Technological Forecasting & Social Change 135 (2018) 66–74

Contents lists available at ScienceDirect

Technological Forecasting & Social Change

journal homepage: www.elsevier.com/locate/techfore

China's manufacturing locus in 2025: With a comparison of "Made-in-China 2025" and "Industry 4.0"

Ling Li

Old Dominion University, Norfolk, VA 23454, USA

ARTICLE INFO

Keywords:
Made-in-China 2025
Industry 4.0
Emerging economy
Cyber-physical systems (CPS)
Internet of Things (IoT)
Manufacturing capability
Human capital
R & D
Smart factory
Collaborative robots

ABSTRACT

In this study, we have compared Germany's "Industry 4.0" and China's "Made-in-China 2025" and estimated China's locus in "Made-in-China 2025". "Made-in-China 2025" has clear goals, measures and sector focus. Its guiding principles are to enhance industrial capability through innovation-driven manufacturing, optimize the structure of Chinese industry, emphasize quality over quantity, train and attract talent, and achieve green manufacturing and environment. Data show that currently China is no longer the lowest–cost labor market; it is being squeezed by newly emerging low-cost producers such as Vietnam, Cambodia, and Laos. Meanwhile, China is not the strongest player in the high-tech arena; well-established industrialized nations, the US, Germany, and Japan, have all effectively deployed digital technology to create new industrial environments, produce new products, and improve their well-established brands. Having analyzed the data from the World Bank and China's National Bureau of Statistics, we find an upward trajectory in China in manufacturing capability development, research and development commitment, and human capital investment. However, implementing an ambitious strategic plan such as "Made-in-China 2025" is coupled with challenges. This research helps us understand the relationship between technological entrepreneurship and socio-economic changes in emerging economies such as China. Furthermore, the experience accumulated in China can be referenced by both emerging economies and developed nations to advance their technological entrepreneurship.

1. Introduction

Over the past decade, China has emerged as one of the most significant manufacturing miracles since the industrial revolution began in Great Britain in the eighteenth century (Li, 2013). By the end of 2012, China became a global leader in manufacturing operations and the second largest economic power in the world. The Made-in-China paradigm has been evidenced by products made in China ranging from high-tech goods such as personal computers, mobile phones to consumer goods such as air conditioners. According to a report from *China Daily* (Chinadaily.com.cn, 2015), in 2014, China produced 286.2 million personal computers, which was about 90% of the world total (Table 1), 109 billion air conditioners counting for 80% of the world total, 4.3 billion energy-saving lamps approximately 80% of the world total, and its mobile phone production counted for a little over 70% of the world total.

These statistics indicate that China is good at making many things, from daily consumer goods to high-tech gadgets, from children's toys to giant vessels. China is looking forward to climbing new heights in manufacturing. In 2015, China issued a 10-year national plan, "Made-in-China 2025". This strategic plan states China's will to move up the value chain and reinvent itself from a world manufacturing production workshop into a world-class industrialized power (Chinadaily.com.cn, 2015).

In 2013, Germany, a world leading industrialized nation published its "Industry 4.0" strategic plan (Branger and Pang, 2015; GTAI, 2014; Lu, 2017; Xu, in press). Well-known for many of its prestigious brands, Volkswagen, BMW, and SAP, to name a few, Germany's leading industries have emphasized their innovative strength which allows them to reinvent themselves time and again. "Industry 4.0" is one more example of Germany's manufacturing strategy to compete in the new round of industrial revolution that focuses on industrial integration (Xu et al., 2016; Lu, 2016), industrial information integration (Xu, 2016; Chen, 2016), manufacturing digitization (Xu et al., 2014b; CPS (Gürdür et al., 2016), Internet of Things (IoT) (Liu et al., 2017; Lai et al., 2017; Xu et al., 2014a), and artificial intelligence.

In this study we have analyzed China's manufacturing potential in 2025 using data from the World Bank and China's National Bureau of Statistics. We focus on the following two research questions, (i) what is the difference between China's "Made-in-China 2025" plan and Germany's "Industry 4.0" plan? And (ii) what are the critical factors that will affect and support the implementation of the "Made-in-China

E-mail address: lli@odu.edu.

http://dx.doi.org/10.1016/j.techfore.2017.05.028
Received 22 February 2017; Received in revised form 12 May 2017; Accepted 19 May 2017
Available online 10 August 2017

Table 1
Top ten products China makes.
Source: Based on "Top 10 products China manufactures most in the world." Chinadaily.com.cn, 9/16/2015.

No	Products produced in China	Volume produced	Account for % of world Total
1	Personal computers	286.2 million personal computers in 2014	90.60%
2	Air conditioners	109 billion air conditioners annually	80%
3	Energy-saving lamps	4.3 billion energy-saving lamps	80%
4	Solar cell	21.8 million solar cell kw annually	80%
5	Mobile Phone	1.77 billion mobile phone annually	71%
6	Shoes	12.6 billion number of shoes	63%
7	Cement	1.8 billion tons of cement annually	60%
8	Pork	1.5 million tons of pork annually	49.80%
9	Coal	1.8 billion tons of coal (oil equivalent) annually	48.20%
10	Ship	766 million tons of vessels annually	45.10%

2025" plan?

Identifying the critical indicators that impact China's economic development in the digital era is one of the major contributions of this study. Three critical indicators (manufacturing capability, human capital, and R & D) are found to be the major source of China's social-economic change in the past 30 years. Manufacturing capability, human capital, and R & D commitment will continue influence China's implementation of "Made-in-China 2025". These indicators help us understand the relationship between technological entrepreneurship and socio-economic changes in emerging economies such as China. Furthermore, the experience accumulated in China can be referenced by both emerging economies and developed nations to advance their technological entrepreneurship.

2. Background

2.1. Industry revolutions

The world has experienced three industrial revolutions and each has benefited mankind and moved society forward. The first industrial revolution began in the 1770s in England and spread to the rest of Europe and the United States in the 19th century (Stevenson, 2015). Prior to that time, products were made in a family workshop by craftsmen and their apprentices. The introduction of the steam engine during the 1st industry revolution provided a source of power to mechanize production in factories, which provided jobs for millions of people who migrated from rural farms to urban areas.

Mass production was the key contribution to the 2nd industrial revolution. When demand for Ford T-model cars came at sonorous pace, the company experienced a difficult time to keep up with the orders. Subsequently, the moving assembly line was invented with the intensive use of electrical power to produce a large volume of standardized products with division of labor and specialized skills at a low unit cost. This revolution provided many well-paid manufacturing jobs and significantly improved ordinary people's living standards.

Then computer technology, information technology, and the widespread digitalization cast a major influence on the digital revolution which is often called the 3rd industrial revolution. Digital technology has allowed automation of production and service. Manufacturing has evolved from mass production to mass customization, a strategy of manufacturing products with the help of programmable machines to produce standardized products with some degree of flexibility at the sub-assembly or final assembly. The third industrial revolution ushered in globalization. The concept of a manufacturing supply chain is no longer simply a vertical integration within a company. Instead, a manufacturing supply chain has become virtual integration around the world. This revolution benefited more people in the world than that of the previous two industrial revolutions. Wealth has been redistributed among industrialized nations, emerging economies, and developing countries.

The term of "fourth industrial revolution" emerged recently (Schwab, 2016). The 4th industrial revolution is due to significant technological development through ICT, cyber-physical systems (CPS), and IoT (Xu, in press). The vision of economies of scope realized in mass customization will lead to a batch size of one while maintaining mass production's economies of scale (Lasi et al., 2014). Paring with advanced digitalization and manufacturing technologies, the 4th industrial revolution will result in a new fundamental paradigm shift, much more than simple manufacturing advancement. The concept of the 4th industrial revolution stimulated the introduction of Germany's "Industry 4.0" plan which was announced in April 2013 (Lasi et al., 2014) and the "Made-in-China 2025" plan released in May 2015. We may say that "Made-in-China 2025" is a Chinese version of "Industry 4.0". Both are described in detail below.

2.2. The Made-in-China 2025 plan

If the goal of China's economic reform, which began in 1978, was to lift hundreds and thousands of people from poverty, that goal has been achieved. After 30 years of economic development, China's manufacturing growth has entered a new era. New opportunities and challenges have now emerged. Resources and environmental constraints continue to intensify, labor and material costs increase, environmental responsibility continues to rise, foreign direct investment flow and export growth have slowed down. Rethinking and planning manufacturing strategy is inevitable.

In response to the recent global reindustrialization tide and Germany's high-tech strategy "Industry 4.0", the State Council of China announced the "Made-in-China 2025" Plan in May 2015. This plan laid out strategic goals for economic development of the next 10 years from 2016 to 2025. This blueprint was developed jointly by China's National Development and Reform Commission (NDRC) and by the Ministry of Science & Technology (MOST), with additional inputs from the Ministry of Industry and Information Technology (MIIT) and other constituencies (State Council of People Republic of China, 2017).

The "Made-in-China 2025" plan is China's industrial development master plan for the next 10 years. The plan signals China's intention to launch an industrial transformation from labor intensive production to knowledge intensive manufacturing, and usher in a major breakthrough at a fast speed. "Made-in-China 2025" is the first-stage of a "three-phase" grand plan, which will guide China to become a world manufacturing power from the current grand production workshop of the world. The plan focuses on improving the quality of products made in China, creating China's own brands, building a solid manufacturing capability by developing cutting-edge advanced technologies, researching new materials, and producing key parts and components of major products. According to the State Council of People Republic of China (2017), ten industries have been prioritized: information technology, high-end numerical control machinery and automation, aerospace and aviation equipment, maritime engineering equipment and high-tech vessel manufacturing, rail equipment, energy-saving vehicles, electrical equipment, new materials, biomedicine and high-performance medical apparatus, and agricultural equipment (State Council of People Republic of China, 2017).

Based on China's own experience of economic reform which took a step-by-step implementation procedure, the "Made-in-China 2025" plan is anticipated to be extended to three phases. Phase One covers year 2015 to 2025; during this period, China strives to be included in the list of global manufacturing power countries. Phase Two covers year 2026 to 2035; in this period, China will rise to the medium level in the world's manufacturing power camp. Phase Three, from year 2036 to 2049, the time when the People's Republic of China celebrates her 100-year anniversary, China dreams to be a leading manufacturing power in the world.

China has accumulated rich experience in implementing nation-wide strategic plans. Its economic reform in 1978 started with a pilot city in Shenzhen Special Economic Zone (SEZ). The special economic zone experimented with free market business models paired with a state planning policy, providing subsidiary, and preferential tax benefits to foreign firms that were interested in and doing business in China (Li, 2013). This approach has been adopted to implement "Made-in-China 2025". Ningbo, a port city, was chosen to be the first pilot city to speed up the construction of its own industrial and manufacturing capability, collaborate with regional innovation systems, personnel training systems, and policy support systems, to create a healthy ecological environment and achieve diversity in development. Then, a 2nd cohort of 20 to 30 cities will be selected to join the development effort (ifeng.com, 2017).

2.3. *Industry 4.0*

Germany is well-known for the design and quality of its products (Selko, 2015). Seven companies are the engines of Germany's GDP and source of corporate revenue. Three of its seven giant companies are Volkswagen (the biggest corporation in Germany), Daimler (the second largest in Germany), and BMW. All three are famous for the design of automobiles. Each has substantial exports and global markets as well. Volkswagen is tied with General Motors Co. for sales in China, the world's largest car market. BWM and Mercedes are the two leading luxury car brands in the world (McIntyre, 2012). Germany is strong in electronics and automation industry. Founded in 1847, Siemens is a German conglomerate company with principal businesses in industry, energy, healthcare, and infrastructure. BASF, a chemical firm in Germany, has annual sales exceed $80 billion. Its primary divisions are in agriculture, chemistry and other practices. In the financial sector, Germany has Deutsche Bank, the largest bank in Europe. Another Germany's financial group is Allianz, an insurance company, but it actually is a financial services holding company that conducts businesses in the global market.

"Industry 4.0" which was first introduced in 2013 by the German government, focuses on the concept of the smart factory and cyber-physical systems (CPS) which integrates advanced technologies such as automation, data exchange in manufacturing technology, 3D printing, cloud computing, Internet of Things (IoT), and goods and people. This type of industrial integration (Xu et al., 2016) includes a wide range of current concepts including cyber-physical systems, smart factory, decentralized self-organization, new systems in distribution and procurement, product and service systems that will be individualized, and corporate social responsibility (Lasi et al., 2014). The core concept of "Industry 4.0" is integration (GTAI, 2014): Integration of the physical basic system and the software system, integration with other branches and economic sectors, integration with other industries and industry types (Fettke, 2013; Hermann et al., 2016). In this sense, "Industry 4.0" is interpreted as a new level of organization and control over the entire value chain of the lifecycle of products (Ganzarain and Errasti, 2016).

2.4. *Comparison of "Made-in-China 2025" and "Industry 4.0"*

Both "Industry 4.0" and "Made-in-China 2025" focus on the new round of industrial revolution and employ manufacturing digitization, CPS, IoT, and intelligent manufacturing. The core of "Industry 4.0" is cyber-physical system (CPS) and integration in dynamic value-creation networks. "Made-in-China 2025", in addition to an action plan of "Internet Plus Industry", has a broader scope on consolidating existing industries (Gorkhali and Xu, 2016), promoting diversity and broadening the range of various industries, enhancing regional cooperation (Lima, 2016), using Internet of Things to realize manufacturing without boundaries (Bi et al., 2014; Xu et al., 2012), innovating new products and improving product quality.

One of the common priorities of both "Industry 4.0" and "Made-in-China 2025" is to speed up automation and develop collaborative industrial robots. Advanced robots are a form of complex machines that support and relieve the human operator, improve productivity, increase flexibility, reduce cost, and increase security. Collaborative industrial robots are good devices to be used in small parts assembly and the sorting of materials (Yang, 2017). Another priority of both plans is Internet of Things, Internet of Services, Internet of Media, big data and data analytics. Germany's "Industry 4.0" has emphasized cyber-physical systems, interoperability (Avanzi et al., 2017), decentralization and full virtualization of value chain (Magruk, 2016; Xu, in press).

The new technological innovations, such as cyber-physical systems, Internet of Things, and virtualization of value chain that stated in Industry 4.0 and Made-in-China 2025, have already led to socio-economic change in emerging economies. Collaborative influence and legal value of patents, and research and development (R & D) in advanced nations and emerging economies have demonstrated positive effect on better R & D outcomes because diverse knowledge and complementary competences from different countries generate inventions that may not happen in a single country. Additionally, collaborative R & D promotes the probability of product commercialization and international trading activities. The increasing research collaborative projects in East Asian countries has internationalized R & D activities cross country borders to enhance competitive advantages by obtaining foreign resource or knowledge (Su, 2017). In a study of legal value of international R & D, Su (2017) analyzed legal value of collaborative research and development between China and Japan, China and Korea, Japan and Taiwan, Japan and Korea, and Korea and Taiwan, and concluded that international R & D collaboration generated higher cross-country patent infringement (Su, 2017). The virtual supply chain described in Industry 4.0 will have strong impact on the economic development of emerging economies.

A recent score-card of China's infrastructure, scientific and technological achievements lists six areas that have amazing results (Gu, 2017); these six areas include new energy, numerous recent-built mega length bridges, aerospace equipment (e.g. satellite launch), e-business (e.g. Alibaba.com), transportation network (e.g. high speed rail, high way, tunnels, etc.), and supercomputers. These achievements have improved the quality of life of Chinese people and laid a solid foundation for the next level industrialization and economic development. However, China's strength mirrors the areas that it needs to improve. Most of these six developed areas are in the domestic infrastructure development scope and are not world-wide recognized brands like Germany's Volkswagen, Mercedes, BMW, and Siemens, which produce many consumer goods that are sold internationally.

Table 2 provides a comparison of "Industry 4.0" and "Made-in-China 2025". The two plans were issued within a short period of time: one in 2013, and the other 2015. The aim of "Industry 4.0" is to enhance a new level of organization and control over the entire value chain of product life cycle, while "Made-in-China 2025" aims at moving from "Made-in-China" to "Designed-in-China", and making China's manufacturing strong and innovative. Germany's size of GDP in 2015 is $3.363 trillion and China's is $11.007 trillion; China's GDP is more than

Table 2
Comparison of Industry 4.0 and Made-in-China 2025.

Country	Germany	China
Issue time	April 2013	May 2015
Aim	Intelligent manufacturing, cyber-physical systems, i.e. applying the tools of ICT to production	From Made-in-China to Designed-in-China; Make China's manufacturing strong & innovative
GDP (in Year 2015)	$3.363 trillion	$11.007 trillion
Industry, value-added (% of GDP in 2015)	30.95%	40.92%
Change of GDP 2007 to 2015	− 2.22%	209.89%
Current well-known industry	Volkswagen, Daimler, BMW, Siemens, BASF, Deutsche Bank, Allianz	New energy, bridges, aerospace equipment, e-business, transportation network
Strength	Well-established brands, global reputation of its products	Innovation driven, emphasize quality over quantity, emphasize achieving green development, emphasize optimizing the structure of Chinese industry
Implementation period	10–15 years	10 years; extend to 2049
Implementing phases	Not clearly explained	Three Phases
Pilot plan	N/A	City of Ning Po be the 1st pilot city

3 times larger than that of Germany's. According to World Bank's data, China's industry value added as percentage of GDP in 2015 is about 10% more than that of Germany's. This implies that China is the world's largest manufacturing workshop, while Germany's financial firms, such as Deutsche Bank and Allianz contribute a good portion to the nation's GDP.

Germany's well established brands are all known for their superior design and production quality, and each is a major exporter, or has large operations in other countries. China's score card lists bridges it built in recent years, aerospace accomplishments, high speed rail, highways, transportation network, and e-business. These are remarkable accomplishments. However, China needs to develop sustainable brands, reduce its one-time transaction mentality that inhibits China's reputation as a global manufacturer. As for the time frame, Germany plans to realize the goal of "Industry 4.0" in ten to fifteen years; China sets the similar time frame, but this is only the first phase of its grand industry plan. The other difference between the two plans is that China implements "Made-in-China 2025" with a pilot city, Ning Po, and will follow up with more cities, while Germany does not have a pilot study.

Implementing "Industry 4.0" requires digital transition which will lead to significant innovations. 3D printing, an important part of the future of additive manufacturing, is one of the examples of cyber-physical systems. For example, applying 3D technology, manufactures will manage spare parts and critical parts using different methods. Low demand and none critical parts are manufactured using 3D technology at a local site near the end user when there is a demand, while critical parts are produced at factory with quality specifications and process control skills (Jiang et al., 2017). Making spare parts using additive manufacturing will simplify logistics and change the current supply chain network configuration which can affect social, economic, and supply chain structure in emerging economies which serve as major manufacturing hub for the industrialized nations now. A 3D focus could help reduce slow moving spare parts in storage, so as to increase efficiency and reduce distribution costs (Jiang et al., 2017). Extending the premises of "Industry 4.0" to the focus of "Made-in-China 2025", building a solid manufacturing capability via developing cutting-edge advanced technologies is a common goal of these two grand plans.

The comparison of 'Industry 4.0' and 'Made-in-China 2025' presented in Table 2 comprehensively discusses the two plans, compares and contrasts the similarities and differences of the two plans. From the discussion in this section, we have answered the first question "what is the difference between 'Made-in-China 2025' and 'Industry 4.0'"?

3. Data and analysis

3.1. Data

Operations Management and strategic management literature has long identified a number of indicators for analyzing a nation's manufacturing capability. These indicators included low-cost production, differentiation strategies such as new product development and technology innovations, and manufacturing soft-power development such as workforce development and technology (Li, 2005, 2013). In this study, soft power competencies include human resources, R & D investment, foreign direct investment net flows, and high-tech exports. To make a nation great in manufacturing in a digital world, the twenty-first century calls for new technology innovation, new product development, and new market deployment.

We use data and information from the World Bank Data (2017) and China's National Bureau of Statistics to analyze the potential of advancing the plan from "Made-in-China" to "Designed-in-China". Table 3 shows the data that are used in this study as well as the data sources. With the availability of data, we group the variables into three major categories: (i) manufacturing capability, (ii) research and development, and (iii) human capital (Li, 2012). Four items are included in the category of manufacturing capability: they are GDP, "industry value added as a percentage of GDP", "high technology exports as percentage of manufacturing exports", and "foreign direct investment net flow".

Table 3
Data.

Indicator	Indicators	Data source
Manufacturing capability	Industry value added as percentage of GDP	The World Bank data (2017)
	High technology exports as percentage of manufacturing exports	The World Bank data (2017)
	Foreign direct investment net flow	The World Bank data (2017)
R & D	Expenditure on R & D	
	Number of patent applications	The World Bank data (2017)
Human capital	Urban and rural residents	China's National Bureau of Statistics
	Primary and secondary high school graduates	China's National Bureau of Statistics
	College graduates	China's National Bureau of Statistics
	Graduate students	China's National Bureau of Statistics
	Returned study abroad students	China's National Bureau of Statistics

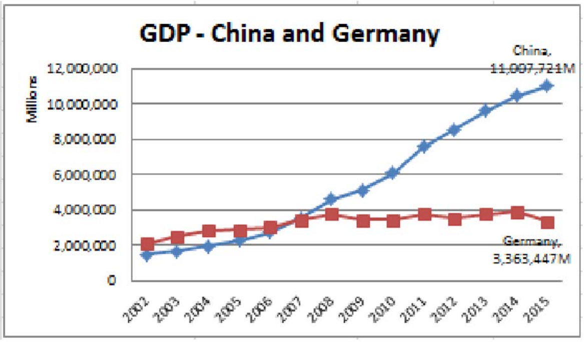

Fig. 1. GDP: China and Germany. Data source: The World Bank Data (2017); data are in 1,000,000 US$.

Two items are shown in the R & D category, expenditure on R & D and number of patent applications. Five indicators are included in the human capital category. Urban and rural residents, primary and secondary high school graduates, college graduates, graduate students, and returned study abroad students.

3.2. Manufacturing capability

Gross Domestic Product (GDP) is a well-accepted measure of a national's economic performance. By 2007, the size of China's GDP was the world's third-largest, in 2009 its GDP was ranked the second largest and the same year, China's GDP surpassed that of Japan and became the world's 2nd largest economy. China became a member of World Trade Organization (WTO) in 2001. In 2015, China's GDP was $11 trillion and was 3.27 times that of Germany's (Fig. 1).

At the dawn of the 21st century, more industrialized nations made strategic turns to focus on high-tech products and technology, and reduce the proportion of labor-intensive, low-value-add, low-profit-margin production. This decision led to a global manufacturing reconfiguration (Li, 2013). The epicenter of manufacturing moved from industrialized nations in North America and Europe to Southeast Asian countries and South American countries. This industry evolution can be illustrated using a couple indicators, GDP, percentage of GDP as industry value added, foreign direct investment net flow, and high-technology exports.

In China, the percentage of GDP as industry value added reaches its peak at the value of 47.77% in year 2006 (Fig. 2). In 2015, the percentage of GDP as industry value added dropped to 40.93%. The highest foreign direct investment net flow happened in 2013 with a value of $290.928 billion and then curved down in 2014 and 2015 (Fig. 3).

The largest high-technology exports as percentage of manufactured exports occurred in 2006, accounts for 30.52%, and then the export

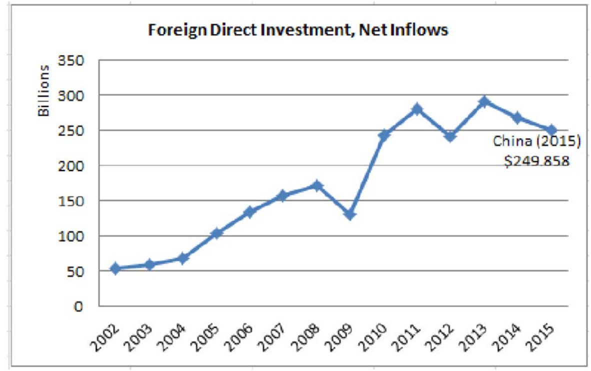

Fig. 3. Data source: The World Bank Data (2017); data are in 1000 US$.

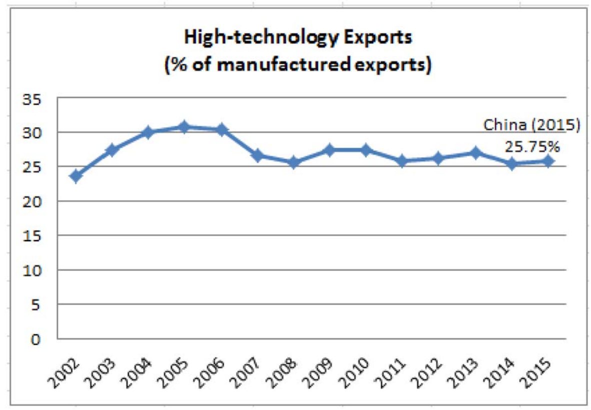

Fig. 4. Data source: The World Bank Data (2017); % of manufactured exports.

number stabilizes in the range of 25.3% to 27.5% of the percentage of manufactured export (Fig. 4). The reduction in high-tech exports can be explained in a couple of ways. First, China's domestic consumption has increased, and second, the ripple effect of reduction in foreign investment.

3.3. Research and development

Two items are shown in the R & D category: expenditure on R & D and the number of patent applications. According to the World Bank, R & D expenditures have been made on creative work to increase knowledge, including knowledge of the humanities, culture, and society, and the use of knowledge for new applications. R & D covers basic research, applied research, and experimental development. In the period of 2002–2015, the amount of investment in R & D has increased dramatically. In 2015, China spent 14,169.88 million Yuan on research

Fig. 2. Data source: The World Bank Data (2017); data are in % of GDP.

and development, which is 10 times as much as that of in 2002. During the period of 2002–2015, the expedition on R & D has increased by 1000% (Fig. 5).

Patent applications are defined as "applications filed through the Patent Cooperation Treaty procedure or with a national patent office for exclusive rights for an invention - a product or process that provides a new way of doing something or offers a new technical solution to a problem (the World Bank Data)." According to World Bank Data retrieved in 2017, the number of patent applications filed by Chinese citizens in 2014 reached more than 800,000 (Fig. 6), an increase of 1912.6% compared with 2002.

Both Figs. 5 and 6 show an S curve. The S curve usually describes the growth of a variable over time. In addition to describing growth, the S curve predicts the performance of a company or a product over a period of time. The growth curve for both expenditure on R & D and patent application started in 2002 with a modest growth, and then a rapid growth. The R & D expenditure and patent applications curves are still in a growth momentum.

3.4. Human capital

To realize the goal of "Made-in-China 2025", human resource development is a key. Human resource practices with commitment orientation help build an adequate work environment to enhance human capital creativity and innovativeness. Human capital is critical to facilitate the appearance of exploitative and explorative practice (Popa et al., 2017).

Research and innovation rely on human talent, therefore, human capital should be nurtured by sound education. People who operate cyber physical systems ("Industry 4.0") or Internet-Plus manufacturing systems in "Made-in-China 2025" need to be educated to be able to run the system. Revitalization through education is a critical step to move up to further growth. Some authors hypothesized that Chinese manufacturers would keep producing low value, labor-intensive products while their counterparts in the industrialized countries would dominate the high-tech industries (Filippetti and Innocenti, 2012). The graphs shown in Figs. 7–9, and 10 refute this conjecture. To China, the global competition in the twenty-first century is no longer in the area of low-cost labor production. It has evolved into a stage of Internet-Plus Manufacturing that competes for talent, human capital, and intellectual resources (Li, 2013). China's goal is to be a power of Designed-in-China.

In 2002, the urban residents of China were 39% of the total population and the rural population was 61% (Fig. 7). By 2010, half of the population was urban residents and the other half rural residents. 2011 ushered in the first year when the urban population exceeded that of the rural (51% versus 49%). In 2015, China's urban population reached 56%. The rural population was a major source of low-cost labor. In the past 30 years, China had a good supply of "farmer-workers" or migrant workers who served as a pool of flexible workforce that covered peak demand seasons and smoothed ripple effects of demand forecast errors. Farmer-workers also encompass those who "worked in the factories but had residence registration in the rural areas". They worked in the city when factories needed them and returned to their farms when there was no need of their labor in the factories," (Li, 2013). The migration of rural residents to urban areas reduces the supply of low cost labor. In turn, China has since had to adjust its manufacturing strategy that focused on low-cost labor.

Looking at the overall picture of China's education in period 2002–2015, the number of primary school students is decreasing steadily. This age group has decreased about 39% in the period 2002–2015 (Fig. 8). The number of senior secondary high school students has increased from 2002 to 2008, and then decreased about 4.59% from 2009 to 2015. These statistics indicate that China's one-child policy is impacting the size of K-12 enrollment.

On the other hand, the number of students who have completed college and graduate education has increased dramatically. In 2015,

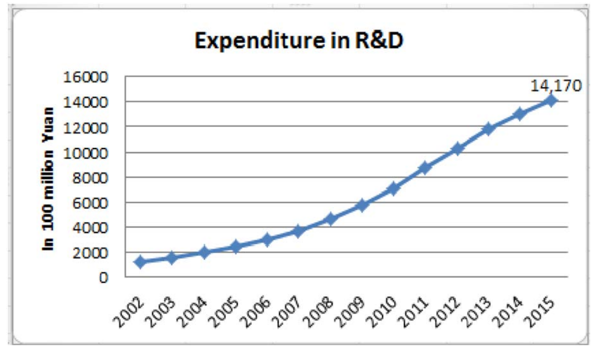

Fig. 5. Data sources: China's National Bureau of Statistics.

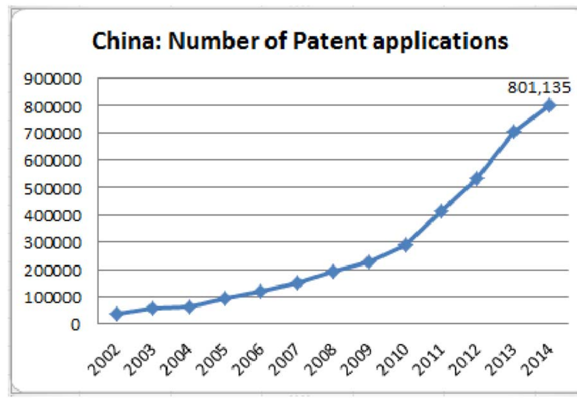

Fig. 6. Data source: The World Bank Data (2017).

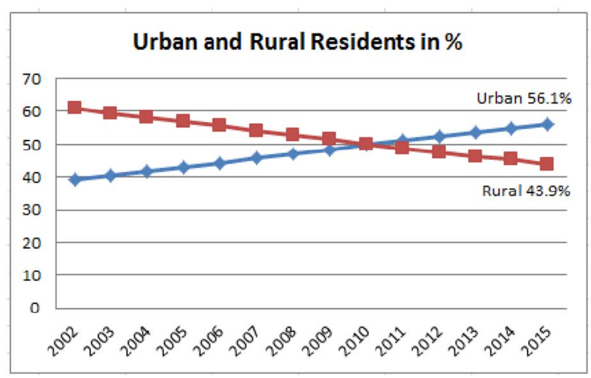

Fig. 7. Data sources: Chinese National Bureau of Statistics.

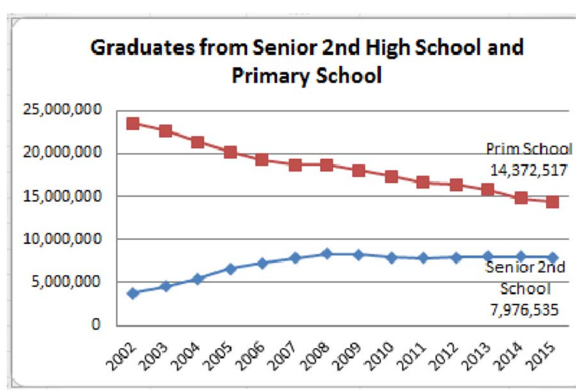

Fig. 8. Data sources: Chinese National Bureau of Statistics.

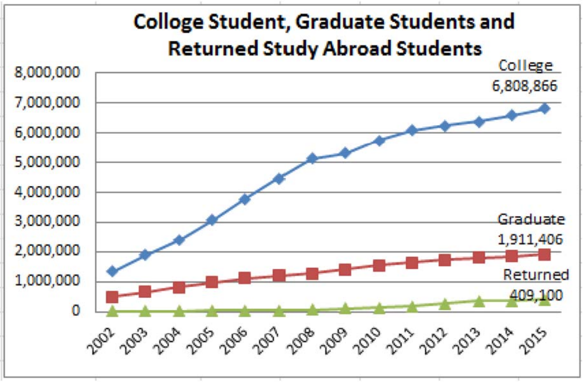

Fig. 9. Data sources: Chinese National Bureau of Statistics.

China graduated 6,808,866 four-year college students (Fig. 9), which is a little more than the size of the total labor force of Denmark and Norway combined (the World Bank Data).[1] In 2015, 1,911,406 graduate students finished their degree in Chinese universities; this number is 282 times the size of the graduate student population who completed degrees in 2002. In the past 30 years, many Chinese students and scholars have studied abroad. They acquired international experience, improved language capabilities, and developed cross-cultural communication skills; all of these are fundamental qualities to succeed in the global economy. This group of educated talent forms a unique category of human resource, which has been named "the returned study-abroad students". The number of students in this group increased about 2190% in the period 2002–2015 (Fig. 9). These globally minded, highly educated people, who have promoted economic, technological, cultural and social exchanges, have benefited China and the rest of the world in the past 30 years.

Based on the statistics presented above, China won't have as many young people who are willing to take low cost blue-collar jobs in the next ten years. China is a country which values white-collar professional career. The 21st century is an era when industries are competing for qualified professionals and talents. In order to sustain the growth, manufacturing industries, especially, high-tech industries need qualified professionals from around the world to exploit their expertise and creative potential.

Data presented in this section help us answer the second question, "what are the critical indicators that will affect the implementation of the 'Made-in-China 2025' plan"? The critical indicators are manufacturing capability, research and development, and human capital.

4. Discussion

For China, the challenge is not merely continuing the trajectory of "Made-in-China" from big to mega, rather, it is to advance from "Made-in-China" to "Designed-in-China" and "Innovated-in-China" as Germany and the United States have successfully done for decades. In "Made-in-China 2025", the goals and implementation ideas have been laid out, including advancing cutting edge new technologies through investment in R & D, increasing intellectual property accumulation, creating distinct technical standards, leveraging access to the Chinese market in inviting foreign investors, enhancing Internet Plus industry, and fostering manufacturing and industrial development. Three major critical factors are identified; they are manufacturing capabilities, research and development, and Human Capital. This finding provides an answer to our 2nd question: the critical factors that will affect and support the implementation of the "Made-in-China 2025" plan.

[1] According to the definition of the World Bank, total labor force comprises people ages 15 and older who meet the International Labor Organization definition of the economically active population.

4.1. Manufacturing capability

Manufacturing capabilities that include GDP, percentage of GDP as industry value added, foreign direct investment net flow, and high-technology exports are key competencies to successfully implement "Made-in-China 2025". In the past three decades, China has transformed itself from an agriculture-based economy into an industrial machine that has processed and assembled about 90% of the manufactured goods in the world (Li, 2013). The data from the World Bank indicate that although China's GDP is continuously increasing (Fig. 1), the foreign direct investment net flow (Fig. 3) and high-technology exports (Fig. 4) started to phase down in 2013. These statistics signal that foreign investors have gradually pulled out of the Chinese market. As a result, China has relied more on its own investment and domestic consumption of high-tech products. Since 2011, the percentage of GDP as industry value added has decreased from 47.56% in 2006 to 40.93% in 2015. The absolute dollar value may not change due to the increase in GDP but the proportion has changed. The other possible explanation is that China has increased service operation.

4.2. Research and development

Both 'expense on research and development' (Fig. 5) and 'number of patent applications' (Fig. 6) take an S curve shape, starting in 2002 with a modest growth, and then a rapid upward increase in 2013. R & D investment and activities are an essential foundation to build China's brands. To date, Chinese manufacturing firms established fewer well-known brands than its counterparts in Germany, the United States, and Japan. The increase in investments and patent applications provides noticeable evidence indicating that China is moving away from low-tech content manufacturing, and strives to support the goal of innovation, high-tech, and integration.

Manufacturing is the core component of a nation's economy. Since its economic reform in 1978, China's manufacturing industries have progressed not only in labor intensive industries such as footwear and apparel, but also in advanced technology industries such as electronic appliances and personal computers. As a result, China's manufacturing industry experienced internal growth. There is a 370% increase of net foreign direct investment in China from the year 2002 to the year 2015 (Fig. 3). In the same period, Germany had a decrease of 9.75% in the same category. The effects of high net inflow of foreign investment are on high value-added industrial output and increased export volume. China's value-added manufacturing and mining (as percent of GDP) was 40.9% in 2015, while Germany's was 30.5%. A noticeable phenomenon is that China has kept a stable rate of high-tech exports as a percentage of manufacturing exports in the period 2008 to 2015 (Fig. 4). In this period, China's high-tech export accounts for 25.75% of its total exports; conversely, Germany's high-tech export was 16.7%.

As stated by a few authors (Zhang et al., 2016), in 2010, China's manufacturing outputs accounted for 19.8% of the world total, and in 2014, China's manufacturing outputs accounted for 25% of the world total.

4.3. Human capital

China is a nation well-known for its passion for education. This mentality coincides with the notion of the importance of workforce in its "Made-in-China 2025". Workforce availability and competence are key attributes that contributed to manufacturing competitiveness. When China started its economic reform in 1978, the urban residents counted for only 18% of the total population (Li, 2013). In 2015, the percentage of urban residents exceeds that of rural residents by a little more than 12% in China.

Educational institutions have cultivated and trained hundreds and thousands of college graduates who have contributed to the economic development. The statistics about college graduates, graduate students, and returned study abroad students demonstrate China's commitment to investing in education, research, technology, and innovation. Primary school students (equivalent to elementary school in the US) have continued to decrease since 2000, while the number of secondary high graduates (equivalent to high school in the US) remains stable. These numbers imply that the low-cost labor pool is shrinking and will continue to do so. Historically, the rural population has been a major source of low-cost labor. Today, replacing the shortage of low-cost labor is automation (Liu et al., 2016, Mao et al., 2016; Xu et al., 2012, 2014a; Yang et al., 2016; Zhai et al., 2016), industry robots, artificial intelligence, machine learning; all of these are the cornerstone of the 4th industry revolution, and the core of "Made-in-China 2025".

Returned study abroad students and scholars is a unique category reported by China's Bureau of Statistics. This group increased by 2179% in the period 2002–2015 (Fig. 9). An ability to attract the world's elite talents is a symbol of a nation's power and competitiveness. These highly educated people who have promoted economic and social exchanges will continue to benefit China and the rest of the world (Li, 2013). The United States has successfully attracted millions of world's talents to build its manufacturing and high-tech industries; for example, eBay was founded by Pierre Omidyar, a French-born Iranian-American entrepreneur in 1995 and one of the founders of PayPal, "Max" Levchyn, is a Ukrainian born American. In order to sustain their growth, Chinese industries need qualified professionals from around the world to contribute to their expertise and creative potential to implement "Made-in-China 2025" blueprint. The dramatically growing number in the categories of college graduates and returned study abroad students shows a promising picture of China's capability of attracting the world's top scientists and innovators.

This ambitious strategic plan is coupled with challenges that China is facing (Zhang et al., 2014) On the one hand, China is no longer the lowest–cost labor market; it is being squeezed by newly emerging low-cost producers such as Vietnam, Cambodia, and Laos. On the other hand, China is not the strongest player in the high-tech arena. Advanced industrialized economies, the US, Germany, and Japan, have all effectively deployed digital technology to create new industrial environments, produce new products and improve their well-established brands. A recent New York Times' report provides some evidence of China's high-tech capability (Markoff and Rosenberg, 2017). A well-known Artificial Intelligence researcher gently reminded Microsoft that Baidu (a Chinese version of Google) had achieved similar accuracy in artificial intelligence with the Chinese language two years earlier than their US counterparts. Chinese companies and the nation's government laboratories are making major investments in artificial intelligence. In summary, enhancing manufacturing capability, research and development investment, and human capital give China a head start to transform the "Made-in-China 2025" plan into action.

5. Conclusions

In this study, we compared China's "Made-in-China 2025" with Germany's "Industry 4.0" and estimated China's locus in Made-in-China 2025. "Made-in-China 2025" has clear goals, measures and sector focus. Its guiding principles are to enhance industrial capability through innovation-driven manufacturing, emphasize quality over quantity, achieve green development, optimize the structure of Chinese industry, and nurture human talent. Both plans have recognized the use of the Internet of Things in manufacturing, employing digital networking of production to create smart manufacturing systems within and beyond the factory to both customers and suppliers, and creating a highly responsive, innovative, and competitive global manufacturing landscape. A recent study on global manufacturing competitiveness by Deloitte Global predicts that the U.S. will be the most competitive manufacturing nation in the world in 2020, followed by China, Germany, Japan, India, South Korea, Mexico, Taiwan, Canada and Singapore (Deloitte, 2016). Six out of the ten nations are in Asia, one in Europe, and the other three are NAFTA countries.

The world is anticipating the 4th Industrial revolution which is propelled by advanced technology. During the process of comparing Industry 4.0 and Made-in-China 2025, we find a few research gaps that worth more research effort. First, more work needs to be done to understand the managerial implications and the strategic advantages of collaborative scientific activities and innovation that involve more than one country. Second, the chasm between the industrial and societal impact of collaborative innovation deserves more research. Third, future research may differentiate international R & D results from different business activities, e.g. manufacturing outsourcing, R & D, collaboration, licensing, and join-venture. Finally, in terms of the geographical coverage, more research is needed from regions beyond those major emerging economies such as BRIC countries (Brazil, Russia, India, and China). New emerging economies such as South Africa, Vietnam and Hungary that have contributed to the world economy in recent years require more attention.

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Dr. Ling Li is the Chair of the Department of Information Technology and Decision Sciences, Coordinator of Maritime and Supply Chain Management discipline at Strome College of Business, Old Dominion University, USA. She is university professor and a fellow of APICS (the Association for Operations Management).

In tribute to her research records, she was awarded the title of Eminent Scholar. She has published over 100 peer-refereed research articles in high quality journals, three single-authored books on supply chain management and logistics, encyclopedia articles, business cases, conference proceeding papers, and book chapters. She is the winner of many awards.

She serves as the First Secretary (officer) of International Federation for Information Processing TC8 WG 8.9, an organization which is under the auspices of UNESCO. She is Area Editor of *Systems Research and Behavioral Science* Journal, Associate Editor of *Journal of Management Analytics*, and an Editorial Board Member of *International Journal of Integrated Supply Management*.