close the talent gap and to reposition redundant workers amidst technological upgrading, some employers actively engage in on-the job training. It is reported that some factories that have introduced robots on the shop floor invited external engineers to train workers who were made redundant by robots to operate and repair these robots; and that to avoid their own staff being poached by end users, robot manufacturers tended to help factories with related training. But it seems that on-the-job training plays a minor role in preparing robot-savvy talent. According to a survey conducted by a vocational school in Guangdong, of the skilled workers related to the functioning of industrial robots in enterprises, only 12.3 per cent were upskilled or reskilled incumbent employees (Xu 2018).

In addition, the Government encourages private capital to invest in vocational education and training and allows private training institutions to engage in evaluation and certification of vocational skills. According to the *Implementation Plan of National Vocational Education Reform*, enterprises that actively engage in collaboration with vocational schools have access to a package of incentives concerning fundraising, governmental subsidies, land use, credit building and tax cuts; enterprises that operate vocational schools may have their education-related contribution to governments waived for one year. The Plan also makes it clear that selected training institutions (whether public or private) can develop criteria for vocational skill levels and be in charge of the examination, evaluation and certification of vocational skills (State Council 2019a). This provision has raised concerns around the inflation of vocational skill certificates (Feng 2019a).

Last but not least, the Government has introduced serial policies to promote training for peasant workers, redundant workers in industries that are cutting overcapacity, and unemployed new college graduates, and to use funding from unemployment insurance contributions to subsidize training. Workers who are made redundant during technological upgrading may benefit from these policies. It is unclear how these policies have been implemented. They include the following:

- In March 2014 the MOHRSS issued the *Implementation Plan of Spring Stream: A Plan to Improve the Vocational Skills of Peasant Workers*. According to this plan, the Government will coordinate training services from all walks of training institutions to make sure that every year seven million person-time employment training opportunities will be provided throughout society for peasant workers who are newly added to the workforce, as well as three million person-time specific skill trainings for peasant workers already in employment, and one million person-time entrepreneurship trainings for peasant workers who want to set up their own businesses (MOHRSS 2014).
- In June 2016 the MOHRSS issued the *Circular on Implementing the Special Vocational Training Plan for Staff in Cutting-Overcapacity Enterprises*. According to this plan, the Government will subsidize training for unemployed and repositioned workers in enterprises that have cut overcapacity between 2016 and 2020 (MOHRSS 2016).
- In May 2017 the MOHRSS issued the *Circular on Related Problems regarding Using Unemployment Insurance to Support Insured Staff to Improve Vocational Skills*. According to this circular, the Government will use funding from unemployment insurance contributions to subsidize insured workers who have obtained vocational qualification certificates from 1 January 2017 (MOHRSS 2017a).
- In September 2017 the MOHRSS issued the *Circular on Long-term Skill-for-Employment Action for Unemployed New College Graduates*. According to this circular, the Government will provide subsidies for unemployed new college graduates to receive training from all kinds of institutions to enhance their employability or to prepare them to set up their own businesses (MOHRSS 2017b).
- In January 2019 the MOHRSS issued the *Plan for Improving the Vocational Skills of New Generation Peasant Workers (2019–2022)*.[25] According to this plan, in response to the skill needs of key manufacturing industries, modern service industries, and the rejuvenation of rural China, the Government will provide more subsidies to expand training for new-generation peasant workers and hopes to have popularized this kind of training by the end of 2022 (MOHRSS 2019b).

25 "New-generation peasant workers" refers to peasant workers born in and after 1980.

4.2 Other policies to harness the technological shock

In addition to policies regarding education and training, the Government has introduced other policies which may or may not aim at the synchronization of technological and social upgrading but have implications for it. To buffer the unemployment pressure from multiple sources, the Government has strengthened active employment policies. To alleviate the shortage of skilled workers, it has introduced policies to boost compensation for skilled workers. The Government has an ambivalent attitude towards enhancing labour security and has been embroiled in continuous trade-offs between labour costs and labour security. It has taken no action with regard to intensified under-representation of and discrimination against female workers in certain industries in the context of technological upgrading, unlawfully long working hours, and technology-enabled excessive control over workers.

The active employment policies introduced by the Government are a response to the intensified structural unemployment owing to technological upgrading and looming unemployment pressure owing to economic slowdown. Before going into detail, it is worth noting that the Government has no special policy to buffer labour displacement caused by the mass deployment of automatic equipment. In April 2015 the State Council put forward the *Opinion on Further Promoting Employment and Entrepreneurship under New Circumstances*, highlighting employment creation as a key goal of macro-economy regulation. It proposes to develop labour-intensive industries, to support the development of small and micro businesses that are major employers in China, to better control the risk of layoffs, and to encourage start-ups (State Council 2015b).

In April 2017 the State Council updated China's active employment policy by introducing the *Opinion on Promoting Employment and Entrepreneurship for the Present and the Years to Come*. Compared with the 2015 Opinion that gave its main attention to employment promotion, the 2017 *Opinion* has a more balanced stance. Rather than focusing on the one-way impact of economic development on employment, it puts emphasis on the coordination between economic growth, employment promotion and employment structure optimization. In addition to labour-intensive industries, the updated *Opinion* also proposes to develop capital-technology-and-knowledge-intensive manufacturing and emerging strategic industries. Moreover, in response to the emergence of new forms of business such as the platform economy, new *Opinion* makes it clear on the one hand that the central Government will encourage these businesses by encouraging local governments to grant them access to preferential credit policies and to purchase their products and services; on the other hand, owing to concerns around the quality of employment in these new forms of business, the new *Opinion* proposes to explore new institutions regarding employment arrangements and social insurance to enhance the security and welfare of workers involved in these businesses (State Council 2017).

As the national economy continued to slow down and unemployment pressure intensified, the Chinese Government upgraded employment promotion measures in 2019. Hoping to cushion unemployment through the platform economy, in August 2019 the State Council issued the *Guidance for Promoting the Lawful and Healthy Development of Platform Economy*. This *Guidance* aims to unleash the potential of the platform economy by massively loosening the regulations over it. For example, it waives the necessity for platform operators to obtain the various administrative permits that were required before (State Council 2019c). In December 2019 the State Council issued the *Opinion on Further Stabilizing Employment*. This *Opinion* promises a wide range of employment promotion measures, including but not limited to extending financial support to small and micro businesses, facilitating enterprises in new market entry, boosting domestic consumption and investment to create more jobs, encouraging all kinds of flexible employment, providing professional skill training on a massive scale, and so on (State Council 2019d).

Regarding the shortage of skilled workers, in addition to efforts to improve the education and training system the Chinese Government has also introduced policies to increase compensation for skilled workers. Given that poor compensation has discouraged young people from becoming skilled workers, in March 2018 the State Council issued the *Opinion on Boosting the Compensation for Skilled Workers*. This Opinion puts forward detailed policies to increase such compensation, including political, economic and social welfare. In particular, it proposes to streamline the remuneration system for skilled workers, to establish normal wage growth mechanisms for them, and to explore long-term incentive programmes for them (State Council 2018b).

Poor job security in China is not an issue arising from technological upgrading. Rather, workers in such industries are not immune to the pervasive precarity of China's workplaces. After decades of labour market creation and flexibilization in a rigid state-led labour allocation system, from 2007 onwards the Government began to shift policy orientation towards labour protection by introducing pro-labour laws led by the *Labour Contract Law*. However, in the face of economic difficulties in recent years, balancing labour protection and labour costs has become a challenge.

Employment stabilization has always been a priority for the Government. The *Opinion on Further Promoting Employment and Entrepreneurship under New Circumstances* issued by the State Council in 2015 suggests that enterprises in financial difficulty should use flexible production arrangements to avoid dismissals (State Council 2015c). In December 2018 one MOHRSS vice-minister stated that enterprises with no or few dismissals could get 50 per cent of their unemployment insurance contributions refunded (Ye 2018).

The Government's attitude towards non-standard employment has been ambivalent. On the one hand, as already mentioned, it encourages the development of new forms of business in which employment tends to be more insecure than that in traditional businesses. On the other hand, it has also tried to curb the abuse of non-standard employment arrangements, such as labour dispatch, that have been prevalent in China's ICT sector. China has almost half of the world's agency workers. The 2007 *Labour Contract Law* has a special section aiming to counter the abuse of agency workers. But by enhancing protection for formal employees, the *Labour Contract Law* in fact triggered an explosion of agency workers. Thus, in 2012 the Government introduced an amendment to the Labour Contract Law that further emphasizes equal pay for equal work between agency workers and formal employees and limits the applicability scope of agency labour. Then, in 2014 the Government enforced the *Interim Provisions on Labour Dispatch*, which requires enterprises in China to lower their proportion of agency workers in the entire workforce to a maximum of 10 per cent before 1 March 2016. The serial regulation against the abuse of agency workers has produced mixed effects. It has helped to narrow the compensation gap between agency workers and formal employees in some enterprises and to reduce the number of agency workers, but has also triggered the abuse of more precarious "outsourced" workers (those who are de facto agency workers under the guise of "outsourced" workers). The regulation fails to limit agency workers to temporary, auxiliary and substitute positions (Feng 2019b).

Social insurance entitlements help to enhance workers' security. In China, employers' obligatory contributions for social insurance and housing fund amount to 30-40 per cent of wages. In a context of economic slowdown, the Government also appears ambivalent towards social insurance policies. On the one hand, to lower the operating costs of enterprises, it lowered both the payment base and premium rates for social insurance; for example, after 1 May 2019 the officially designated premium rate for pension contributed by employers is 16 per cent, down from 20 per cent (State Council 2019b). On the other hand, however, the Government has attempted to use tax collection bureaus to collect social insurance contributions. Compared with the social insurance bureaus that were charged with the collections of these contributions before, tax bureaus have better data regarding the headcount and real wages of each enterprise and are thereby in a better position to counter social insurance evasion. It was reported in August 2018 that the central Government planned to enforce this reform from 1 January 2019 (Wu 2018). However, in December 2018, news came out that the reform had been stalled, and several provinces excluded enterprise social insurance in the reform (Han 2018).

The Government has issued laws and guidelines concerning privacy protection in the workplace. However, it is questionable whether these can effectively protect workers from excessive workplace control enabled by management software. In late 2009 the Standing Committee of the National People's Congress (SCNPC) introduced the *Tort Law*, which for the first time regards privacy as a civil right in China and stipulates that Internet service providers and users who infringe upon the civil rights of another person are subject to tort liability (SCNPC 2010). In 2012 the Government issued the *Decision on Strengthening Information Protection on Networks*. It stipulates that network service providers and other enterprises and public institutions shall publicize the purposes, means and scope of their data collection and usage activities, and obtain consent from those whose data is collected; otherwise, they are liable to penalties (SCNPC 2012). In late 2012 the National Technical Committee for Information Security Standardization of China introduced *Information Security Technology Guidelines for Personal Information Protection in Public and Commercial Information Systems*. This document provides guidance on personal data protection at different stages of personal data handling in information systems, including data collection, processing, transfer and deletion. It was updated in 2017 when the Standardization Administration of China released the final version of the national standards on personal data protection, officially titled *Specification for Information Security Technology and Personal Data Security*. Compared to the above *Guidelines*, the *Specification* clarifies and broadens the scope of its application to include all entities that handle personal data, including employers, and gives more detailed guidance on the collection and handling of personal data. It is worth noting that the *Guidelines* and *Specification* are not legally binding. Moreover, it remains unclear what kind of information employers can collect from employees. Many employees are reluctant to let employers know their real-time whereabouts during working hours and whether they have read messages sent by managers. However, once an employer introduces management software such as DingTalk to the workplace, if individual employees have no plan to quit, they have to give consent to the whole package of DingTalk's privacy policy, including monitoring their whereabouts and message-reading status.

As shown in Chapter 3, technological upgrading is likely to aggravate the entrenched under-representation of and discrimination against female workers in China's workplaces in certain industries. To boost the alarmingly low fertility rate, in late 2015 the Government abolished the decade-old one-child policy and encouraged couples to have two children, which has made employers more reluctant to hire female staff because they may take paid maternity leave more than once (*The Economist* 2018). It is in this context that in February 2019 the central Government issued the *Circular on Further Regulating Recruitment Behaviour and Facilitating the Employment of Women*. This circular rules out the following behaviours by employers: pro-male recruitment in positions suitable for females; asking female candidates' marital status and childbirth records; including a pregnancy test in the physical examination for new hires, and so on (Hu 2019). Clearly, this circular intends to remedy the unintended consequences of the abolition of the one-child policy. The Government has no specific policy to promote gender equality amidst this wave of technological upgrading.

The Government also appears indifferent to the unlawfully long working hours in China's software and ICT services industry. In the spring of 2019, with the defence of the 996 work schedule and the overwork culture from Jack Ma and Richard Liu (both are business leaders in China's e-commerce industry) (Jung 2019), 996 became the focus of a nationwide public debate. From late March 2019 numerous "netizens" shared related postings on China's most widely used social platforms such as WeChat and Weibo and gave their own comments every day for quite some time. As mentioned in Chapter 3, according to China's labour law the 996 work schedule is illegal; unpaid overtime, as is the case in many ICT companies in China, is illegal too. However, compared with the heated discussions about 996 on social media, the Government appeared rather quiet. It is reported that a local inspectorate investigated a company that declared it would implement the 996 work schedule in its 2019 New Year gala (Kong 2019) and no news followed the result of this investigation. *People's Daily*, the CCP's official news outlet, joined the debate by publishing an editorial (2019). While the editorial points out that to encourage hard work does not necessarily mean enforcing a 996 work schedule, it does not mention the illegal nature of 996 and does not call for the implementation of related legal provisions.

4.3 Prospects for workers' collective action

Theoretically, through technological upgrading, enterprises that were once at the lower end of the GVCs can climb up the value chains and capture a larger share of value. Through collective action, workers at these enterprises may be able to share in the enhanced value. The launch of the MIC 2025 in 2015 aimed to accelerate technological upgrading; meanwhile, since Xi Jingping became President in 2013, the Government has dramatically intensified its control in society, rendering much less room for workers' collective action than ever before. Buffering technological unemployment or helping workers to capture the gains enabled by technological upgrading is not on the policy agenda of the ACFTU. Collective labour action provoked by the technological upgrading is budding; but the effects of such labour action on working conditions appears meagre.

Chinese workers' collective action faces not only institutional deficiencies but also legal barriers. Generally, institutionalized workers' collective organizations, which means trade unions in the Chinese context, are expected to carry out the mobilization and organization of workers in mass grievances. Independent trade unions have long been an anathema to the CCP. In fact, all trade unions in China are supposed to be affiliated with the ACFTU, which is controlled by the CCP. In other words, when collective bargaining is practised, only official trade unions can represent workers to bargain with employers. But whether or not trade unions led by a developmental State can genuinely represent workers' interests is questionable. Moreover, classic labour relations theory contends that the right to strike and freedom of association are indispensable to collective bargaining rights; unless labour possesses some coercive power, capital will not take workers' demands seriously. But in the early 1980s, the right to strike was removed from China's Constitution and has not been reinstated so far (Friedman 2017).

Against this background, owing to a combination of both international and domestic factors, party leaders handle labour relations differently. And the approach of the Xi administration appears more coercive than that of his immediate predecessor Hu Jintao (2002–12). During most of the Hu era the global economy was sound; owing to the rapid expansion of trade and foreign investment, China's economy grew fast. After two decades of market-oriented reform that improved the living standards of Chinese but enlarged social inequality, for the first time in the reform era the Government began to emphasize social inclusion and redistribution. Under this circumstances the Hu administration made earnest efforts to remedy labour grievances, both by allowing constructive activities of non-party actors and by reforms within the party system. It put forward pro-labour laws and allowed considerable room for civil society actors such as labour NGOs and law agencies to exert influence on workers and policies. By educating workers and intervening in their action, labour NGOs strengthened workers' ability to organize collective action. The growth of labour NGOs also generated pressure on the ACFTU to better protect its members' interests. Moreover, the Hu administration fostered innovation and experimentation related to collective bargaining, such as grassroots trade union elections, arbitration committees and the election of worker representatives for collective negotiation (a term the Chinese Government uses to replace the more antagonistic sounding term "collective bargaining") (Howell and Pringle 2018).

In contrast, when President Xi took office in 2013, the global economy was in recession; from 2010 onwards the GDP growth rate of China has been in decline. From fear that the economic slowdown might heighten the likelihood of unrest, the Xi administration renewed restrictions. While the Government's inclination towards labour protection has not been reversed, albeit not without ambivalence, its means to do so have shifted from dual efforts from both inside and outside the party system under Hu to exclusive efforts from inside (Howell and Pringle 2018).

The other side of the coin is that the central Government has urged the ACFTU to reform itself so as to be a better mediator between labour and capital. But there have not been significant moves from the ACFTU in this regard (Howell and Pringle 2018). According to the official website of the ACFTU, its main response to the MIC 2025 has been in supporting vocational education and training and holding professional skill competitions, with almost no attention paid to technological unemployment or pushing employers to share the gains enabled by technological upgrading (ACFTU 2020). In addition, at the beginning of the Xi administration the Government did put forward pro-labour laws. For example, as mentioned earlier, it passed the *Interim Provisions on Labour Dispatch* in 2013 to counter the abuse of agency workers, although the implementation of this regulation has been far from satisfactory. In 2014, the provincial government of Guangdong passed the *Guangdong Regulation on Enterprise Collective Contracts*, which requires employers to engage in collective negotiation upon the request of more than half their workforce. The key provisions of this regulation are a significant setback to its earlier drafts regarding the number of employees required to initiate a collective negotiation. Moreover, after its passage, the *Regulation* seems to have been mothballed by the government and has made hardly any real difference in mediating labour relations so far (CLB 2016).

Despite these unfavourable circumstances, Chinese workers have never given up on efforts to safeguard their rights and improve their conditions. But the prospects for cellular labour resistance to grow into a strengthened and transformational labour movement are faint (Lee 2017). Owing to the lack of effective official channels for collective bargaining, Chinese workers have turned to wildcat strikes to unleash their grievances. As mentioned in Chapter 1, according to the statistics compiled by CLB (2020), the number of strikes in China rose sharply between 2011 and 2015, were maintained at over 2,000 in each year 2015 and 2016, and dropped to 1,258 in 2017 before rising to 1,706 in 2018. The CLB recorded 1,385 strikes in China in 2019. In 2014, China witnessed the largest strike since 1949 in which over 40,000 workers at Guangdong factories of Yue Yuen, once the largest shoe manufacturer in the world, protested against their employer's evasion of payments for social insurance and the housing fund and invalid labour contracts. Despite pressure from the Government, the workers managed to strike for two weeks and forced Yue Yuen to repay the arrears (Chen 2015).

In particular, technological upgrading has generated new labour grievances and consequent resistance. While low-skilled workers still initiate the majority of labour protests in China, skilled workers have become vocal about their poor working conditions. But such budding resistance can hardly force the ongoing technological upgrading into a path that better benefits rank-and-file workers. In the software and ICT services industry, for example, in contrast to recurring passive resistance such as overwork death, at the end of March 2019 Chinese programmers for the first time launched an online campaign called 996.ICU (by following the 996 work schedule, you are risking yourself getting into the Intensive Care Unit) against the toxic overwork schedule on Microsoft's GitHub, one of the world's largest code-sharing communities. The web page of this campaign shortly became one of the most bookmarked pages on GitHub (Qu 2019). According to the 996.ICU page, the campaign aims to "uphold the labour law and request employers to respect the legitimate rights and interests of their employees". It approaches this aim mainly by leveraging the power of open-source developers over entities that use their codes: two campaigners drafted the Anti-996 License and encouraged developers of open-source projects to adopt the license, which requires users of licensed projects to comply with labour regulations in their jurisdictions (996.ICU 2019a). In early May 2019 some 150 projects were subject to the Anti-996 License (996.ICU 2019b). It is not clear, though, how important these projects are to large companies in the 996 blacklist.

The mass deployment of automatic equipment in China's factories has been carried out quite peacefully. On the one hand, as shown in Chapter 3, most Chinese workers welcome the use of robots on the shop floor. On the other hand, by displacing and deskilling workers, the introduction of automatic equipment has incited grievances, particularly among skilled workers. But due to the absence of functioning labour organizations, such grievances do not automatically lead to collective action. In fact, collective action animated by the deployment of robots is rare in China. Yu Huang reports two cases in this regard. One is at a unionized Japanese auto parts factory in Guangzhou, Guangdong: after the introduction of welding robots, the factory decided to suspend welders' exclusive allowance and reposition displaced welders to low-skilled jobs; the enterprise-level trade union intervened and in the end the factory curtailed welders' exclusive allowance but increased the allowance for low-skilled workers (Huang 2019c). But based on a survey that involved multiple auto parts enterprises (many have functioning enterprise-level trade unions) in the Pearl River Delta, Yang (2019) found that the impacts of the introduction of automatic equipment on workers were hardly included at all in the collective bargaining between workers and employers. The other case concerns a door-making factory in Dongguan, Guangdong: under the piece-rate wage system the factory had adopted, automation increased workers' wages but decreased skill demand from them; the factory owner responded by lowering veteran workers' wages and recruiting new workers at a wage level much lower than the wages of the veteran workers. The workers, both veteran and new, stopped working to protest; given that the majority of strikers were veteran workers aged 40–50 years old, for whom it was not easy to find new jobs with comparable compensation to their current jobs, the stoppage only lasted for a couple of hours and all the worker participants were fined 100 RMB (Huang 2019c).

5 Conclusion and suggestions for future research

Technological transformation is one of the major forces reshaping the future of work. Understanding the labour implications of technological transformation in China is indispensable for understanding both this global shift and the prospects of economic and social rebalancing in China. China is the largest manufacturer and has the largest workforce in the world. Technological changes in China are likely to interact with technological changes in other parts of the world, recalibrate the GVCs and thereby affect employment and working conditions worldwide. Moreover, in the face of dwindling economic growth and growing social unrest, the Chinese Government is pursuing innovation as the new engine of economic growth and is introducing policies to accelerate technological upgrading. This report maps widespread and profound ongoing technological upgrading in China, its implications on working people in China, and the efforts multiple stakeholders have made to boost social upgrading amidst this wave of technological upgrading. This chapter summarizes the main findings of this report and provides suggestions for future research on the topic.

5.1 Conclusion

With regard to the status quo of technological upgrading in China, this report finds the following:

- China pursues technological development mainly by indigenous innovation, which is supplemented by foreign technology transfer. Compared with the European Union and the United States, China still spends a smaller share of GDP on R&D and has fewer avid corporate R&D investors; but the gap has narrowed dramatically in the past two decades and is projected to further narrow in the years to come. In recent years China has witnessed increasing high-tech FDI inflows and has actively engaged in overseas M&A in the high-tech sector. As a result, China has filed the largest number of patents in the world. However, the trade war between the United States and China is overshadowing the prospects of technological upgrading in China: the US Government not only has pressured China to give up on the MIC 2025 but also has imposed restrictions on technology transfer from the United States to China.
- When it comes to process upgrading, while developed economies are pursuing Industry 4.0, China is pursuing Industry 3.0 and 4.0 at the same time. Overall, with

regard to both the development and deployment of process technologies, China lags behind developed economies. The gap is much wider in technologies that underpin Industry 3.0 in developed economies such as CNC machine tools and robots than it is in technologies that underpin Industry 4.0 such as IoT and AI. Chinese companies have made efforts to narrow these gaps and their attempts have been facilitated by state support. It is worth noting that rather than being a pure imitator and follower of foreign industrial leaders, Chinese companies are forging ahead in certain technologies such as the 5G mobile network.

China is the largest manufacturer of machine tools in the world, but with regard to related technologies it lags far behind developed economies although it has made progress in narrowing the gap. It is unclear whether Chinese machine tool makers can seize the opportunity afforded by the new-generation machine tools, namely intelligent machine tools, in order to advance. Chinese manufacturers are still far from taking full advantage of CNC machine tools in the manufacturing process but are making efforts to boost the popularity of such equipment.

China has emerged as a world-class manufacturing hub of robots. With regard to technological capabilities, its robot manufacturers lag far behind their counterparts in advanced economies but are making efforts to catch up. China is also an active adopter of industrial robots but is still at the early stage of robot adoption. Eastern China adopts robots more actively than the other parts of China. The density of industrial robots in Chinese manufacturing is much lower than in the advanced economies. Owing to a confluence of factors such as the progress in robotics and strong state incentives, this gap will be gradually narrowed. But lack of capital, lack of capacity to tailor automatic equipment to their needs, failure to find appropriate automatic equipment in the market, and shortages of relevant skilled labour are discouraging Chinese enterprises from adopting industrial robots more actively.

China is an emerging manufacturer and exporter of low-end 3D printers but is catching up technologically. 3D printing technologies are mainly used for prototyping. Owing to technological bottlenecks, they are highly unlikely to be used for mass production in the near future in China.

The development of Chinese enterprise software lags behind foreign counterparts in advanced economies. Chinese industrial design software is catching up in certain subfields. Chinese companies have not developed a strong appetite for management software, but to boost the efficiency of domestic companies, the Chinese Government has offered subsidies to increase the popularity of enterprise software.

In the global race of IoT development and deployment, companies in advanced economies still take the overall lead but Chinese companies come close. In the development and adoption of the 5G cellular network technology which is key to IoT, China is at the global frontier. Financial incentives have been provided by the Government to boost IoT adoption.

While the United States is the global leader in AI. China comes second. But AI applications more deeply penetrated into China than into the United States.

- China's role in the GVCs reflects the extent of the product upgrading it has achieved so far. As a result of growing production of parts and components, while maintaining its dominance as an assembly station for the GVCs, China is emerging as an OEM supplier. In some industries, the role of China in the GVCs has moved up to OBM. Generally, Chinese brands tend to be at the lower end of the global market and their profit share significantly underperforms their market share. That said, in some niche markets such as telecoms equipment and electric cars, Chinese companies are likely to have leapfrogged their foreign competitors with regard to technological advances, or are about to do so. In addition, growing Sino-US tensions are weighing on product upgrading in China.

  Leading Chinese ICT equipment companies have managed not only to capture market share from foreign brands in the domestic market, but also to establish a foothold in the global market; their products have entered the global premium market albeit at the lower-price segment. In contrast, gasoline automobiles still dominate the global automobile market, and leading Chinese gasoline automobile companies have only managed to enlarge their domestic market share and are far from penetrating into the global market; Chinese-brand gasoline automobiles are concentrated at the lower end of the domestic market. Nonetheless, in the niche market of electric cars, Chinese makers not only dominate the domestic market but also rival their foreign counterparts in the world market and are likely to overtake them in future.

  By creating barriers to their international penetration and disturbing their supply chains, the intensified tension between China and the United States has overshadowed the prospects of China's top brands. Excessive reliance on foreign suppliers for key technologies has rendered Chinese high-tech brands vulnerable amidst the Sino-US trade war. It remains unclear whether the ongoing tension between China and the United States will be a catalyst for progress or a hindrance for indigenous innovation in China.

With regard to the impacts of technological upgrading on social upgrading, this report finds the following:

- Overall, in recent decades, owing to a combination of multiple factors including technological upgrading, the employment landscape in China has changed dramatically.

Such changes have created a distinct context from that of many developed economies in which the new wave of technological transformation unfolds. The tertiary sector has replaced the primary sector to provide the lion's share of employment. Skilled workers remain a small fraction of Chinese employment. Professionals and technical staff have seen improved gender balance over the years, while the primary sector has witnessed feminization and the secondary sector has witnessed masculinization. Present-day China is experiencing a shortage of both skilled and low-skilled labour in the secondary and the tertiary sectors. Given that the slowdown of China's economic growth is weighing on employment, it is unclear how long this scenario will continue. Eastern China is likely to experience more severe labour shortage than the other parts of China. Both college graduates and peasant workers have been opting out of manufacturing and going into services. Wages in China have increased rapidly in recent years, with the increase rates above the global average; the wage growth of skilled workers has outshone that of low-skilled workers. Average working hours have decreased.

- Owing to the limitation of data available, this report focuses on the substitution and complementation effect of process upgrading. In the short term, in a context of dual shortage of both skilled and low-skilled workers and limited rolling-out of new process technologies, process upgrading aggravates the shortage of skilled workers and reduces the shortage of low-skilled workers.

Chinese enterprises mainly use robots and other automatic equipment to alleviate labour shortage and lower labour costs. Against this background, at least in present-day China, the deployment of robots and other automatic equipment has been welcomed by most workers. Automation enhances the competence of enterprises, thus entailing potential benefits for workers. It reduces the demand for low-skilled workers and boosts the demand for related skilled workers, which as a result reduces the shortage of low-skilled workers rather than leading to a bifurcation of the workforce. However, automation deskills workers and does not necessarily open up opportunities for upskilling. Existing studies indicate that it has failed to significantly increase workers' wages or shorten working hours. It enhances the bargaining power of a few robot-related skilled workers but curtails the bargaining power of other skilled and low-skilled workers by deskilling them. It also reduces workers' control over the labour process, but reduces work-related injuries as well. In the face of automation, low-skilled, elderly and female workers tend to be more vulnerable than skilled, young and male workers. At present, with automation taking place only on a small scale in China, it has not caused mass unemployment. Automation-induced dismissals are rare. Employers mainly rely on natural workforce turnover for automation-induced redundancies.

3D printers have displaced hardly any workers on China's shop floor, and will remain unable to do so in the near future. On the other hand, the manufacturing of 3D printers in China has created jobs, although the number created is underwhelming and most of them are likely to be low-skilled.

The rise of the software and ICT services industry that underpins the development of enterprise software, IoT and AI in China has created millions of relatively well-paid and skilled jobs. However, although workers in this industry are well-educated, they generally find their work repetitive, stressful and precarious, and have to work illegally long hours. Female workers are severely under-represented in the technical workforce in this industry and are often penalized in compensation because of their gender.

The penetration of management software into the workplace has dramatically intensified employers' control over the labour process.

The booming AI industry in China has created jobs (both white-collar and blue-collar) and labour shortages in this industry. But AI technologies have reduced labour demand in related industries it has penetrated. The redundancy created by the deployment of AI applications in these industries, though, seems to have been offset by natural labour turnover; AI-induced dismissals are rare in China. Male workers overwhelmingly dominate the global AI industry and there is no evidence indicating that the Chinese AI industry is an exception.

- Thanks to product upgrading, China's ICT and automobile industries have each seen expansion in overall employment and in technical employment, and expansion in employment in the ICT parts and components manufacturing and in the auto parts industry in particular.

  At the enterprise level, the comparison of Huawei (which has entered the global premium market) with Foxconn (which is a major contract manufacturer in the global electronics industry) well illustrates the impacts of product upgrading on social upgrading in China. The upgrading from Foxconn to Huawei is associated with upskilling, a higher share of labour costs in revenue, and masculinization of the workforce, but has not led to a reduction in working hours or significant improvement in job security and trade union representation. At Geely (which has only managed to build a domestic brand image and whose products remain concentrated at the lower end of the market) the above effects are less pronounced.

With regard to synchronizing technological and social upgrading, this report examines how efforts regarding education and training, better governance to harness the technological shock, and collective action of labour have played out in China, as well as the challenges multiple entities have faced during this process. The following findings are made:

- Since the beginning of the new millennium China has dramatically increased its investment in education. In both secondary and tertiary education priority has been put on academic over vocational education. In addition, in recent years women have gained ground in enrolment numbers in both secondary and tertiary academic educational institutions and in tertiary vocational educational institutions, but they have lost ground in enrolment in secondary vocational educational institutions.

- In response to the MIC 2025 and technological changes that are consistent with what the MIC 2025 promotes, the Government maintains its focus on academic education but has diverted more attention to vocational education and training.

  With regard to academic education, many universities have set up new programmes and expanded related programmes in the ten key fields listed in the MIC 2025. Such expansion has been uneven: while all nine of the key fields listed in the MIC 2025 have seen expanded enrolment in related engineering disciplines in higher educational institutions, the field of agricultural machinery has witnessed a decline in enrolment in the discipline of Agricultural Engineering. The effectiveness of such expansion in alleviating certain labour shortages has also been compromised by the fact that engineering graduates increasingly seek jobs outside manufacturing as well as the dubious quality of some programmes.

  With regard to vocational education, the Government plans to expand it at both the tertiary and secondary levels, but is facing challenges such as a shortage of students, teachers and teaching facilities. It is encouraging enterprises to play a larger role in the supply of vocational education and training and has also introduced new policies to promote training for vulnerable groups and the working population in general.

- In addition to policies on education and training, the Government has introduced other policies that have implications for the synchronization of technological and social upgrading. To buffer the unemployment pressure from multiple sources, including the technological shock, the Government has strengthened active employment policies. To alleviate the shortage of skilled workers, policies to boost compensation for skilled workers have been introduced. Enhancing labour security in a challenge, however; the Government has been embroiled in continuous trade-offs between labour costs and labour security. It has issued laws and guidelines concerning privacy protection in the workplace, but it is questionable whether these can effectively protect workers from excessive workplace control enabled by management software. The Government has not yet risen to the challenges of intensified under-representation of and discrimination against female workers amidst technological upgrading in certain industries, and of illegally long working hours.

- Since Xi Jingping became President in 2013, the Chinese Government has dramatically intensified its control over society, allowing much less room for workers' collective action than ever. Buffering technological unemployment or helping workers to capture the gains enabled by technological upgrading is not on the policy agenda of the ACFTU. Collective labour protests provoked by technological upgrading are nascent and the effects of such labour action on general working conditions appear meagre.

5.2 Suggestions for future research

Both technological upgrading and its labour implications in China are multi-faceted issues. Despite the efforts made, this report remains far from capturing the full range of complexities of these issues on the ground. Moreover, we are living in a tumultuous world. The issues are entangled in tremendous uncertainties. Given their wide social implications, the inadequacies of this report and the ever-changing realities call for future research. This section suggests some general directions for future researchers to consider.

- *The impacts of US-China rivalry and the COVID-19 pandemic on technological upgrading and workers in China*

  The US-China rivalry is still at its dawn. The COVID-19 pandemic is one of the biggest challenges humans have faced since the Second World War and may last for several years. These two intertwined events have profound implications for technological upgrading and workers in China, to which future researchers should pay close attention.

  The US-China rivalry, with the trade war as one of its many manifestations, will continue in the foreseeable future. To be clear, the trade war is not only about trade, but also about efforts on the part of the United States to curb China's rise to technological supremacy. The dual nature of the trade war is clear in the content of the Phase One deal signed on 15 January 2020: in addition to commitment to purchasing more US goods and lowering market barriers to US financial service providers, China promises to address longstanding US concerns about intellectual property and technology transfer (US Government and Chinese Government 2020). As mentioned earlier in this report, since the Phase One deal, US$250 billion worth of Chinese products (approximately half the value of Chinese commodity exports to the United States in 2018) are still subject to 25 per cent US tariffs, while $110 billion worth of US goods are subject to between 5 and 25 per cent Chinese tariffs. It is reported that a Phase Two deal to further lift tariffs on both sides is on the agenda (Franck 2020). Meanwhile, given the dual nature of the trade war, it is no surprise that in early April 2020, shortly after

Phase One deal was signed, senior US officials were reported to have agreed on, but not finalized, new measures to stop Chinese companies from buying certain optical materials, radar equipment and semiconductors, among other things, from the United States (Freifeld and Alper 2020). In late April 2020, claiming that China might acquire US technology through civilian supply chains or under civilian-use pretences, and might use such technology for weapons development, military aircraft or surveillance technology, the US Government tightened restrictions on technology exports to China (Ross 2020). Moreover, the Phase One deal does not cover key disputes between China and the United States such as state subsidies to nurture industrial champions in China, which is among the Chinese Government's key promises in the MIC 2025 and is likely to be the trigger of future trade wars.

The COVID-19 pandemic has further complicated US-China relations. On the one hand, the global crisis provides opportunities for the two major powers to work together to develop vaccines, proliferate life-saving medical equipment, and restore disrupted global supply chains (Cutler and Russel 2020). Such cooperation does happen on the ground. For example, China has supplied the United States with planeloads of medical gear since the outbreak of the coronavirus. Nonetheless, there is little likelihood for such cooperation to extend to other parts of the relationship (Wong and Swanson 2020). On the other hand, the pandemic has become a new front in the US-China confrontation. The pandemic has been weaponized by the United States to hold the Chinese Government accountable for it and to discredit the CCP because of the alleged cover-up when the virus first appeared in the Chinese city of Wuhan. On the Chinese side, the pandemic has been weaponized to legitimize the Communist Party's rule in China for quickly getting the virus under control and to discredit the United States for its incompetence in doing so (Cutler and Russel 2020; Wong and Swanson 2020). The politicization of the pandemic might bring extra uncertainties for future trade negotiations between the two parties.

The full range of impacts of this ongoing rivalry and of the COVID-19 pandemic on China's technological upgrading and its workers is still developing. The tensions between the two sides, which might escalate because of the pandemic, are likely to both strain and fuel China's product upgrading. Increasing difficulties for Chinese companies to source key parts and components from the United States, heavily relied on by Chinese assemblers and brands, is definitely a blow to China's infant-stage product upgrading. Nonetheless, the withdrawal of foreign suppliers from the Chinese market poses huge opportunities for indigenous suppliers in China. The incentive of potential profits and the unfailing determination of the Chinese Government to bolster the development of technologies of strategic significance will encourage Chinese suppliers to fill the gap left by their foreign counterparts and ease the anxiety of Chinese manufacturers.

The 25 per cent tariffs on US$250 billion worth of Chinese products exported to the United States, as well as the pandemic, may push investors to leave China, which will have mixed effects on its process upgrading. The US-China trade war and the disruption to GVCs when the COVID-19 hit China have revealed the risk of concentrating too much production in a single country and has pushed leading companies in GVCs to diversify the geographical location of their suppliers. As a result, many companies have disinvested from China. To take Taiwanese electronics companies for example: to circumvent the tariffs while continuing to benefit from China's supply-chain clusters, assembly companies such as Foxconn, Wistron and Pegatron have expanded their presence in Southeast Asian and South Asian countries such as India, Malaysia and Viet Nam. The most aggressive of them is Wistron, which plans to lower the proportion of its production capacity in China to 50 per cent by the end of 2021. The relocation of assembly companies and the push by leading GVC companies to diversify supplier locations have led suppliers of electronic parts and components to reshore to Taiwan (China) or relocate to other Southeast Asian and South Asian countries (Chinafpd. net 2020).

In addition, during the COVID-19 pandemic the disruption of supply chains and the shortage of medical equipment have reminded developed countries of the vital importance of keeping strategic manufacturing at home. In light of this, the Japanese Government has tried to bring home overseas production facilities by providing loans for companies' relocation costs and subsidies for labour-saving measures to mitigate increases in labour costs after reshoring (Kodachi 2020). In the United States, Larry Kudlow, President Trump's top economic adviser, said that the US Government should allow companies to deduct the entire cost of capital spending, including relocating from China, from taxation, which means that the US Government shares the moving costs of US companies from China back to the US. This suggestion might be included in the US Government's post-pandemic plan to revive the economy. As tens of millions of people in the United States have applied for unemployment benefits during the pandemic, eagerness to bring back US companies is stronger than ever (Wingrove 2020).

That said, the attractiveness of China as a GVC manufacturing hub will not diminish overnight. First, China has one of the largest consumer markets in the world, a stable political environment, superb logistics infrastructure comparable to that of developed countries, large numbers of hardworking and highly efficient workers, and wide-ranging supply-chain clusters, among others, which many Southeast Asian and South Asian countries simply cannot rival (Shi 2020). Second, the possibility that Southeast Asian and South Asian countries may be future targets of US trade wars can upset companies' relocation decisions (Saldanha, Chowdhury and Shetty 2020). Third, the Chinese speed in restarting production after extraordinary shock adds to the reliability of China as a key node in global manufacturing. Despite alleged cover-ups of the COVID-19 epidemic, the Chinese Government then took strict measures to combat the virus so that the social order was successfully resumed in most parts of the country within two months. Third, in the short term the COVID-19 pandemic may drag the global economy into recession and thereby discourage companies from making new investments for relocation (Xing 2020). All these factors serve to offset the factors favouring disinvestment and will help China to retain its manufacturing base.

It remains unclear how many factories will leave China in the coming years and what are the ramifications of the disinvesting factors on process upgrading in China. Companies pressured to leave China because of the tariffs may leave or choose to stay and invest more in process upgrading to cut labour costs and thereby offset the extra tariffs. Companies pressured to leave China because their buyers want to diversify the geographical location of suppliers are more likely to leave, sooner or later. Before they leave, the prospect of relocation will discourage them from investing in process upgrading. When they leave eventually, many Chinese workers will lose their jobs. Companies which manufacture in China and target the Chinese market will in the short term be discouraged to invest in process upgrading as the tug-of-war between the United States and China, and the COVID-19 pandemic, dramatically exacerbate economic uncertainties and loosen the job market. For future researchers, there is much to look at in this regard.

- *The impacts of economic slowdown on technological upgrading in China*

There is no sign that China can reverse its slowdown in economic growth in the near future. For future researchers it will be worthwhile to look at how the economic slowdown weighs on investment in technological upgrading by firms and the Chinese Government. China's annual GDP growth has decelerated since 2010. In the first quarter of 2020, as the coronavirus epidemic brought the economy to a standstill, China's economy shrank by 6.8 per cent compared with a year earlier (Cheng 2020). The development of the COVID-19 crisis from a national epidemic into a full-blown global pandemic will affect China's exports and decelerate Chinese economic growth in the whole of 2020, if not 2021 as well. The prospect of long-lasting tension between China and the United States has similar effects, but in a longer time frame. In an era of economic distress, firms may prefer cash in hand over new investments in technological upgrading. Moreover, with the slowdown in economic growth comes the slowdown in the growth of the Chinese Government's revenue. Between 2010 and 2018, the growth rate of this revenue, including both the central Government and local governments, rose from 21.3 to 25.0 per cent in 2011 before gradually dropping to 6.2 per cent. During the same time frame the share of expenditure in science and technology in the Government's overall expenditure dropped from 4.7 to a low of

3.3 per cent in 2015, before climbing again to 3.8 per cent in 2018 (National Bureau of Statistics 2019a). With sluggish growth in revenue, the Government has little financial room to expand its support for technological upgrading, which, however, is regarded as the new engine of economic growth.

- *The impacts of innovation in forms of industrial organization on working conditions in China*

This report adopts a rather narrow definition of process upgrading, which omits innovation in forms of industrial organization. In fact, both innovation in production technologies and innovation in forms of industrial organization can reshape production and have implications for working conditions. In the Chinese case, the booming e-commerce industry has changed the way production is integrated into distribution, which pushes manufacturing to evolve to the needs of online shops. According to existing studies, platforms such as Taobao function as matchmakers between online shops and manufacturers. These shops follow customers' ever-changing and diversified needs and place small-batch, customized orders. Manufacturers bid for these orders, as in the gig economy. These manufacturers often form supply-chain clusters in geographically bound areas. The e-commerce platforms facilitate price competition between online shops selling similar products, which then intensifies price competition between manufacturers, who often respond by contracting and subcontracting orders to smaller workshops and family workers nearby. In this way, the innovation in distribution informalizes employment in manufacturing for online shops; alongside highly sophisticated online platforms stand workers subject to permanent competition for low-wage work (Fan 2019; Lüthje 2019). Given that online retail sales make up a substantial share (20.7 per cent in 2019) of the total retail sales of consumer goods in China (China Internet Watch 2020) and that existing studies on the impacts of online shopping platforms on manufacturing and its working conditions remain somewhat preliminary, future researchers have much to do on this topic.

- *The impacts of a full range of product upgrading on working conditions in China*

Due to data limitation, this report has been unable to outline the full range of product upgrading ongoing in present-day China. In fact, product upgrading is taking place not only in China's ICT manufacturing industry and automobile industry, as covered in this report, but also in a wide range of other industries. Moreover, while many Chinese enterprises are imitators and followers of global leaders, some are making progress in uncharted territories such as drones and unmanned driving. Time permitting, these followers and pioneers combined may have a considerable impact on employment in China, which future researchers will need to study.

- Wider social implications of technological upgrading

This report adopts a narrow definition of social upgrading and measures it with indicators on working conditions. By doing so, it misses more systemic social changes generated by technological upgrading and, most important, changes in capital accumulation and production. There has been preliminary research on this issue (Lüthje 2019). As technological upgrading gradually unfolds and incremental changes in capital accumulation and production become salient in China, future researchers will be in a better position to examine these social changes.

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The labour implications of technological upgrading in China

This study provides a comprehensive, state-of-the art overview of technological upgrading in China and its labour implications. While developed economies are pursuing Industry 4.0, China is pursuing Industry 3.0 and 4.0 at the same time. While maintaining its dominance as an assembly station for global commodity chains, China has emerged as a manufacturer of parts and components, and has established global brands in some industries. In a context of dual shortage of both skilled and low-skilled workers and limited rolling-out of new process technologies, process upgrading has aggravated the shortage of skilled workers and has reduced the shortage of low-skilled workers. Product upgrading in leading industries has expanded skilled employment and increased those workers' wages, but has not led to a reduction in working hours or significant improvement in job security and trade union representation. The Chinese Government has taken measures to streamline the education and training system to cater for the skills need of technological upgrading and has introduced other policies to harness the technological shock. However, the prospects for collective labour action to capture the gains enabled by technological upgrading are hardly promising.

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