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Transition from factor-driven to innovation-driven urbanization in China: A study of manufacturing industry automation in Dongguan City

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ABSTRACT

Following the reform and opening up of China, the Pearl River Delta (PRD) region became a center of foreign investment due to its comparative advantages of cheap labor costs and low land use prices. The tide of migrant workers, comprising a large surplus rural labor force that flooded into the PRD region, caused a rapid increase in the urban population. From the 1980s to the 2000s, migrant workers were a key force that drove urbanization in China. The utilization of automation technology in production since the 2010s has increased the number of unemployed laborers and shifted the dynamics of urbanization. This study investigated how automation is applied in production processes and its effects on different industries, namely, those related to textiles, electronic information, and home electrical appliance manufacturing; specifically we sought to examine the complex relationship among automation, the labor forces, and urbanization by illustrating the implementation of automation in production processes and its influence on labor forces and urbanization. This study revealed that companies in different industries implement automation to differing degrees and through varied upgrading paths. All industries can ultimately achieve technological transformation and cross-industry development. For labor forces, automation exerts two simultaneous folded effects, namely, the direct replacement of low- to middle-skilled workers and the creation of new jobs. The penetration of automation into manufacturing industries has changed the dynamics of urbanization and the social spatial structure of cities, leading to a polarization of the labor forces and the emergence of "dual cities".

1. Introduction

Urbanization has been a major issue worldwide for centuries. Over half of the population lives in towns and cities, and the figure is expected to increase to 68% by 2050 (Department of Economic and Social Affairs, United Nations, 2018); a large portion of this population resides in Asia. Among those comprising the urban population, about 90% of people live in India, China, and other countries due to the large number of rural-to-urban migrants therein. Future increases in the size of the world's urban population are estimated to be concentrated in a few countries. Among these countries, it is estimated that China will account for 255 million

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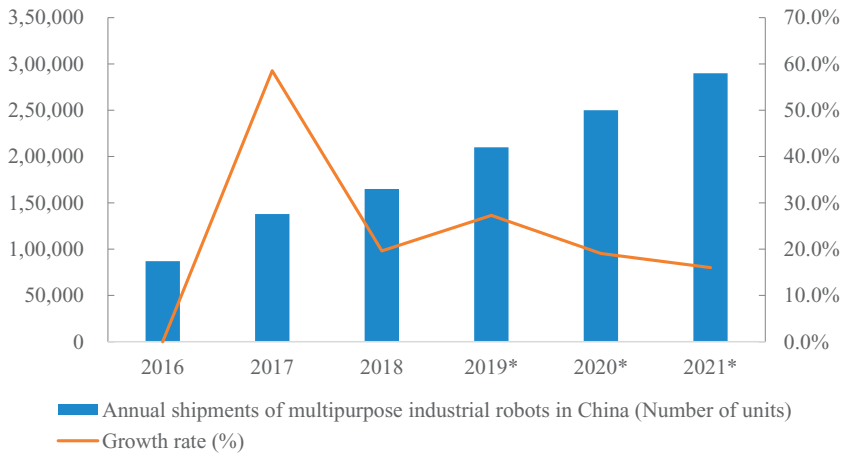


Fig. 1. Annual shipments of multipurpose industrial robots in China (number of units) and the annual growth rate (%). Notes: Annual shipments of multipurpose industrial robots in China refers to the volume of industrial robots sold to China. Data source: World Robotics 2018 Industrial Robots by International Federation of Robotics (IFR), 2018, retrieved from https://ifr.org/downloads/press2018/Executive_Summary_WR_2018_Industrial_Robots.pdf, accessed on April 4th, 2019.

individuals (Department of Economic and Social Affairs, United Nations, 2018). In the developing world, which has the highest urban population growth worldwide, China's urbanization remains the fastest, and the number of migrants expected to become urban dwellers therein is estimated to increase from 11.3% in 2018 to 20.2% by 2050 (UN HABITAT, 2018). Migration is a significant contributor to urbanization because when many migrants from the agricultural population move into the cities, the urbanization process is accelerated (Andersson, Quigley, & Wilhelmsson, 2009). Industrialization drives migration and increases both the urban population and the number of individuals seeking social and economic opportunities in cities, who constitute the bulk of the labor force in China.

With the advancement of technology, the revolution of industrialization and technology led by automation and robotics has exerted new influences on urbanization and migration in recent years. The earliest industrial automation occurred in the U.S. in the 1980s, when Americans used computers and information technologies in their automotive industry; this usage was recognized as the initial stage of automation. Waves of automation have reshaped the economy throughout history. Today, automation is booming worldwide. The global robot density was 74 per 10,000 employees in 2017 compared with 66 per 10,000 employees in 2016. By region, the average robot density was 99, 84, and 63 per 10,000 employees in Europe, the U.S., and Asia, respectively. The implementation of robotics in Asia is the fastest (e.g. China's fast growth in the robot industry (see Fig. 1)). From 2010 to 2016, the average annual growth rate of robot density in Asia, the U.S., and Europe was 9%, 7%, and 5%, respectively (International Federation of Robotics (IFR), 2018).

The emergence of automation in the new economy and technological era, accompanied by a decrease in technology cost, is expected to exert global effects. The impact of robotics prompts both hope and fear in people (Hunt and Hunt, 1983; Zhou & Tyers, 2018). On the one hand, automation has considerably reduced the working time per unit of output (Castells, 1989; Knoben, 2009). On the other hand, the replacement of labor forces in the 21st century has triggered the concern that technology may lead to large-scale unemployment in the future. According to the McKinsey Global Institute's research report, by 2030, 400 to 800 million jobs worldwide will be replaced by automation (Manyika, 2017). Two-thirds of jobs in developing countries may disappear due to automation (World Bank Group, 2018). The replacement of migrant workers undoubtedly hinders the industrialization and urbanization process dominated by labor-intensive industries or jobs (Golley & Wei, 2015; Harris & Todaro, 1970). In the future, automation will replace low- to middle-skilled workers and gradually leave many migrants unemployed (World Bank Group, 2018). Automation will also create new jobs, such as robot repair technicians.

Urbanization is largely driven by forces comprising a rural push or an urban pull, and rural-to-urban migration is expected to create an urban–rural utility gap (Chen, Lang, Chan, & Phillip, 2018; Harris & Todaro, 1970). Cities are extending their boundaries to accommodate the increase in population and the growth in land use. For example, China's urbanization was largely driven by surplus migrant labor and rural land and is internationally defined as a “rural push and an urban pull force.” Various studies have adopted the forces comprising a rural push and an urban pull as factors that drive urbanization (Jedwab, Christiaensen, & Gindelsky, 2015; Liu, Liu, Chen, & Long, 2010). The penetration of automation in manufacturing has changed the dynamics of urbanization and the social spatial structure of cities (Castells, 1989; Frank, Sun, Cebrian, Youn, & Rahwan, 2018). Automation not only serves as the fundamental force driving upgrading in the manufacturing industry, but also affects the urban social and spatial structure and migrants' employment in the urbanization context (Andersson et al., 2009). Thus, understanding the dynamics, processes, and influences of automation may provide support for addressing the question regarding how technology advancements affect migrant workers and drive urbanization.

Automation exerts global impacts at different speeds and in various ways, shapes, and forms (Gumbel & Madgavkar, 2018). Automation in China is proceeding rapidly due to the country's unprecedented urbanization, and China has been reported as the

Table 1
Summary of semi-structured interviews with the representative companies.

No.	Company	Industry	Type	Number of employees	Summary of Responses
1	xx Electronic Factory (Dongguan)	Electronic information industry	L/T	1100–1300	The introduction of automation promoted the production efficiency by about 20%; Labor costs were greatly reduced (about 30 people per device); The R&D investment was key (e.g. over 14 million in 2015). The investment in automation will also increase.
2	xx Precision Technology Co., Ltd. (Dongguan)	Electronic information industry	L/T	5000~ 10,000	Automation started with labor-intensive production processes and safety; the production efficiency was improved by 200% and 60% of labor costs were reduced owing to automation.
3	Dongguan xx Technology Co., Ltd. (Dongguan)	Electronic information industry	L/T	5188	By adopting automated assembly and spray lines, as well as machining centers, the production process became safer, more precise, and more cost-effective, which resulted in the replacement of about 1000 employees, or about 16.7% of the previous total.
4	Dongguan xx Electronics Co., Ltd. (Dongguan)	Electronic information industry	L/T	488	The production efficiency increased by 50% due to the adoption of automated assembly lines in 2017, which costed about 100 million RMB. One assembly line now requires two people instead of 20 (the number required before) and the labor replacement rate was about 90%.
6	Dongguan xx Knitting Garment Co., Ltd. (Dongguan)	Textile and garment industry	L	315	The processes of discharging, reclaiming, and setting the modes were automated, and the production efficiency was greatly improved from a requirement of five people to operate one machine to one in which a single person can handle five machines at once.
7	Dongguan xx Textile Technology Co., Ltd. (Dongguan)	Textile and garment industry	L	20	Handcarts were replaced by automatic washing lines in 2015 and the production increased by 40%; the number of employees was reduced to 20, down from 200 employees, and the labor replacement rate was about 90%, greatly reducing labor costs.
9	Dongguan XX Group Co., Ltd. (Dongguan)	Garment industry	L	10,000	By adopting automatic production lines for domestic hanging, the production efficiency increased by 20%; instead of a scenario in which one person operates one machine in the sweater weaving process, each person can manage 10 machines. The labor efficiency has therefore increased by 90%.
10	Dongguan xx Shoes Co., Ltd. (Dongguan)	Footwear industry	L	600	The process involving forming, combining, etc. was automated and the number of front-line workers decreased; therefore the labor cost was significantly reduced.
11	Dongguan xx Shoes Co., Ltd. (Dongguan)	Footwear industry	L	147	By adopting automated machines for shoes, cutting, etc., the production process was upgraded.
12	xx Group Co., Ltd. (Foshan)	Household appliance industry	L/M	11,4765	Automating aspects of production, such as packing and handling, etc. greatly improved productivity by reducing the previous population of 20,000 workers; the labor replacement rate was about 20%, which greatly reduced labor costs.
13	xx Electronics Co., Ltd. (Dongguan)	Household appliance industry	L/M	1000–5000	Automating injection molding and the assembly line saved a significant amount of work.
14	xx Intelligent Technology Co., Ltd. (Dongguan)	Household appliance industry	L/M	200	By automating the assembly line and the equipment, the number of employees was reduced from 300 to 200, thereby decreasing the number of workers by about 33% while increasing revenue by 7%–8%.
15	Dongguan xx Furniture Co., Ltd. (Dongguan)	Furniture manufacturing industry	L/M	150–170	Due to automation, the business volume increased by 50%, and product accuracy increased to 95%; the number of employees was reduced by 65, and the labor replacement rate was about 40%.
17	Shunde xx Industry Development Partnership. (Foshan)	Plastic manufacturing industry	L	40–60	The use of automated machines dramatically increased productivity, significantly increased the number of orders received, reduced labor cost, and replaced about 33% of workers.
18	xx Electronics (Dongguan) Co., Ltd. (Dongguan)	Plastic manufacturing industry	T	500–1000	Automation greatly improved the productivity; the labor force was reduced by about 80% and the number of customers increased to over 1000 and includes companies such as Huawei and ZTE.
19	xx Ceramic Sanitary Ware Co., Ltd. (Foshan)	Ceramic manufacturing industry	L	Over 10,000	The process involving forming equipment, embryo modification, and glaze spraying was automated. The product is now more intuitive, while its precision and speed were improved as well.
20	Dongguan xx Auto Accessories Co., Ltd. (Dongguan)	Auto parts manufacturing industry	L	100–499	Using automatic equipment such as robots in injection molding has reduced staff, increased efficiency, and saved energy; the labor replacement rate of the first-line workers was about 6%.
21	xx Automobile Technology Co., Ltd. (Foshan)	Auto parts manufacturing industry	L	4000	The process involving grinding, polishing, and welding was automated; consequently, productivity was greatly improved and the labor cost was reduced.
22	xx Optics (Guangzhou) Co., Ltd. (Guangzhou)	Instrumentation manufacturing industry	L/T	300	By using automation equipment, the accuracy of the production process was improved, the rate of defects in robot processing was 2–3 times less, and the labor cost was reduced.
23	xx Optical Technology Co., Ltd. (Dongguan)	Instrumentation manufacturing industry	L/T	Over 2000	Automation equipment greatly improved the accuracy of production; significant labor was also saved, e.g. an automated slicer was able to replace over 15 people.

(*continued on next page*)

Table 1 (*continued*)

No.	Company	Industry	Type	Number of employees	Summary of Responses
24	xx Precision Electronic Technology Co., Ltd. (Guangzhou)	Machine equipment manufacturing	L/T	400	The automated process now includes loading and unloading and quality inspection processes; each assembly line now only needs one person, as opposed to 14–15 people.
25	xx Electric Heating Machinery Co., Ltd. (Dongguan)	Machine equipment manufacturing	L/T	500–1000	Automation increased labor productivity by five pieces per person; the automated production line reduced the labor force from 98 to 49, and the labor replacement rate was about 50%.
26	xx CNC Tools Co., Ltd. (Dongguan)	Machine equipment manufacturing	L/T	38	Automated equipment upgraded the products, increased production speed, and doubled the value of the products; the labor replacement rate was about 60%.
27	xx Intelligent Equipment Co., Ltd. (Dongguan)	Machine equipment manufacturing	L/T	437	Over 40 R&D personnel are now involved in automation production, in which over 10 individuals are dedicated to robot development.

Note: L = Labor-intensive, T = Technology-intensive, M = Market orientation. The key questions during the interviews included: “1) What kind of automation has been implemented? 2) What are the changes in production and how does it affect the production efficiency? 3) What is the proportion of labor replacement?”

fastest expanding market of robotics in the world (Twentyman, 2018). Since the 1980s, China's urbanization has exhibited the highest speed and the largest scale in human history. The Pearl River Delta (PRD) region, which is dominated by labor-intensive manufacturing, is known as the "world's factory." It was the first to open itself to the world as part of *China's Reform and Opening Up*, and it has created a complex industrial network of textiles, clothing, shoes, electronic information manufacturing, home appliance manufacturing, and other industries. Migrants have become the driving force of urbanization (Xu & Li, 2009a, 2009b) and have promoted urban labor-intensive manufacturing development. The "migrant labor tide" gradually emerged in the late 1980s, and many surplus rural laborers flooded into cities. The PRD region has been deeply embedded in the global production network and has become an indispensable part of the global manufacturing network (Wang, 2001).

New technology advancements, such as automation, have been reshaping our cities and regions and have triggered the transition of China's urbanization from one driven by factors to one driven by innovation owing to increases in labor forces comprising migrant workers and expansion in land use. This study explores the complex relationship among automation, migrant labor forces, and urbanization in the PRD region and illustrates the impact of automation on employment and job structures in three different industries in Dongguan. In-depth surveys were conducted with over 20 representative companies that implemented automation between 2015 and 2017. Semi-structured interviews were conducted with enterprise managers for at least one and a half hours. On-site visits were also performed, and questionnaires were distributed in the factories and production workshops (see Table 1). It was found that urbanization depends not only on capital and investment, but also on industries and enterprises. The labor force of migrant workers is not the only driver of urbanization or economic growth, in that, automation's effects may limit the benefits of population agglomeration. Innovation-driven factors, such as automation and enterprises' choices in technology advancement, will be the key driving forces in China's urbanization (Lang, Long, Chen, & Li, 2019). Automation technologies affect industries and occupations differently. Automation has prompted new changes to the employment structure of the industry. The occupational structure is divided into two parts: skilled and physical labor. The number of operators required is decreasing. Well-educated and highly skilled workers will be the main personnel needed for manufacturing industries in the future. Enterprises will have to attract, grow, and retain highly skilled workers to maximize the productivity of their labor forces.

The remainder of this paper is structured as follows. The second section reviews relevant literature on the development of automation in manufacturing enterprises and the influences of migrants on urbanization. Related studies conducted worldwide are summarized and compared. The third section lays out the current study's analysis framework and analyzes the automation driving force, its process, and its impact on manufacturing enterprises. The fourth section presents the findings regarding the three industries investigated herein, with focus on the characteristics of enterprises specialized in automation replacement. The fifth section concludes this study.

2. Literature review: urbanization, technology, and labor forces

2.1. Drivers of migration and urbanization

The impetus for urbanization has been a consistent focus of academic studies. Many scholars have attributed urbanization motivation to the industrialization process (Xing & Zhang, 2017), which forms the basic driving force of urbanization. Ranis and Fei (1961) analyzed the dynamics of urbanization and the factors that affect rural migration to cities. The urban population and land use increase rapidly when a large number of surplus rural laborers and skilled personnel flood into cities. Chinese and Indian labor forces added 1.3 billion new workers to the global labor pool between 1970 and 1990 and accelerated the global trade of goods and services (Harris, Kimson, & Schwedel, 2018). The theory of "rural push and urban pull" has been used to explain the mechanisms of a growing urban population, namely, urbanization. A fast-growing population implies that rural migrant workers are pushed or pulled to cities due to the attraction of job opportunities (Su, Tesfazion, & Zhao, 2018). Migrants have become an important force in promoting urbanization (Xu & Li, 2009a). McGee, (1985) believed that the urbanization that occurred in Asia in the 1980s was fundamentally different from that expected in Western urbanization theory. Urban–rural integration is a type of urbanization driven by labor migration (Li, 2000; Li, Hui, Chen, Lang, & Guo, 2019).

However, the era of abundant labor is ending and has been restructured. Today, technology and innovation are the core drivers of urbanization. The abundance of labor forces is due to global labor pools created by the fastest growth in the labor force in modern history in the 1950s, the coming of age of the baby boomer generation, women's entry into the workforce, and the integration of China and India into the global economy. Many migrant laborers have contributed to the development of cities' labor-intensive manufacturing industries, which positioned the cities to become centralized locations for the textile, garment, electronic information manufacturing, home appliance manufacturing, and other industries (Golley & Meng, 2011). The mobility of migrant workers and the labor force is now determined by technological advances, which include automation technology. The implementation of new technologies has changed the in production organization, improved production efficiency, and achieved upgrades in the production process (Scott, 1986). Economic geographers are concerned with the upgrading loci of enterprises following the implementation of new technologies (Humphrey & Schmitz, 2002). China's urbanization is changing from one driven by factors to one driven by innovation (Fig. 2).

2.2. International patterns of automation

Automation and robotics are driving the fourth industrial revolution and reshaping the urban space and people's lives in all domains. In the beginning of the 21st century, with the rapid development of technologies (e.g., artificial intelligence, industrial

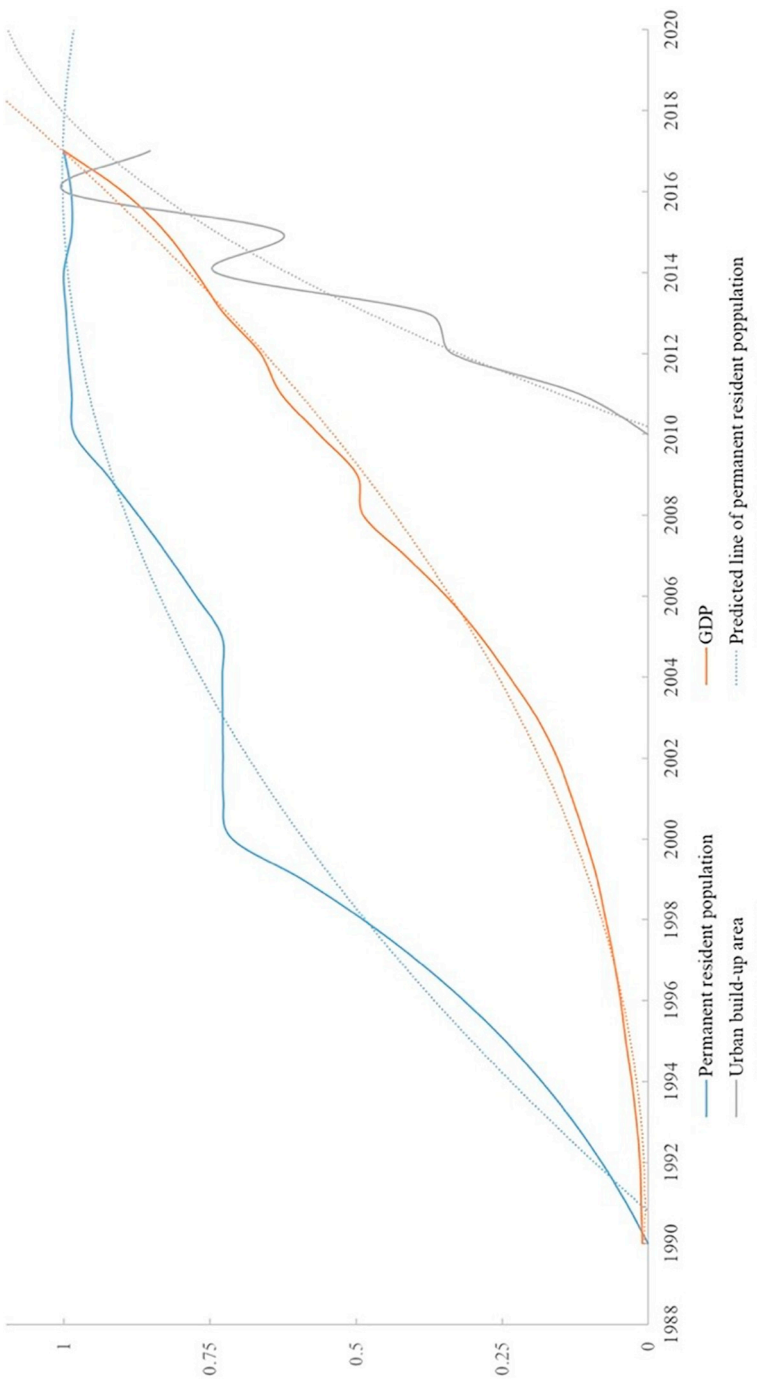


Fig. 2. Urbanization transition in China: from a circumstance driven by factors in land use expansion and urban population increase to one driven by innovation. Source: analysis of normalization data from *China City Statistical Yearbook*, GDP and permanent resident population from 1990 to 2017, and urban built-up area from 2010 to 2017.

robots, and digital manufacturing), the world entered the era of automation and intelligent industrialization (Napoletano, Sandri, & Strube, 2018). Automation technology has achieved rapid progress and expansion (Aghion, Jones, & Jones, 2017). Automation technologies are being implemented in many countries around the world, and include autonomous vehicle trials, automated ports and warehouses, delivery robots and drones, automated control systems for traffic, automated vertical farms for food production, and social robots ranging from police officers to restaurant waiters (Frank et al., 2018; Majumdar & Venkataraman, 1993).

Automation has changed the industrial production process, which has brought great benefit to enterprises, as the implementation of technology increases possible development opportunities. Computerization and industrial robotization have increased production efficiency (Kromann et al., 2011; Graetz & Michaels, 2017). Automation is expected to increase labor productivity by 30% from 2015 to 2030; this change will vary among different industries, such as healthcare, education, food service, retail, transportation, and warehousing (Harris et al., 2018). However, companies' adoption of new technologies is subject to the market environment and market competition pressure, as well as other attributes that affect the implementation of new technologies (Dunne & Hughes, 1994; Bartelsman & Dhrymes, 1998; Hofmann & Orr, 2005; Jäger et al., 2016).

Automation technology has changed the demand for labor. Automation directly replaces the workforce and reduces the number of jobs, leaving many unskilled and low-skilled workers unemployed. The medium-skilled workforce is the largest group that will be replaced, and a dual city characterized by unskilled and highly skilled workers is emerging as a result (Castells, 1989). Concern related to these changes is not only focused on the number of jobs that are lost but also on the types of jobs that are rendered obsolete (Rumberger & Russell, 1984). This problem has been widely discussed since the 1980s. For example, in American factories, 10 to 15 million manufacturing workers and a similar number of service workers have been displaced from their existing jobs (Hunt and Hunt, 1983).

Automation can dramatically re-invigorate urbanization. In the U.S., a new wave of automation could stimulate as much as $8 trillion in revenue by the end of the 2020s. The labor force growth in the U.S. will slow to 0.4% per year during this time. A major shift will occur, in which the abundance of labor forces that have invigorated urbanization since the 1970s will stagnate and decline. Automation could replace as many as 20% to 25% (40 million) of existing jobs in the U.S. (Harris et al., 2018). Automation-related risks of labor forces disproportionately exert impacts on low-income and low-skilled labor forces in America, the situation that is confronted by migrant workers that this circumstance exacerbates Occupations at the lowest risk (10%) have average wages of $84,000 per year, whereas those at the highest risk (10%) have average wages of about $36,000 per year (Hicks, 2017).

A similar pattern has occurred in Europe, Japan, and many other countries, and automation in China may also follow this pattern, as shown in (Fig. 3), which illustrates China's robot industry scale and its growth trend. In the past five years, the U.S. government has regarded automation as the key to new urbanization processes, such as facilitating daily life through autonomous cars, autonomous pharmacists, service robots, and autonomous drones for delivery (Kovacic, 2018). The Japanese government established the “Robot Revolution Realisation Council” in 2014 to oversee Japan's robotization and economic reinvigoration. The Singaporean government is developing robots and automation at a rapid rate to improve city management and control areas, such as health and social care (Kovacic, 2018). The impact of manufacturing automation on different geographies depends on many factors and is not the direct focus of this study. Notably, advanced economies are investing in automation to close the labor cost gap with emerging markets. In 1997, the manufacturing value added per dollar of labor was twice as high in Mexico as that of the U.S. By 2013, that gap had shrunk to less than 15% (Harris et al., 2018).

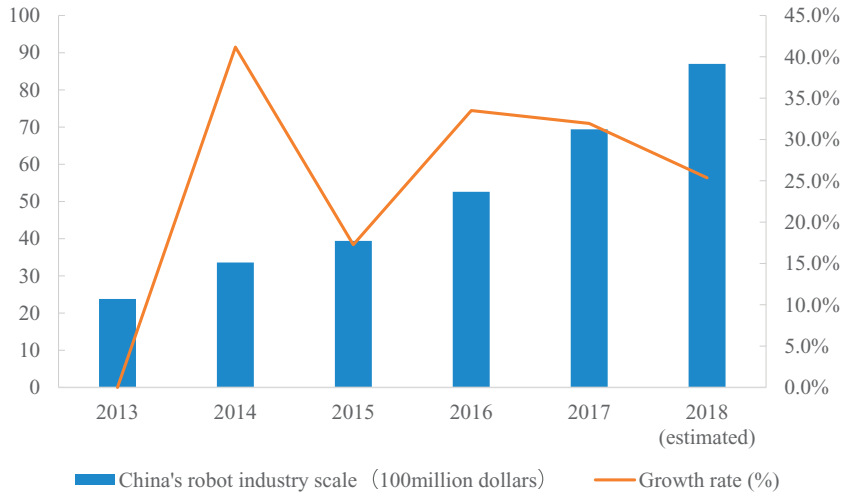
https://ifr.org/downloads/press2018/Executive_Summary_WR_2018_Industrial_Robots.pdf, accessed on April 4th, 2019.

Existing studies have analyzed the strengths and weaknesses of substitution and the supplemental effects induced by automation, discussed the future demand for labor forces, and proposed policy recommendations and government responses to the spread of automation (Hunt and Hunt, 1983; Rumberger & Russell, 1984; Castells, 1989; Barbieri, Di Tommaso, & Bonnini, 2012; Liu, 2017). However, these studies disregarded the degree to which new technologies would be adopted (automation among different industries) and the characteristics of labor forces in different industries and their varied adaptive abilities when confronting automation. Despite the increase in new jobs in service industries, such as take-away delivery, express delivery, and online car-for-hire drivers, these new opportunities are not mentioned in the existing literature. Nevertheless, they comprise an important sector of automation technology development and changes in the labor force. To systematically explore the complex relationship between the labor force driven by migrant workers and urbanization as it relates to automation, this study introduces the automation processes of select companies specialized in three industries within the PRD region, explains the specific role of automation in restructuring the labor force, and furthers the understanding of the rise of dual cities driven by technological advancement following the decline of labor migration in cities.

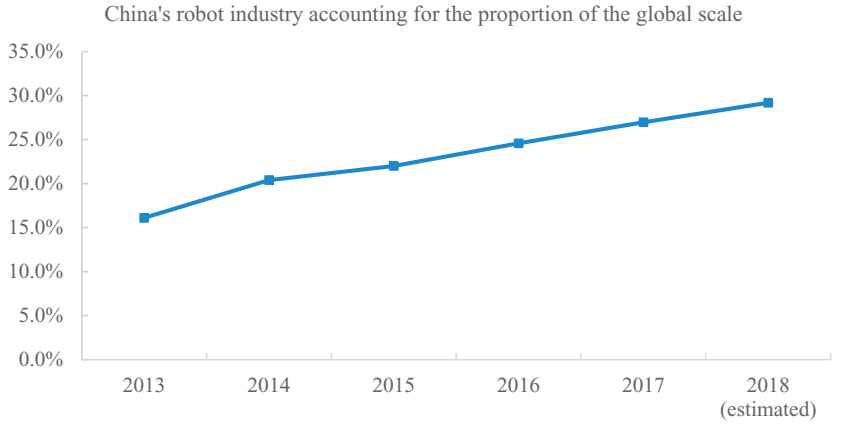
3. Automation in China's manufacturing industries: the framework

In China's manufacturing industry, automation occurred primarily in the Yangtze River Delta and PRD. Companies in these areas achieved improvements in production efficiency, enhancements in their working environments, and reductions in labor costs by implementing automation technology (Wu, 2016). Since the reform and opening up of China, eastern coastal areas have been receiving concentrated foreign investment due to the advantages of cheap labor forces and low land use prices that they offer. As a result, countless laborers have become assembly line workers. However, the introduction of automation technology has directly replaced the labor force in these factories. Thus, the main driving force of urbanization is the shift from labor-intensive to innovation-intensive work. The National New-type Urbanization Plan (2014–2020) officially delineates China's new urbanization direction as one driven by innovation and technology (Lang, Chen, & Li, 2016).

A few studies have thoroughly investigated the influence of automation regarding urbanization and migration in China.



(a)



(b)

Fig. 3. China's robot industry development and growth trend. (a) China's robot industry scale (100 million dollars per unit) and the annual growth rate (%). (b) China's robot industry considering the proportion of the global scale. Data source: World Robotics 2018 Industrial Robots by International Federation of Robotics, 2018, retrieved from.

Compared with Western literature, research on China's automation lags behind, especially regarding the implementation of automation in different industries and its impact on the labor forces. This study adopted the PRD region as a case study through which the way automation is implemented in different types of factories, its influence on the labor force (i.e., migrant workers), and how it has changed the process of urbanization can be investigated. To fill the research gap, this study developed a research framework to analyze the complex relationship among automation, the labor force of migrant workers, and urbanization (Fig. 4). The impact of automation technology varies from one industry to another because different industries are sensitive to different factors, the latter of which can be divided into three major groups: costs, technologies, and markets (World Bank Group, 2018). Thus, we performed an in-depth analysis from the perspective of three different industries, namely, textiles, electronic information manufacturing, and home electrical appliance manufacturing.

Textile and garment manufacturing is a typical labor-intensive industry that is considerably affected by costs. The global wave of industrial transfer in the 1950s began with the textile industry, mainly owing to the increase in labor costs in developed countries, such as Europe, the U.S., and Japan (Chang et al., 2016). Due to advancements in intelligent manufacturing technology during the fourth industrial revolution, the cost of intelligent equipment, such as robots, is declining. Labor-intensive enterprises are gradually introducing automated production equipment instead of that characterized by manual production, thereby reducing enterprise dependence on human labor in the manufacturing process. On this basis, companies have continuously attempted to position themselves at the upper end of the value chain and at the lower end of brand marketing to increase their added value and enhance their competitive advantage. The main impact of automation on the textile and apparel industry is experienced by workers engaged in direct production in traditional factories, as they are replaced. Following restructuring due to technological change, digitization, and

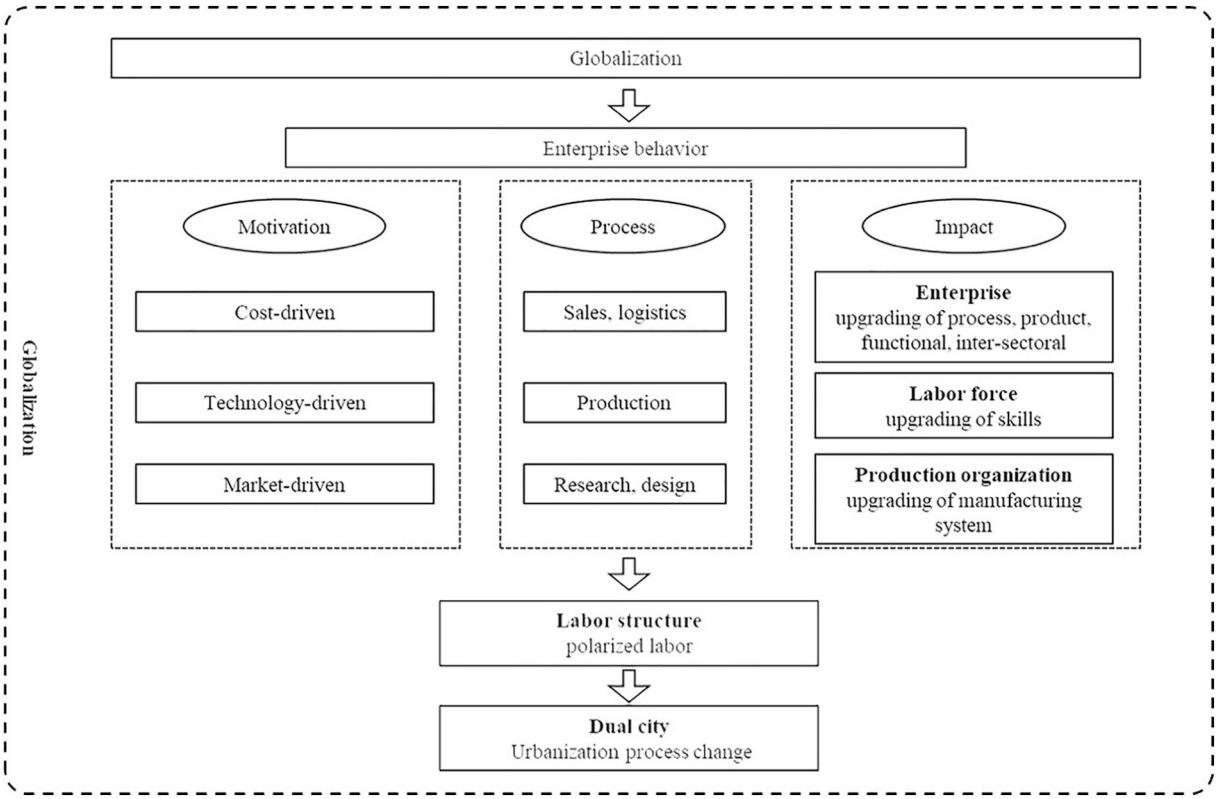


Fig. 4. Analytic framework of China's innovation-driven urbanization via technology and automation.

networking, low-skilled, low-paying jobs quickly disappear. The labor forces in these jobs comprise vulnerable groups, such as women and migrants. After losing their jobs, they cannot easily return to employment through re-education. Conversely, fashion designers, machine engineers, and logistics personnel are valued in this industry.

Technology advancement is particularly important for the electronic information manufacturing industry because the technical level largely determines production efficiency, especially in technology-intensive industries, such as electronics, automobiles, and machinery. To control production costs, increase production efficiency, and improve yield, these enterprises typically introduce automation to improve the overall manufacturing capacity. Enterprises frequently invest extensive manpower and material resources into the development of production technology to achieve a competitive advantage. Automation reduces the direct labor input of the electronic information manufacturing industry and indirectly transforms the labor force. Owing to the rapid growth in technology, the number of skilled workers and physical laborers is increasing, but that of first-line assembly workers is decreasing. This trend indicates the polarization of the professional structure comprising skilled and blue-collar workers, which also prompts organizational and technological restructuring. Technical and professional workers in the electronic information industry have higher skills and knowledge than those in other industries. When these workers are replaced, they can easily acquire new jobs. Their prospects are more favorable than those of workers in traditional labor-intensive production industries (Graetz & Michaels, 2017; Guan & Pang, 2017).

Market changes dominate the production of the home appliance manufacturing industry. Given the increasingly fierce market competition and the diversification of consumer preferences, this type of industry directly engages with consumers and devotes significant attention to products; it must diversify its products, improve their quality, and increase the added value. The price, quality, and brand effect of products directly affect the market performance of companies. Therefore, to achieve an increased market share, control costs, and improve quality in the manufacturing process through automation, companies need product design, back-end brand marketing, and logistics at the front end of the value chain. Workers are at risk of replacement due to the deepening of automation technology, and the workers themselves will gradually become polarized. The production organization is changing and will become flatter than before. Therefore, the demand for skilled workers, such as research and development staff, design engineers, logistics and distribution personnel, and sales talents, is increasing at both ends of the industrial chain. These workers will become the main labor force of this industry.

These three industries have different automation effects on workers as well as different technical requirements for them. The occupational structure is generally divided into two groups, namely, skilled workers and physical laborers, both of which are increasing in number. Meanwhile, the number of operators (i.e., assembly line workers) is declining. This is a fundamental impact of automation on the employment structure. Technology also plays a complementary role in producing new jobs to absorb the newly

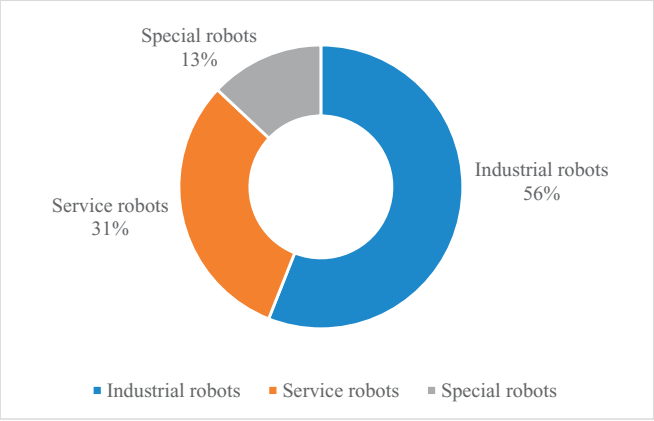


Fig. 5. Chinese robot industry scale in 2018 (proportion). Data source: World Robotics 2018 Industrial Robots by International Federation of Robotics (IFR), 2018, retrieved from https://ifr.org/downloads/press2018/Executive_Summary_WR_2018_Industrial_Robots.pdf, accessed on April 4th, 2019.

unemployed. Recently, many new jobs have emerged in the service industry, most of which are low-tech jobs, such as food deliverers, couriers, online car-for-hire drivers, salesmen, and waiters. According to a report released by the *Meituan* Food Delivery Company in 2017, they employ 2,260,000 delivery personnel, including part-time employees, among which 31% transferred from manufacturing industries (Research Institute of Meituan Review, 2018).

Automation increases the production capability and profit of enterprises and industries. In the near future, machine substitution will cause the service industry in cities to become a mixture of low-skilled jobs, self-employment, and informal employment. In the long run, automation will replace middle-skilled workers in the industry. Automation in manufacturing has been changing the dynamics of urbanization and the social spatial structure of cities, thereby leading to the polarization of workers and the emergence of dual cities.

4. The selected cases from different industries: an analysis of automation

4.1. Overall characteristics of automation in the PRD region

This section examines the characteristics of automation and the accompanying impacts on labor displacement, as well as increases in the productivity of labor forces, by conducting case studies of three enterprises in Dongguan. A survey was conducted between 2015 and 2018. The impact factors of automation were summarized to further develop the understanding regarding how automation is applied and its impacts on different enterprises, industries, and labor forces of migrant workers. Differences exist between various industries in terms of automation initiatives, processes, influences, and the paths followed for industrial upgrading processes. Fig. 5 shows the Chinese robot industry scale in 2018 (proportion). Industrial robots are one of the most popular and best-selling robots on the market, and automation infrastructures are mostly comprised this type, which indicates the boom of intelligence and automation in China on a large scale.

Enterprises from three industries in Dongguan City in the PRD region were selected to illustrate the status quo of automation in China. These enterprises are located in the Mideastern portion of the PRD region, which was known as “the world's factory” at one point in time. After the financial crisis in 2008, Dongguan encountered serious problems, such as rising costs, labor shortages, and the dissolution of manufacturing companies. To address such issues, enterprises reduced their production costs by intensifying the implementation of advanced technology. With the rapid development of automatic and intelligent manufacturing technology, an increasing number of enterprises introduced automatic and intelligent equipment into their production processes. By 2013, the Ministry of Industry and Information Technology issued the *Guiding Opinions on Promoting the Development of Industrial Robot Industry*, proposing the formation of a relatively mature robot industry infrastructure by 2020, and the cultivation of leading enterprises and supporting industrial clusters with international competitiveness. Automation is booming across China, in which Dongguan, formerly known as the “world factory,” was one of the “earliest and most advanced” cities, in which over 60% of the industrial enterprises have implemented automation. In 2014, Dongguan City issued a policy called “*Dongguan City's Promotion in Enterprises ‘Automation’ Action Plan (2014-2016)*” and concurrently established special funding, which significantly promoted the automation process in industrial enterprises.

The Dongguan Municipal Government has deliberated and adopted the *Opinions on Accelerating the Implementation of the Development of Industrial Robot Intelligent Equipment Industry* and intends to realize the strategy of “Dongguan Manufacturing 2025,” achieve the transformation from “big manufacturing city” to “strong manufacturing city” by 2025, and establish a manufacturing industry city whose industrial robot intelligent equipment industry output value approximates 70 billion RMB, to build 23 industrial robot industrial parks and 68 intelligent equipment industrial agglomeration areas. It is located within Guangdong Province and is China's most competitive and influential industrial robot industry base, as well as a model intelligent manufacturing city. The

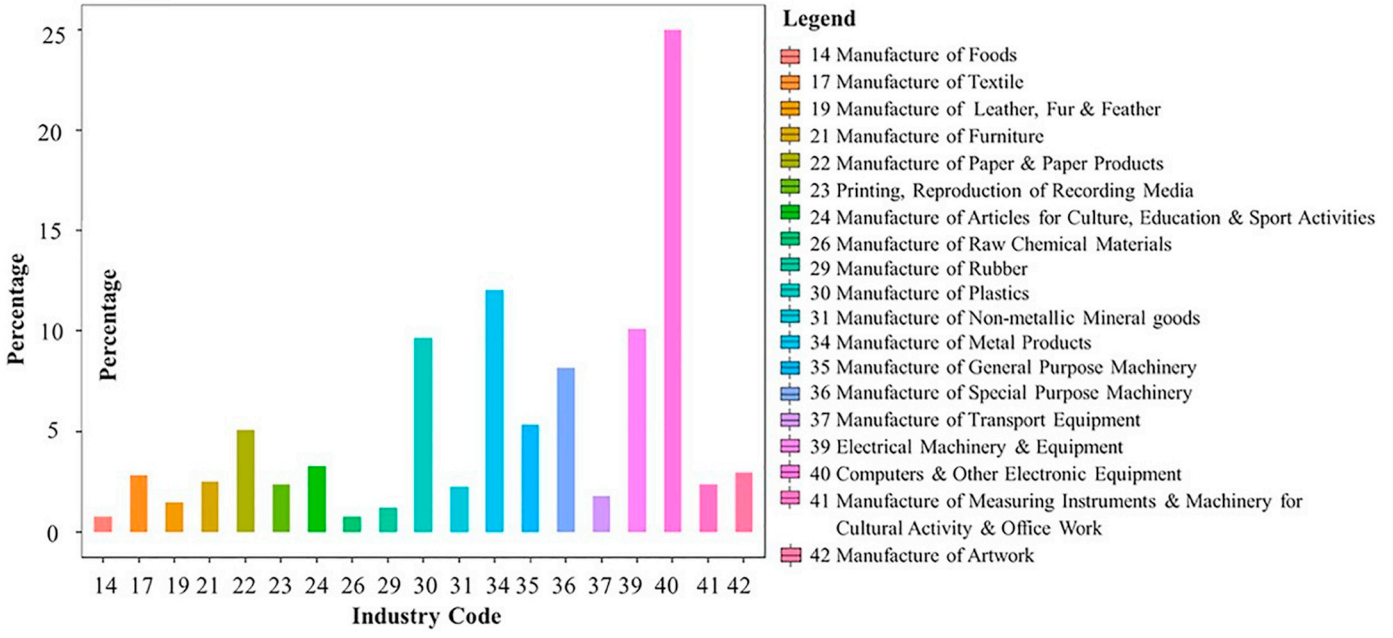


Fig. 6. The industry distribution of automation implementation among different industries in Dongguan City from 2014 to 2016. The x-axis shows the two-dimensional, numerical code for China's industry. Data were collected from the author's funded project *"Dongguan City's Promotion in Enterprises 'Automation' Action Plan (2014-2016)."*

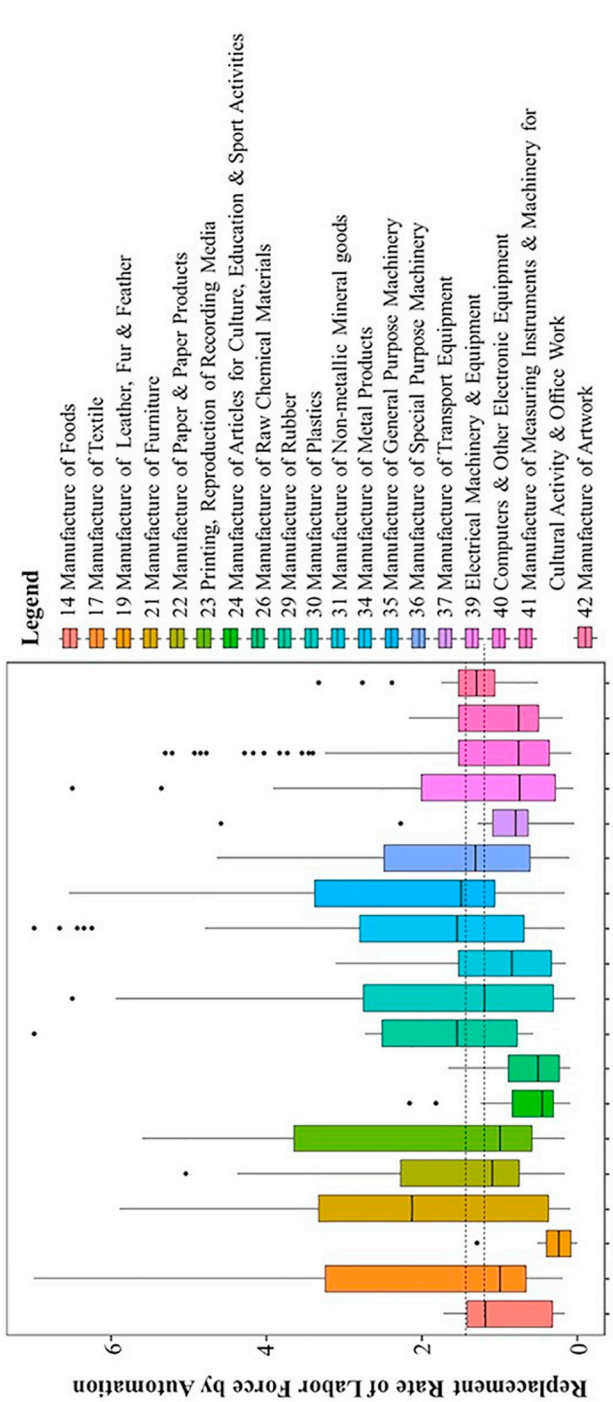


Fig. 7. Labor force replacement rate among different industries in Dongguan City. The x-axis shows the two-dimensional numerical code from China's industry. Data were collected from the funded project *"Dongguan City's Promotion in Enterprises 'Automation' Action Plan (2014-2016)."*

"Dongguan Model of Automation Application" was featured by China's central TV channel, which introduced the city before and after its transformation, shared details on the yields and inspiration of the Dongguan automation plan, and told the story of "Made in China 2025" using the "Dongguan Automation Application" as an example.

The general circumstance of the enterprise implementing automation in different industries is shown in Fig. 6. Evident differences exist among the industries in terms of the distribution of enterprises that apply automation. The implementation of automation in most enterprises can be seen in communications equipment, computers, and other electronic equipment for manufacturing and accounts for 25% of the total enterprises (Fig. 6). Automation is replacing human labor by introducing humanoid service robots, collaborative robots, drones, artificial intelligence, and machine learning algorithms.

Enterprises can reduce the costs of workers and improve production efficiency by using new robots or automatic machines. Automation reduces the need for workers and the relative costs of goods, and also increases the overall material standard of living and the production of other goods. We calculated the labor substitution rate by using the number of workers reduced in each enterprise to reveal the degree to which automation machines displace workers. Overall, automation may exert a replacement effect of about 16% in Dongguan City. Moreover, the substitution rate in the manufacture of general purpose machinery (Scott, 1986), metal products (Rumberger & Russell, 1984), rubber (Majumdar & Venkataraman, 1993), and furniture (Jedwab et al., 2015) is relatively high, as shown in Fig. 7.

On the one hand, the rate at which robotics replace the labor force (about 16%) indicates a shrinking trend in job availability. On the other hand, according to a government report, 2017 yielded 80,600 new jobs and 10,043 unemployed people, which indicates that although robots have replaced human workers, the decline in total employment is not significant. Automation forces assembly line workers to work as engineers by teaching themselves and through training provided by their peers. In the manufacturing industries, technology advancement has resulted in a serious employment shift from the secondary to the tertiary industry, such as food delivers, couriers, and DiDi drivers. Didi Chuxing Technology Co. (stylized as DiDi) is a Chinese ride-sharing, artificial intelligence (AI), autonomous technology conglomerate company. Its headquarters are in Beijing, and it provides services, such as taxi hailing, private car hailing, and social ride-sharing, to users in China via a smartphone application.

4.2. Labor force changes by labor cost-driven automation: textile industry

The high competitiveness of the textile industry makes it susceptible to production costs. Hence, companies in the textile industry always move from one country to another in search of the lowest costs. Starting in the 1980s, the PRD region attracted millions of textile companies due to the region's comparative advantages of a cheap labor force comprising migrant workers and urbanized land use resources. The local industrial agglomeration formed the *Dalang*, *Changping*, and *Liaobu* textile clusters in Dongguan City. After the global financial crisis in 2008, costs and recruitment difficulties placed enormous pressure on these companies. The disappearance of the "demographic dividend" exacerbated such difficulties. Given the rising production costs, determining the best means of reducing the labor force and production costs has become a key issue in the further development of these companies in the secondary industry.

The upgrading process of one company surveyed is a typical case, in which automatic loom machines were introduced to replace hand-knitting machines (Fig. 8). Traditionally, a textile worker controlled one hand-knitting machine, and over 20 workers worked together in the workshops. This company hired about 100 to 200 workers at once, which is fairly typical for a textile factory. In 2015, the company bought eight automatic loom machines from Germany, Japan, and Taiwan and immediately put them to use. Only four to six workers were needed to monitor the production process. Now, with the implementation of automation, only about 20 workers work in the factory; 90% of the workers have since been displaced. Each worker cares for two or three machines to knit cloth, and these workers must only monitor and manage several routine problems, which means that the machines complete most aspects of the production process automatically and without human participation.

After replacing the workers, automation promoted the production efficiency to 22.2 times that of the prior situation. Given the transformation in production, the company can focus on material texting, design, and brand development. Automation has stimulated this company to cooperate with colleges and universities to conduct research on spinning raw materials. Aside from material innovation, this company also devotes attention to the design process. Each year, it receives designers from across the country and offers design training practice to attract young designers from universities. The transformation of automatic manufacturing is a common upgrading process that is also seen in many other similar labor-intensive industries, such as the footwear manufacturing industry. Another textile company in *Dalang* Town, Dongguan City, adopted an automatic loom into its production process to replace spinner workers. With 10% of the workers previously required, the company can now produce more garments than before. The ascendancy of automatic machines has prompted numerous factories to shift from the traditional manual type of production to that which is automatic, enhanced companies' production capabilities, and alleviated pressures caused by the labor shortage.

This transition in the production process has caused companies to adjust their requirements of the skills a member of the labor force must possess. With the increasing pace of automation implementation in the promotion of production efficiency, companies can focus on fashion design to occupy the upper stream of the value chain and realize functional upgrading. Therefore, talents with design, artistic, marketing, and sales skills are preferred in the textile industries today. Overall, the automation in labor-intensive industries has reduced labor costs and helped companies upgrade their production processes.

4.3. Labor force changes by technology-driven automation: electronic information manufacturing industry

One of the companies surveyed is an electronic information manufacturing enterprise specializing in technology products and

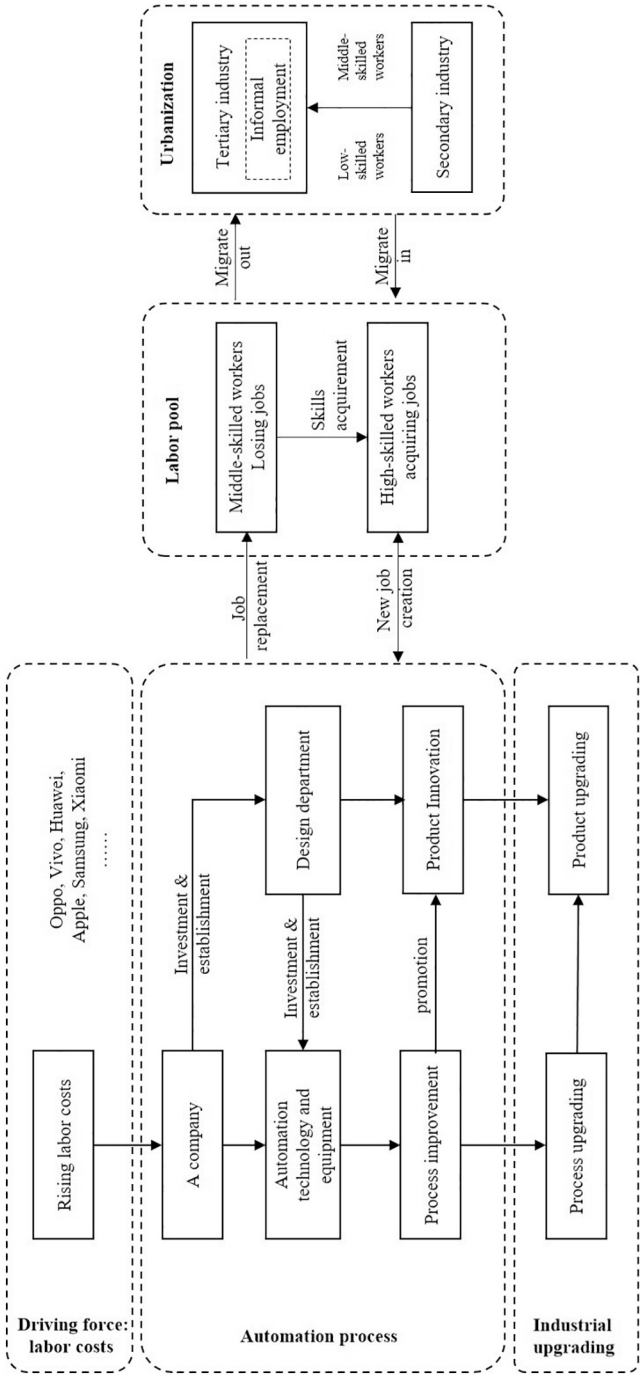


Fig. 8. Diagram illustrating the impact of automation from the case study on the textile industry.

sales; it is a component supplier for mobile phone companies, such as Huawei, OPPO, Vivo, and Xiaomi. This company was established in Shenzhen City in 2001 but moved its manufacturing factories to Dongguan City and has been maintaining rapid development since 2010. Its operating income has exceeded 8.4 billion RMB yuan, and its net profit was 571 million RMB yuan in 2017. It has become a leading enterprise among China's mobile phone parts suppliers.

One of the most competitive products produced by this company is its metallic mobile phone covers. Apple and Samsung have set a high-end trend of metallic mobile phone covers, which use a double-sided glass in addition to a metal frame solution. To keep pace with the trend and occupy a market share, this company introduced automatic machines to enhance its production capability. On the one hand, this company realized its production process upgrading by utilizing mechanical arms, robots, and other automatic machines to rebuild and upgrade its current production lines. It has introduced over 2000 robots, 1500 automatic machines, and over 70 specialized automatic production lines, such as automatic grinding and inspection lines, into its production process, which is now a highly automated production process. The company increased the production efficiency of its processes related to polishing, laser engraving, injection molding, testing, and others but reduced its number of workers by nearly 6000.

On the other hand, functional upgrading was achieved by the company's continuous increase in investment for the production process towards improving production technology and capability. This company, which has a high degree of automation, has established a team of over 800 technicians to focus on production technology and has applied for over 600 patents. Half of the patents are directly relevant to the production methods, automatic equipment, and automation production processes, such as grinding, loading and unloading, device surface treatment, and stamping. In 2016, the company spent about 438 million RMB yuan on research and development work; this figure accounted for 7.89% of the company's operating income and showed an increase of 84.35% over the previous year.

Aside from the process and functional upgrading, the company also experienced inter-sectoral upgrading by transgressing on its traditional boundary and focusing on developments in the robot industry. Given similarities in the foundational knowledge system, the electronic information manufacturing industry is likely to obtain the technology of the robot or automation industry, which indicates that electronics-producing companies intend to move upward along the value chain by increasing their research and development investment in automation technology. This company has established an in-depth cooperative relationship with four robot enterprises, namely, Yaskawa, Fanuc, KUKA Aktiengesellschaft, and ABB Group, and established a robot company to construct the layout of intelligent equipment manufacturing and industrial robots towards the realization of upgrades in upstream and downstream suppliers in the supply chain.

Driven by the demand for high-end production technology and increased production efficiency, the company has also actively introduced advanced automatic machines and intensified its research and development investment in production process innovation, thus achieving significant upgrading (Fig. 9). Moreover, its research and development work signifies functional upgrading. Given its beginnings as a mobile phone component supplier and subsequent transformation to an entity supplying industrial robots with aspirations to become an intelligent equipment solution servicer provider focused on Industry 4.0, this company has successfully achieved inter-sectoral upgrading.

The locus of this company's upgrading process is not exclusive to the electronic information manufacturing industry in the PRD region. Let us take another company that also produces mobile phone components as an example; 90% of the company's production lines currently use automated technology and have achieved satisfying returns. Just one year after the implementation, the total output increased by 1.2%, and labor productivity was 1.6 times higher than before. Furthermore, the product was of higher quality, and the qualification rate increased from 95% to 98%. During the process, the total number of workers was reduced by 50%.

Automation prompts electronic manufacturing companies to focus on research and development work and helps them acquire added value through upgrading. For the employees themselves, the future is not as promising. Given that automation technology can already accomplish most tasks, companies have raised their standards for their employees. Hence, talents, such as programming engineers, mechanical engineers, machine operators, and mechanical maintenance technicians, who have been nurtured by good education and have obtained certain skills, are preferred over young or physically strong laborers.

4.4. Labor force changes by market-driven automation: home electrical appliance manufacturing industry

Electrical appliance manufacturing is a type of industry that is dominated by the consumer market, product prices, differentiated products, and brand effects. These factors affect the market share of electrical appliance companies. Since the 1980s, the PRD region has been an essential foundation for white goods manufacturing, such as washing machines and refrigerators. However, under the massive pressure of increasing labor force costs and rapidly changing markets, this industry suffers from low profits. To address this dilemma, automatic and intelligent production technologies have become an essential choice for these enterprises to reduce their production costs, develop new functional products, and revitalize the industry's profitability (Fig. 10).

As a leading manufacturer of home electrical appliances, the company surveyed possesses 12 overseas and 14 domestic production bases. Its products are sold to over 200 countries and regions around the world. In 2016, this company's annual revenue reached 159.8 billion RMB yuan, which was an increase of 14.7% compared with revenue from the previous year. The overseas revenue, which accounted for 40% of the total annual revenue, reached 64 billion RMB yuan. This company was ranked the second-largest among all global home electrical appliance companies, with a share of 4.6% in the global market.

A cost-leading strategy is the key to this company's development. Initially, this company attempted to control its labor costs to maintain a comparative advantage in a fiercely competitive industry. In 2003, the company introduced robots into its production lines for the first time and replaced many workers on the assembly lines. Automation has become increasingly popular in recent years to confront rising labor costs and the labor shortage. Since 2011, the company has been implementing the use of robots for automated

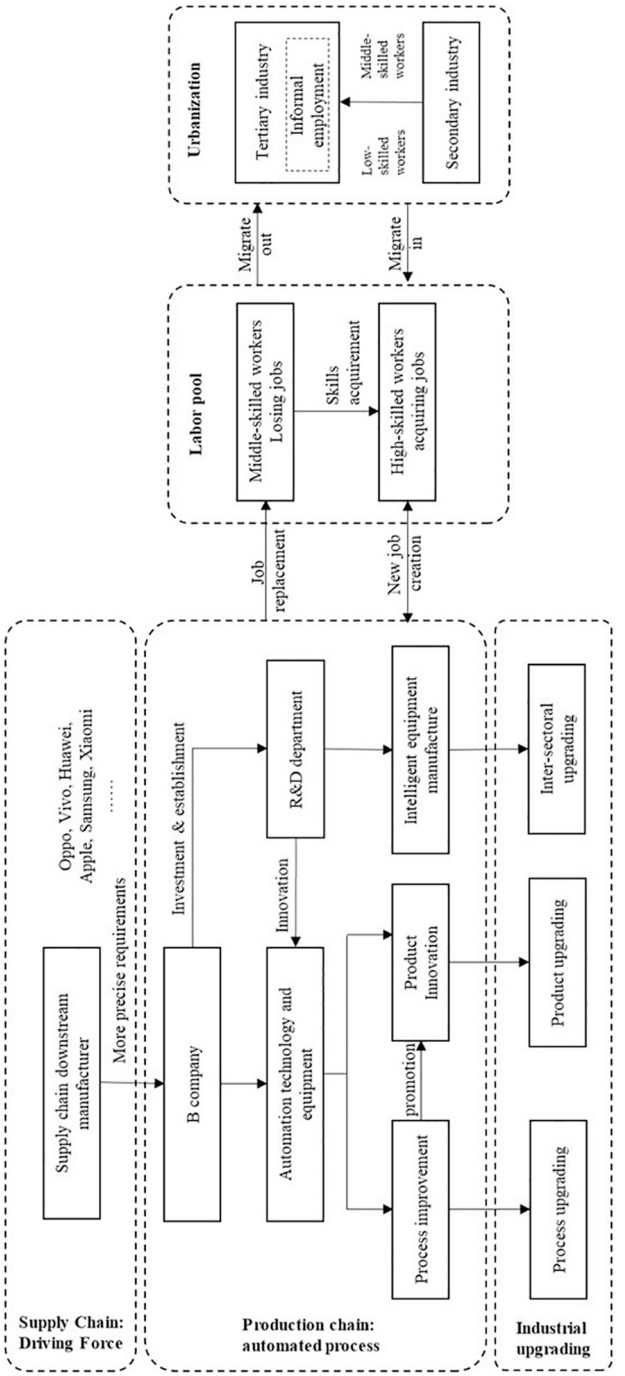


Fig. 9. Diagram illustrating the impact of automation from the case study on the electronic information manufacturing industry.

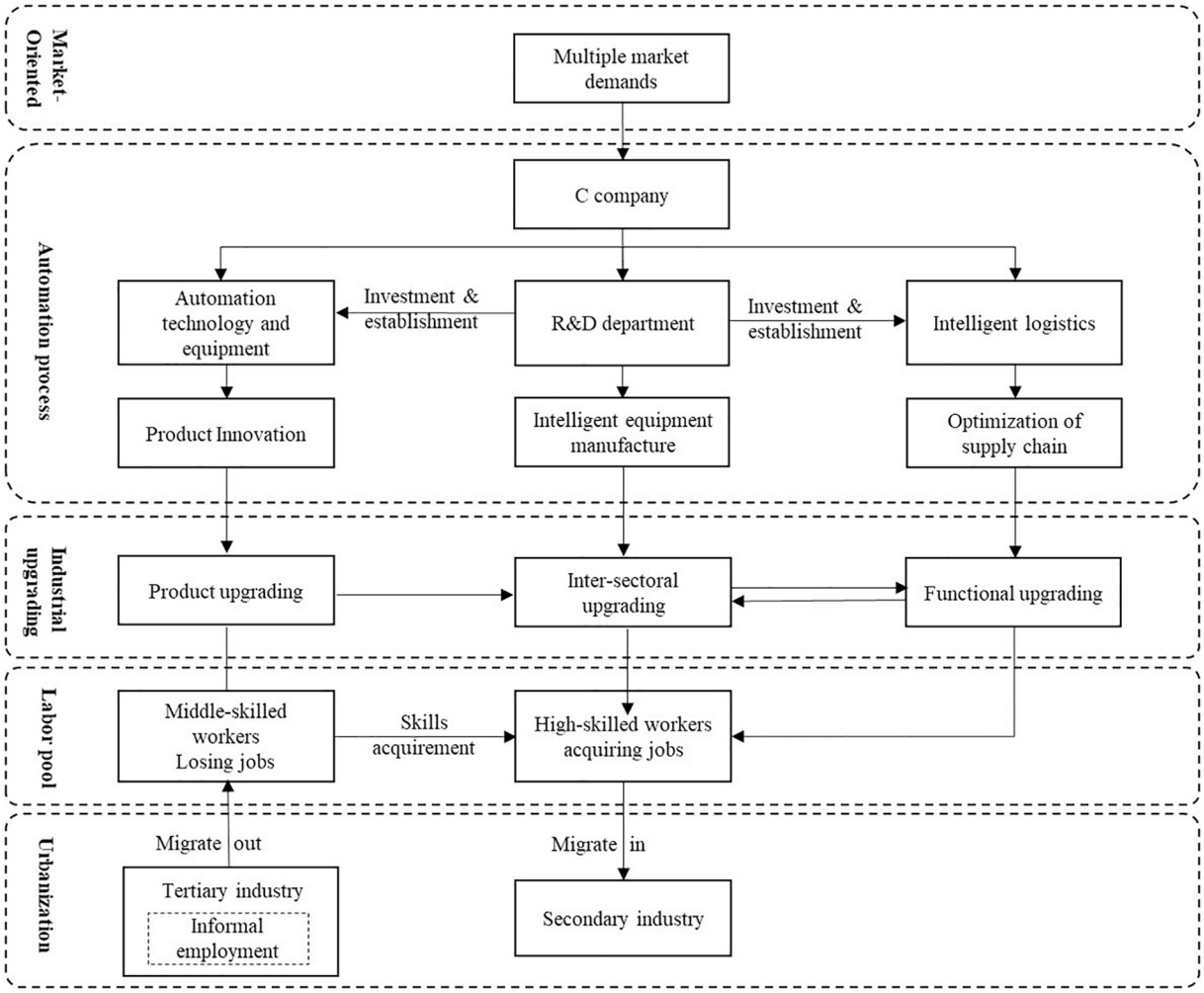


Fig. 10. Diagram illustrating the impact of automation from the case study on the home electrical appliance manufacturing industry.

production on a large scale. The data show that the number of robots in the air conditioning production lines increased from 50 in 2011 to 562 in 2015, which is over 10 times that of 2011. The labor force sharply decreased accordingly. The total number of workers decreased from over 50,000 in 2011 to 28,000 in 2015, and the reduction comprised approximately 44% over four years.

Driven by the diverse demands for products in the consumer market, this company has also established a department responsible for new product development. By referring to an online buzz tool, the company launches new products regularly, and these products are regarded as intelligent, fashionable, and multi-functional. To keep pace with the developing trend, the company recently launched a new series of smart products, including smart refrigerators, washing machines, and dishwashers. Through research and design investment, the company is attempting to meet customers' demands for products by upgrading its production process and changing the traditional image of home electrical appliances.

In addition to the production process and product upgrading, inter-sectoral upgrading is also a significant approach to industrial upgrading. Along with the upgrade in Chinese people's consumption capability, the smart home electrical appliance market, comprising products such as service robots, has a huge potential and is anchored by this company as a main development direction in the future. In 2015, together with Yaskawa Electric Co., Ltd. the company established a service robot company that covers the entire service robot manufacturing industry chain and promotes the construction of a smart home electrical appliance ecosystem. To enhance its manufacturing capacity and automation level, the two companies established another joint company focusing on home electrical appliance manufacturing. Through cooperation with the robot company, the company surveyed has ventured into both the downstream and upstream sectors of the industry, thereby positioning itself as the leading home electrical appliance manufacturing company in the field of robotics and automation in China and also the world. In 2017, this company moved forward and acquired the well-known Israeli motion control manufacturer Servotronix, which enriched the company's technology and products in the field of motion control and automation solutions.

The upgrading process is common in other electronic appliance production companies. For example, a robotic sweeper factory introduced a series of automatic production lines to automatically assemble components. This reduced labor costs dramatically.

Table 2
Summary of automation effects on the three industries.

Type of industry		Changes			
		Labor productivity	Low-skilled labor	Middle-skilled labor	High-skilled labor
Textile industry	Labor-intensive	+	+	−	+
Electronic information manufacturing industry	Technology-intensive	+	−	−	+
Home electrical appliance manufacturing industry	Market-oriented	+	−	−	+

Thereafter, the company could focus on product innovation and inventing new products to fulfill market demands. On the one hand, automation helps companies control production costs, realize diversity and subdivisions in the product market, and achieve an increase in its overall production efficiency. On the other hand, when automation machines replace workers, companies change their preferences in labor forces. Those capable of product design, research and design, mechanical operation, mechanical maintenance, sales, etc. will be welcomed in the future.

These three case studies clearly illustrate that the effects of automation vary for companies in different industries in terms of labor forces, wage stagnation, displacement, or a combination of the two (see Table 2). For different manufacturing sectors, automation improves productivity and production technology when research and design departments are established in companies for functional upgrading. For labor forces, different industries have varying technical requirements for workers. In general, the occupational structure is divided into two parts, namely, skilled and physical labor, both of which are increasing; meanwhile, the number of operators (i.e., assembly line workers) is declining. This is the fundamental impact of automation on the employment structure. In the long run, automation will replace middle-skilled workers in the industry and will gradually change the dynamics of urbanization. The implementation and prosperous development of automation in manufacturing have changed the social spatial structure of cities, leading to the polarization of labor forces, especially for rural migrant workers. Table 3 shows the comparison of companies with and without the adoption of automation in production processes, which indicates the dramatic impacts of automation on the industry and its development in the long run.

Regarding the three cases of automation and intelligence implementation selected in this study, automation options and tendencies among the three industries reflect different development needs due to the varying backgrounds of capital, technology and labor in each industry. The reasons for the absorption and utilization of automation among the three industries are closely related to the difficulties of long-term development experienced in each industry, which are reflected in the differing emphases on key technologies among the three industries. Labor and cost-driven automation in labor-intensive industries (such as the textile and clothing industry) focus on cost-effective control and the core technology behind labor replacement; technology-driven automation in the technology and capital-intensive industries (such as industries for electronic information manufacturing, mobile phone parts and components manufacturing, etc.) focus on the production cost and the key technology of product accuracy control; and market-driven automation enterprises (such as the home electrical appliance manufacturing industry) are very sensitive to consumer and market demand, with preferences for intelligent logistics and big data acquisition techniques.

By and large, the approaches to automation driven by different factors at different links along the production chain have all achieved the respective enterprise's expected effect, including upgrades in product, process and function, and production chain in certain capital-intensive enterprises with strong technical capabilities. In addition, the upgrading process of automation has a major implication for workers in all three industries. An increasing number of highly skilled workers are flowing to cities, in which highly skilled technical talents assert huge demands on productive service facilities, in terms of research and development focused on

Table 3
Comparison of companies with and without the adoption of automation in production processes.

	Companies with automation adoption			Companies without automation adoption		
	2015 (Before automation)	2016 (After automation)	Changes	2015	2016	Changes
	xx Machinery Works Co., Ltd. (Company A)			Foshan Nanhai xx Fasteners factory Co., Ltd. (Company B)		
Labor productivity (pieces/person/ h)	8.15	13	+60%	7	7.6	+9%
Number of labor forces (persons)	98	49	−50%	62	70	+13%
Rate of qualified products (%)	95%	98%	+3%	92%	92%	–

	xx Knitting Factory Co., Ltd. (Company C)			Foshan xx Kitchen Ware Co., Ltd. (Company D)		
Labor productivity (pieces/person/ h)	6	13.3	+127%	7	8	+13%
Number of labor forces (persons)	800	315	−61%	50	60	+20%
Rate of qualified products (%)	95%	99%	+3%	95%	96%	+1%

science and technology, education and training, health care, transportation, and the quality of leisure service facilities. More of these new demanding services drive the optimization of regional space and spatial factors, which further improves the quality of human settlement and is changing the course of urbanization.

5. Discussion and conclusion

Automation in the PRD region, in which many companies have been adopting robotics and automation technology into their core manufacturing industries, is typical but still interesting. The emergence of automation in manufacturing industries and its effects on the replacement of labor forces have drastically changed the impetus of China's urbanization, compared with previous factors driven by growth in either land use or the population. This has also imposed significant changes on migrant workers' choice of employ and their spatial movements. The development and implementation of automation in China have evolved along the same trajectory as that of the U.S., Europe, Japan and other developed countries, but it has occurred with the latest information and robotic technology and is developing against the unique background of China's ever-rapid urbanization. New technologies and innovation are creating extraordinary growth. We expect the era of technological innovation-driven urbanization in the coming decades to result in a sharp increase in productivity.

As one typical area in which manufacturing upgrading is occurring in the 21st century in China, the PRD region has been experiencing a significant industrial transformation driven by automation. Automation and other progressive technologies are experiencing increased popularity in various industries in a highly competitive world. Using the PRD region as a case study, this study has investigated the complex relationship between automation, labor forces, and urbanization, revealed the impacts of automation on enterprises and workers in different industries, and explored the varying effects of automation on different industries through surveys of the three enterprises in three industry categories. The findings contribute to the literature pertaining to the forces of the rural push and urban pull of population growth and urbanization based on innovation and technology advancements and the relationship between urbanization and automation. Urbanization depends not only on capital and investment, but also on industries and enterprises. The labor force of migrant workers is not the only driver of urbanization or economic growth, in that, the effects of automation may limit the benefits of population agglomeration. In the future, factors driven by innovation, such as automation and enterprises' choices in technology advancement, will be the key driving forces of China's urbanization.

Automation technologies affect industries and occupations differently. The characteristics of automation in different industries and the influences of automation on labor forces vary considerably. Our study revealed the following points. First, the textile industry introduced automatic loom machines into its production processes to replace its labor forces. This upgrading in the production lines is helping companies focus on design and brand development. Second, the electronic manufacturing industry's implementation of automation is improving production process technology and productivity through the adoption of robotics and automated machine tools. Given the similarity in the knowledge structure, companies can realize inter-sectoral upgrading by venturing into the robotic manufacturing industry. Talents in those companies should be equipped with specialized knowledge and technical capability. Third, regarding the production processes and functional and inter-sectoral upgrading of the home electrical appliance manufacturing industry, automation improves production efficiency and reduces the production cycle time. Simultaneously, it promotes research and design departments for functional upgrading to keep pace with market demands.

Regarding labor forces, automation exerts different effects on workers in different industries and imposes new technical requirements on workers. Automation has prompted new changes in the employment structure of the industry. In general, the overall size of the labor force has grown. The occupational structure is divided into two parts: skilled and physical labor. Unsurprisingly, however, the number of operators required (e.g. assembly line workers) is decreasing. This is the fundamental impact of automation on the employment structure. Technology advancement also helps produce new jobs, absorbing those who have become unemployed. In recent years, many new low-tech jobs have emerged in the service industry, such as food deliverers, couriers, online car-for-hire drivers, salesmen, and waiters. At the same time, the skill standards for the labor forces has become higher as well. In the future, well-educated and high skilled workers, such as designers, programmers, machine operators and managers, will be the main personnel needed for the manufacturing industries. Advanced manufacturing has higher requirements for machining accuracy and dexterity, which requires the most highly skilled workers. As opposed to labor scarcity at the high end, labor abundance among mid- to low-skilled workers warrants the attention of governments or enterprises to determine how to train migrant workers for a job requiring a higher level of skill. On the other hand, higher-skilled jobs will not be easily displaced. Enterprises will have to attract, grow, and retain highly skilled personnel to maximize their productivity.

All companies are changing their former production modes in ways that result in savings in cost and labor and an increase in quality. Through automation, production costs are reduced, while profits and productivity are increased. The automated companies can focus on upstream and downstream links, such as research and design, brand making, marketing, and logistics, thereby leading to functional upgrading. For labor-intensive enterprises, automation can significantly reduce the proportion of front-line staff and optimize the personnel structure. The production process and management methods in the manufacturing industry have also been adaptively adjusted, especially following the large-scale introduction of robots. Low-skilled and even some skilled workers have been replaced by robots, thus increasing the number of technical positions for debugging, maintaining, and controlling the robots. The high end of the industry, especially the development of high-end manufacturing, will cause an increase in the number of employees in the productive service industry. Based on the existing qualitative analysis, future studies should perform extensive quantitative analysis and modeling to calculate and predict automation in various industries, e.g. different enterprises' choices regarding technological progress in the face of automation and robotics.

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