The evolution of the internet of things industry and market in China: An interplay of institutions, demands and supply

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Abstract:

This paper seeks to provide some explanation as to how demand-, supply- and institutions-related factors in China have affected the creation and diffusion of Internet of Things (IoT)-related products and services. Concerning demand side factors the paper demonstrates how potential market size and existing technology trajectory work in favor of IoT diffusion. As a related demand side factor the paper argues that, in terms of the technological trajectory, China has started farther from the frontier than most industrialized countries. The degree of incremental benefit from the IoT is thus higher in the country. As to the supply side factors, the article promotes an understanding of how Chinese technology companies have capitalized on a huge user base to develop IoT-based applications. It also suggests that technologies and expertise provided by foreign multinationals have also played crucial roles. Regarding formal institutions, the government's proactive policies have been a major factor in the IoT's evolution. It is also in the Chinese government's interest to develop IoT products to make censorship and surveillance more effective. Regarding informal institutions, Chinese consumers are less concerned than Westerners about being tracked and monitored, which provides a favorable condition for the adoption of IoT-enabled devices. Nonetheless, this condition is changing due to increasing abuse of consumer privacy. China and the U.S. are compared in terms of diffusion, key determinants, performance indicators and impacts of the IoT in order to understand the areas that China outperforms—and underperforms—the U.S. Some indicators are proposed to gauge the IoT-related performance and the impacts of the IoT.

Keywords: China | Institutions | Internet of Things | Leapfrogging | Smart city | Standardization

Article:

1. Introduction

The Internet of Things (IoT) is bringing fundamental changes in economic, environmental, healthcare, social and political realms in the developing world (Kshetri, 2016a). It is probably fair to say that among developing countries, China has the most developed IoT industry and related infrastructure. Commenting on the development of the IoT industry and market, one analyst noted that China is "the only big bloc in the world that can still coherently steer on infrastructure, law, spectrum management, hardware, identity management and preferred applications areas" (Sterling, 2013). Some go as far as to say that whereas the U.S. led the PC revolution and Europe played a major role to facilitate the global diffusion of cellphones in the early stage, China is likely to emerge as a global leader in innovation and adoption of the IoT (Friedman, 2014).

Before proceeding, some clarifying definitions are offered. The IoT is the network of physical objects or 'things' (e.g. machines, devices and appliances, animals or people) embedded with electronics, software and sensors, which are provided with unique identifiers and possess the ability to transfer data across the Web with minimal or no human interventions. By doing so, the inter-connected devices can enhance operational efficiency and create new business and economic opportunities. According to Gartner (2016), there are three components of an IoT service: the edge, the platform and the user. The edge is the location where data originates or is aggregated. Data may also be reduced to the essential or minimal parts. In some cases, data may be analysed. The data then goes to the platform, which is typically in the cloud. Analytics are often performed in the cloud using algorithms. A real-time data streaming decides if some actions need to be taken right away or if the data needs to be stored for future use. The user engages in a business action. Machine to machine (M2M) connections can be considered to be a subset of the IoT, which use wireless networks to connect devices to each other and with the Internet. The IoT can be viewed as an evolution of M2M, which requires the coordination of multiple vendors' machines, devices and appliances connected to the Internet through multiple networks (GSMA, 2014).

IoT technologies in China are being integrated in traditional industries such as agriculture and manufacturing as well as in newly emerging industries such as new energy and new materials (Bughim, Chui, & Manyika, 2015; english.gov.cn, 2015; Kshetri, 2016b). According to the GSMA association, which represents 800 operators worldwide in the mobile phone ecosystem, as of 2013, China had over 50 million M2M connections, which made it the world's largest M2M market (GSMA, 2015a). Note that M2M connections are the dominant form of IoT deployment. It is also worth noting that during 2010–2013, Asia, which is the world's largest regional IoT market, added about 55 million M2M connections, of which 39 million were in China (McEnaney, 2014). According to GSMA Intelligence and the China Academy of Information and Communications Technology (CAICT), as of the mid-2016, China had about 100 million cellular M2M connections, which is expected to increase to 350 million by 2020 (Waring, 2016).

While it is not surprising that China, due to its size, is going to be the largest market for some domains of the IoT, there are two points that should be noted about China's IoT industry. First, China has demonstrated an improving trend in IoT-related innovative activities compared to previous generations of technologies. For instance, according to the U.K. Intellectual Property Office, during 2004–2013, China's ZTE ranked #1 on a list of companies worldwide with the most IoT patents. ZTE had about 300 patens during the period. China accounted for 38% of all

IoT patents globally (GBTIMES, 2015). Second, Chinese companies have created some innovative IoT-related products and services. For instance, as of the mid-2015, the Chinese smartphone manufacture, Xiaomi had over ten IoT-based connected devices such as wristbands, air purifiers, blood pressure monitors and smart TV (Griffiths, 2015). The company has also created and sold products related to its Mi Smart Home system. In March 2016, Mi Air Purifier was offered for sale in Singapore (Millward, 2016). Other notable IoT products include Baidu's smart chopsticks to detect food contaminants and an app that has been developed by microblogging service, Sina Weibo and appliance maker Hisense, which can be used to turn on air conditioners using Weibo (Higginbotham, 2014).

In order to better understand the above observations, it is important to look at the key factors that influence the performance of an innovation. Previous studies have extended our understanding of the roles of demand- and supply-related factors (Bessant, 1991; Dosi, 1982; Freeman, 1994; Katz & Phillips, 1982) and formal and informal institutions (Dosi, 1982; North, 1990, 1996; Rothwell & Wissema, 1986) in shaping an innovation's path. It is argued in this paper that new conceptually grounded models are needed to provide new ways of understanding how these factors affect the path of the IoT.

In light of the above observations, this paper's goal is to provide some explanation as to how demand-, supply- and institutions-related factors have affected the creation and diffusion of IoT-related products and services in China. We provide IoT deployment examples from key areas of development such as agriculture, health and environment as well as commercial activities such as manufacturing and retail. Examples, data, and information related to the creation of IoT-related products and innovations are also used to assess China's position in IoT.

Specifically, this paper contributes to the research on the creation and diffusion of technologies by examining the interplay of institutions, industry and market from the IoT's perspective. This issue has several important policy and theoretical implications because the IoT has been touted as the “next major technology revolution after the Internet” which has the potential to transform the global economy and society (Ashton, 2015). It is thus important for policy makers, technology developers and users to observe this rapidly evolving phenomenon and share insights, reflections and observations. China may serve as a testbed for other emerging markets in the development and deployment of IoT products. For instance, in 2014, China's largest venture capital companies and the International Finance Corporation (IFC) launched initiatives to build a cloud for the IoT in China. The IFC was interested in bringing some of the ideas to other emerging markets (Friedman, 2014).

The paper is structured as follows. We proceed by first providing a review of relevant literature on factors likely to affect the path of an innovation. Next, we provide a case study of China's IoT sector and develop a framework that links the impacts, performance indicators and determinants related to China's IoT sector. The final section provides discussion and conclusion.

2. Literature review

This section is organized around three themes stated in the objective: demand side factors, supply-side factors and institutional factors.

2.1. Demand side factors

Rosenberg and Mowery (1979 p. 31) noted that "market is important in determining successful innovations".

2.1.1. Potential market size

Potential market size is an important determinant of profits. Markets use a reward/penalization mechanism in order to check and select among different alternatives (Dosi, 1982).

2.1.2. Existing technology trajectory

Dosi (1982) noted that more powerful and less powerful trajectories exist and argued that when the existing trajectory is "powerful", firms and nations might find it difficult to switch to an alternative trajectory. Demands of a new technology such as the IoT are high when the existing alternative technology trajectory is unattractive. On the other hand, technology firms in an attractive trajectory are likely to be trapped in a legacy system.

2.1.3. Inter-relatedness with complementary technologies

A high degree of interrelatedness with other complementary technologies allows potential users to obtain information and skills needed for a new technology (Allen, 1998). Thus, countries with a small base of high technology and innovative capital goods are likely to experience lower rates of diffusion for emerging new technologies (Antonelli, 1986). To put things in context, wider and deeper adoptions of PCs, mobile devices and other ICT applications are likely to lead to faster diffusion of IoT.

Another aspect of interrelatedness is that compatibility standards that make an innovation work by facilitating interconnection and interoperability between different systems (David & Greenstein, 1990; Greenstein, 1990). Most contemporary electronic products require appropriate software, peripherals, and accessories (Freeman, 1994). Compatibility with existing technologies used by consumers can accelerate the diffusion of a new technology. For instance, healthcare organizations face the challenge of integrating data from consumer-based sensors such as Internet-based blood pressure monitoring system and weight scales into the overall IT architecture. These systems present data exchange challenges since home devices often had lower level of accuracy and thus need to be recalibrated (Robert, 2014).

2.2. Supply-side factors

The effects of supply-side factors such as the technological history and the fields of expertise of organizations also affect a technological trajectory (Dosi, 1982). In China's context, entrepreneurial activities of foreign and local firms have been a key force in the diffusion of previous generations of technologies (Kshetri, 2016c, 2016d). It is thus important to see how expertise, experience, and skills of Chinese and foreign firms operating in the country can contribute to the creation and diffusion of IoT-related products and services.

2.2.1. Skills, experiences and capabilities of local firms

Diffusion of an innovation is dependent on factors such as skill intensity, learning, training, and educational systems and managerial and organizational innovations (Bessant, 1991; Freeman, 1994; Watanabe, 1993). Realizing the importance of relevant skills and training, a number of developing countries such as China and Vietnam taking measures to build appropriate skills and abilities to successfully use emerging technologies such as cloud computing and the IoT (Kshetri, 2010; N° 6, 2013).

In the early phase of a radical innovation, scientific and technological inputs are likely to play more prominent roles in shaping the path of the innovation (Freeman, 1994). For instance, during the early stage of the development of computer, technology push was the strongest and the main element in its development (Katz & Phillips, 1982). It was reported that technology developers had not expected a big market opportunity for computers.

2.2.2. Economic interests of foreign multinational firms

Economic interests of foreign multinational firms are also key aspects of supply side factors (Kshetri, 2016c). Prior researchers have suggested that multinationals exploit technological capabilities internationally by means of activities such as export, movement of production activities abroad, and licensing, which can facilitate the diffusion of technologies in an economy (Archibugi & Michie, 1997; Iammarino & Michie, 1998). Kshetri (2010) reported that the activities of Western multinationals such as IBM, Microsoft and Salesforce triggered the cloud's evolution in the developing world.

2.3. Institutional factors

Like all economic phenomena (Parto, 2005), the IoT industry and market are deeply embedded in diverse sets of formal and informal institutions. Institutions are “macro-level rules of the game” (North, 1990, p. 27) and include: a) formal institutions such as rules, laws, constitutions and b) informal institutions such as social norms, conventions and self-imposed codes (North, 1996).

2.3.1. Formal institutions

2.3.1.1. Proactive and business-friendly regulatory environments

Regarding formal institutions, Mazzucato (2011) has argued for proactive rather than minimalist roles of the state in order to promote an innovation-driven economy. Legal and non-legal influences such as new laws, investment incentives, foreign technology transfer, and other supply-push and demand-pull forces can facilitate the development of an industry related to a new technology (King et al., 1994; Montealegre, 1999). For instance, Singapore has been able to develop itself as an IT hub of Asia by providing attractive infrastructure, skilled workers and a stable labor environment (Kraemer, Gurbaxani, & King, 1992; Wong, 1998). Similarly, strong university–industry linkages and a large pool of highly trained scientists and engineers, mostly

supported by the defense sector, drive technology diffusion in Israel (Porter & Stern, 2001). It is thus not sufficient to just create infrastructures and establish and enforce the rules (Mazzucato, 2011).

During the periods of highest economic growth, the governments of the most successful economies have often acted as an agent that stimulates innovative breakthroughs and the discovery of new applications (Mazzucato, 2011). In addition to the roles in creating the right conditions, such governments thus proactively create strategies around high-growth areas before the technologies' potential is understood by businesses.

2.3.1.2. Regulations to address the weakness of the market

Especially during the initial stage of the formation of an industry, formal institutions such as public agencies and the military are likely to define the directions of technological development and play key roles in addressing the weakness of the market (Dosi, 1982). For instance, financial supports provided to R&D and guaranteed public procurement by the military and the space programs played a key role in the development of the U.S. semiconductors and computing sectors during the first two decades following the World War II (Dosi, 1982).

2.3.2. Informal institutions

Informal institutions also have a powerful influence on the development and diffusion of an innovation. For instance, the culture of a society affects the perceived need for a technological change. Rothwell and Wissema (1986) argued that a reason why organizations in Ancient Greece did not proceed with industrialization, despite its expertise in science, technology and mathematics, was the easy availability of cheap slave labor.

2.3.2.1. Compatibility with the social system

Compatibility, which is defined as the degree to which a technology and the tasks it performs are perceived as being consistent with the existing values, beliefs, past experiences, and needs of potential adopters, affects the diffusion rate (Rogers, 2003). For instance, consumers with a high degree of privacy concern are likely to be reluctant to use technologies such as the IoT that track locations, movements and other activities.

3. The case of China's IoT sector: Impacts, performance indicators and determinants

As a visual aid, Fig. 1 schematically represents the various factors discussed in the previous section that are driving the evolution of China's IoT industry and market. The boxes in Fig. 1 consist of three main building blocks: determinants, performance indicators and impacts. Ahmad and Hoffmann (2008) provide a useful analogy to understand interrelationships among them: Assume that passengers would like to go from point A to point B by time t (policy objective, impacts). There may be various means of transport available. Factors such as a car's engine size, fuel consumption rate, etc. are the determinants. During their journey, passengers are informed about their current status about the direction and time by technologies such as speedometers and GPS readings (performance indicators). Note too that different passengers (policy makers) would

like to go to different places and get there at different times (different impacts), using different modes of transport (determinant).

FIGURE 1 IS OMITTED FROM THIS FORMATTED DOCUMENT
Fig. 1. The evolution of the internet of things industry and market in China: interplay of institutions, industry and market.

The two boxes at the bottom of Fig. 1 provide some examples of performance indicators and impacts of the IoT. Table 1 presents some indicators related to diffusion, performance indicators and impacts of the IoT in China and compares them with the U.S.

Table 1. A comparison of some indicators related to diffusion, performance indicators and impacts of the IoT in China and the U.S.

Indicator	China's situation	Remarks
IoT patents	China accounted for 38% of patents globally (GBTIMES, 2015). ZTE ranked #1 on a list of companies worldwide with the most IoT patents. Huwai: #10	The U.S. accounted for 31% of patents globally (UK Intellectual Property Office, 2014). IBM #5, Intel: #7, Qualcom #9
M2M connections	2013: 50 million connections (over a quarter of the global total) (GSMA, 2014a) 74 million in the mid-2015 (GSMA, 2015a). mid-2016: 100 million, expected to increase to 350 million by 2020 (Waring, 2016).	2013: 32 million (GSMA, 2014). SMA
M2M as a proportion of total connections (2014Q4) (Seals, 2015).	5.1%.	11.3%
No. of electric smart meters (2020, forecast of Navigant Research) (Guerrini, 2014)	More than 435 million	About 132 million.
Size of the IoT market	Ministry of industry and information technology: US$ 32 billion in 2010 (GSMA, 2015b) Xinhua News Agency: US$90 billion in 2014 (english.gov.cn, 2015). Ministry of industry and information technology: US$ 80.5 billion in 2015 (estimate) IDC estimate for 2020: US$344 billion (idc.com, 2015)	IDC estimate for 2020 for North America: US$442 billion (wsj.com, 2015)
Social media users	659 million (active users) (Millward, 2015)	159 million (Perrin, 2015)

Total B2C e-commerce transactions (2015)	$672 billion (CIW, 2015) $590 billion (estimate of the National Bureau of Statistics in China) (Tong, 2016)	$352 billion (Brohan, 2015)
Total mobile commerce transactions (2015)	Prediction: US$334 billion (49.7% of e-commerce) (CIW, 2015).	$104 billion (29.7% of e-commerce) (Brohan, 2015)
Mobile payments (2015)	Third-party-mobile payment transactions about $600 billion in 2015 (PYMNTS, 2015)	$8.71 billion (emarketer.com, 2015)
Industrial robots sale (2014) (ifr.org, 2015)	57,096	26,200

3.1. Impacts of the IoT

The impact indicators are the ultimate objectives that policy makers want to accomplish (Ahmad & Hoffmann, 2008). In China's case, the state strategies toward ICTs have been to balance economic modernization and political control (Kalathil, 2003). Thus the Chinese Communist Party (CCP) views Chinese firms' economic and commercial success as closely tied to its political ideology (Kshetri, 2007; Xia, 2012a, 2012b). Regarding political ideology, the base of the CCP's legitimacy has shifted from MarxLeninism to economic growth and prosperity (Zhao, 2000). Economic development is thus a key priority. Various IoT initiatives have been developed to drive economic modernization-related goals. Some key impact indicators related to the IoT's use to achieve such goals are discussed in this section.

3.1.1. Increasing efficiency and productivity in key industries and sectors

The IoT can enhance operational efficiency and productivity and create new business and economic opportunities, which would help achieve economic modernization-related goals and increase the CCP's legitimacy (Zhao, 2000). According to a study of the management consulting and outsourcing company Accenture, the IoT's potential contribution to the Chinese economy will be US$500 billion by 2030 based on current policy and investment trends and as much as US$1.8 trillion by 2030 if organizations can overcome challenges related to infrastructure, data policy and talent (Gibson, 2015).

Most IoT projects entail connected devices with simple and passive sensors to manage, monitor and optimize systems and processes. China's manufacturing prowess, the Internet of Robotic Things (IoRT) deserves attention. In IoRT, “intelligent devices can monitor events, fuse sensor data from a variety of sources, use local and distributed “intelligence” to determine a best course of action, and then act to control or manipulate objects in the physical world, and in some cases while physically moving through that world” (ABI Research, 2014, para 3), which are likely to bring transformational changes to industry operations and performance. Estimate suggest that by 2019, labor costs in China will be 77% higher than in Vietnam and 118% higher than in India. Unsurprising industrial robot sales in China grew by about 60% in 2013 and the country became the largest buyer of industrial robots (Hagel, Brown, Kulasooriya, Giffi, & Chen, 2015).

3.1.1.1. Addressing quality and safety issues in agricultural and food commodities

There are reports that a significant proportion of milk, meat, rice, vegetables and other food items sold in the country are heavily tainted and contaminated. In order to enhance its image, the Chinese government has thus made food safety a top priority. In 2011, Fudan University's Auto-ID Lab collaborated with 17 other research teams at universities, research institutes and enterprises on a project called Agriculture Internet of Things and Food Safety and Quality. The project was supported by the Ministry of Science and Technology, which uses the IoT to track agricultural products from the field through the supply chain and food-processing environments (Wang & Min, 2013). In Tianjin, a project involves monitoring microorganisms in milk at each stage "from cow to table". The monitoring is expected to enhance transparency and strengthen the reputation and competitiveness of dairy companies.

3.1.1.2. Improving healthcare delivery

The Chinese healthcare sector is experiencing a number of challenges such as high costs, inefficiency in public hospitals and increase in the number of patients with chronic diseases (Wang, 2014). Fixing these problems is the key to achieving the CCP's legitimacy.

Faced with these problems, China is leveraging on new and emerging technologies such as the IoT to transform the healthcare system. The Chengdu Internet of Things Technology Institute is developing a healthcare system, which allows rural villagers to step into a telephone booth-sized “health capsule” in order to get a diagnosis and prescription from a doctor in a distant hospital (harborresearch.com, 2014).

Baidu has launched Dulife, which is an open-ended platform to collect primary data from interface with third-party wearable devices (e.g., weighing scales, blood pressure monitors and wristbands). The data is then processed by the company for healthcare practitioners to advise their patients about the potential risks and improve patient care (Fidelity Worldwide Investment, 2015).

3.1.1.3. Improving environmental monitoring and protection

For the CCP, a key legitimacy issue also concerns severe environmental challenges faced by China for many decades. In 2014, the Chinese government set its environmental targets over a ten-year period, which included: a) reducing fine air pollution Particulate Matter (PM2.5)1 concentration by up to 25% by 2017, b) increasing the proportion of renewable energy to 15% by 2020, and c) achieving a 45% reduction in carbon intensity by 2020 (ibm.com, 2014). Among the key initiatives to achieve this goal is the Beijing Municipal Environmental Protection Bureau's 10-year, US$160 billion project known as Green Horizon, in which IBM provides data analytics services, tools and software. Green Horizon relies on real-time data from IoT-based optical sensors, weather satellites and meteorological data, other structured databases, the cloud, big data analytics and the Internet of things in order to gain deeper insights into the type, source, dispersion and levels the city's pollutant emissions. The system also makes optimization and adjustment to better utilize renewable energy sources. In addition, cognitive computing analyses and learns from real-time data and information (Greengard, 2014).

Using the climate modeling technologies, it is possible for the Beijing municipal government to predict 72 h in advance the location where harmful pollutants are likely to spread. Such a prediction can help the city to perform a scenario analysis that looks at the effects of various short-term policy options such as traffic restrictions, mandatory installation of filtering system, and relocation of facilities. It can also provide relevant information to residents so that they can avoid specific areas in the city. Relevant information can also be posted on electronic freeway signs. The traffic can be diverted to less-congested and less-polluted areas. It is also possible to work with factories to plan and synchronize production cycles (Shumway, 2014).

The Zhangbei Demonstration Project in Hebei Province is China's largest renewable energy project, which integrates wind energy into the grid. IBM's renewable energy forecasting system combines data related to cloud movements, wind speed, temperature and direction, which can be used by utility firms to forecast clean energy power production up to one week in advance (verdantix.com, 2015). It reportedly led to a reduction of energy waste from 30% to 20% (chinatechnews.com, 2014). In 2014, the plant integrated 10% more alternative energy from its wind farm into the grid. The Zhangbei Project's energy forecasting system is reported to have a 90% predictive accuracy (Shumway, 2014).

An accurate and effective forecasting of the availability of renewable energies can help a more sustainable power generation and supply. For instance, weather modeling and cloud imaging tools can be used to more accurately predict the performance of solar and wind farms in advance. This information can be used to maximize and store electrical output (Shumway, 2014).

The Ministry of Environmental Protection is planning to improve a satellite-based remote sensor network. The plan is guided by the goals of the 13th five-year plan (2016-20). Satellites, drones and remote sensors are being used to locate pollution sources. For instance, polluted areas were located in the Tengger Desert in northern China and scattered straw burnings were identified. Since the beginning of 2014, Hebei province teamed up with the Ministry's Satellite Environment Center to monitor the city's pollution (foriegnaffairs.co.nz, 2015).

3.1.2. Improving intellectual property rights (IPR) balance of payments

The outflow of IPR payments has been a focus of concern in China. During 2006–2009, China earned US$1.5 billion by exporting IPR whereas the country's outflow of IPR payments amounted US$36.2 billion (Lan & Hao, 2015). According to the World Bank, in 2009 alone, China had a deficit of US$10.6 billion in IPR balance of payments (Cao, 2013).

Chinese policy makers think that developed countries see developing countries as ‘markets’ for the transnational corporations’ products, which threatens their economic security (China Economic Times, 2000). In the IoT industry, a reliance on the import of sensor and chip technology has been a concern (english.gov.cn, 2015).

Foreign technology imports and outflow of IP royalties have been a focus of concern among Chinese political elites (Kshetri, 2009). China is thus interested in reversing the model, and creating the standards for IoT so that other countries will pay it royalties (Voigt, 2012). The Chinese government's 15-year medium and long-term plan, which was adopted in the early

2010s, tries to strengthen China's IPR landscape and reduce the reliance on foreign IP for core technologies (Cao, 2013).

China has also been trying to develop its own standards for some time in order to reverse the flow of fees (Kshetri, Palvia, & Dai, 2011). Not surprisingly China has been working to create domestic standards in many other ICT industries such as computer operating systems and audio–video compression. In the 1990s, China took aggressive actions in developing DVD and CD standards. Enhanced Versatile Disc (EVD) was China's response to create a red-laser DVD-like format, which was unsuccessful. Likewise, Super Video CD (SVCD) was developed by the government-backed China Recording Standards Committee. However, SVCD could not perform well in the market. China has become an early adopter of the IoT.

Due primarily to Chinese firms' lack of technological competence, China has not achieved the desired goals in its standardization initiatives. For instance, the China-originated 3 G cellular standard, Time Division-Synchronous Code Division Multiple Access (TD-SCDMA), which was accepted by the International Telecommunications Union (ITU) as a global 3 G standard had limited success on the home front. This standard has been virtually absent outside China (Min, 2014). China thus wants to increase the probability in setting global standards in IoT products compared to the other past attempts. As noted earlier, Chinese companies own more IoT-related patents than any other countries in the world.

3.2. IoT-related performance indicators

IoT performance measures are the actions that are instrumental in delivering the impacts of the IoT. Put differently, target indicators used in measuring the IoT performance tell the progress towards achieving the ultimate objectives. For instance, creation of IoT-related products/services and innovations, setting standards and diffusion and adoption of IoT-related products/services are not goals but means to achieving various other objectives related to impact indicators.

3.2.1. Diffusion and adoption of IoT-related products/services

As noted above, China is experiencing rapid diffusion and adoption of IoT-related products and services (Table 1). Due primarily to its size, China has overtaken the U.S. in some areas of IoT deployment. Smart meter is one area that has benefited from the IoT (Table 1). The smart meter segment leads all other segments in both in terms of connections as well as revenues. It is expected that by 2020, smart meter connections will be about 10 times as high as the next highest market segment in total connections (ABIresearch, 2015). Other biggest growth areas include home security automation and monitoring, video surveillance and home appliances. Among the key drivers of the growing demand in these areas include the need of considerable resources to provide care for its aging population. The country's 55 and older population is expected to reach about 340 million by 2020 (ABIresearch, 2015).

The above said, China's higher market size than some industrialized countries in some IoT domains is due to its large size rather than because of the propensity of the country's individuals and organizations to adopt emerging technologies such as IoT. For instance, in terms of the number of things connected to per capita, China ranked sixth out of the 13 countries in

Asia/Pacific excluding Japan. The top countries in the region were South Korea, Australia and New Zealand (idc.com, 2015a). A comparison of M2M as a proportion of total connections indicates that China is a less mature IoT market than the U.S. (Table 1).

3.2.2. Creation of IoT-related products/services

China's private sector firms and SOEs have focused on creating IoT-enabled products and services. The examples noted above include the Chengdu Internet of Things Technology Institute's “health capsule”, and the app to turn on air conditioners using the microblogging service, Sina Weibo.

3.2.3. Creation of IoT-related patents

As noted above, rapidly growing innovative activities have become a critical factor in the creation and diffusion of IoT-related products and services in China. According to the German Fraunhofer-Institute for Industrial Engineering (Fraunhofer IAO), from 2013 until the third quarter of 2015, Chinese inventors filed 2541 IoT patents compared to 1065 by inventors in the U.S. and 441 by German inventors (Koeling, 2015).

Nonetheless, some caveats need to be made here. Analysts have raised questions with reference to quality versus quantity of patents filed by Chinese inventors. A senior fellow at the China Policy Institute noted that the increase in patent applications by Chinese inventors has been “more a product of new government incentives than homegrown entrepreneurial zeal” (Cao, 2013, para. 6). In order to encourage outward patent applications, in 2009, China's Ministry of Finance established a special fund to subsidize foreign patent filings. It provides up to 100,000 yuan (about US$16,000) per patent application (Savitz, 2013). In this way, the patent statistics may reflect structural flaws in the Chinese political system, which provides an incentive to file without considering the patens’ quality. A concern is that Chinese enterprises and academic institutions might be wasting time and resources in generating patents and filing applications, which are of little real-world value (Cao, 2013). A patent application's legitimization and yardstick for performance can lead to a misuse of scarce R&D resources.

Of the 2541 patents filed by Chinese inventors, only 515 were granted approval. 65% of patent applications filed by China's medium and large SOEs are reported to be for design or utility model patents compared to 2.7% in the U.S. Note that such patents do not undergo a rigorous examination process (Koeling, 2015).

3.2.4. Setting standards

Among the key challenges in the growth of the IoT industry are the issues of interoperability and standardization. One observation is that many vendors are building “silos” that do not easily inter-connect or share information (mickinsey.com, 2015). As is the case of the rest of the world, the IoT-related standards currently are fragmented among the relevant, new technologies to ensure the interoperability of communication protocols (itu.int, 2015). From this perspective, the Chinese government can shape the standardization processes due to its role in control and coordination. In the food industry, China has implemented the “National Food Quality Safety

Traceability Platform", which was a result of the collaboration of the Chinese government with the food-production and ICT industries. The Platform utilizes the IoT to improve the quality and safety of food-production supply chains. In order to ensure the traceability of food-safety information, it uses the Handle System of the Digital Object (DO) Architecture. A key feature of the DO Architecture is that each digital object has a "unique persistent identifier" (itu4u.wordpress.com, 2014). A malpractice can be traced to the source and responsible companies can be penalized. The dairy industry was the first to implement the Handle System, which is expected to be adopted by other sectors in the food industry (Jian, 2014). The Chinese government has selected the Handle System as the core technology for major national projects such as 'National Food Quality Safety Traceability Platform and National Public Service Platform for IoT Identifier Management (Zhou, 2014). This platform will make the Handle System available to all industries in order to trace the identity of goods, producers, processes in the supply chain.

3.3. Determinants

Regarding the determinants, the IoT industry has much to learn from the development of the Chinese telecommunications sector. The evolution of the Chinese telecommunications system, for instance, can be viewed as the result of the strategies of technology providers, market, and institutional forces (Xia, 2016b). Prior researchers suggested that the evolution of China-originated 3 G cellular standard TD-SCDMA was a complex process that involved strategies of related firms and the government's industry and technological policies (Gao & Liu, 2012; Xia, 2011).

The bullet points under each category of factors in Fig. 1 present the situation in China. To illustrate some of the key issues involved with demand, supply and institutions presented in Fig. 1, six major Chinese IoT players -- Alibaba Baidu, Huawei, Sina Tencent and ZTE-- are presented in Table 2. Table 2 also summarizes IoT-related offerings of these firms to satisfy market demand, their capability and competence and the effects of institutional factors. These issues in the context of firms presented in Table 2 and other Chinese IoT firms are discussed below.

Table 2. Demand, supply and institutions: an illustration of six Chinese IoT players.

Company	IoT-related offerings to satisfy demand	Capability and competence of the firm (IoT supplier)	The effects of institutional factors
Alibaba	'Internet Car' with SAIC Entry into the smart appliance market with a smart living unit. 2014: sales of smart air conditioners increased by 1,331% on TMall.	Ranked # 24 in MIT Technology Review's 50 Smartest Companies 2016 (MITTechnologyReview, 2016). Core business: e-commerce, BD and cloud. TMall is sales channel.	Political favor: allowed to enter into sectors that the government wants to shake up and make more efficient.
Baidu	Baidu has teamed with BMW to develop driverless cars (Allen, 2016). plan to launch smart chopsticks that can detect contaminants	Ranked # 2 in MIT Technology Review's 50 Smartest Companies 2016 (MITTechnologyReview, 2016).	Political favor: allowed to enter into other sectors that the government wants to

			shake up and make more efficient.
Huawei	IoT-based Smart City and Safe Cities platform: integrates data from the city and combines with IoT infrastructure to provide reports on traffic, crime, and energy usage. Planning to enter Australia and other countries (Curry, 2016). India: agreement with Philips Lighting to ensure the interoperability of the Philips Hue connected lighting system for the home with Huawei's OceanConnect IoT platform (Bureau, 2016).	Ranked # 10 in MIT Technology Review's 50 Smartest Companies 2016 (MITTechnologyReview, 2016). 2012: more than 6000 people working on R&D (http://www.huawei.com/enapp/1209/hw-133186.htm).	Headquartered in Shenzhen $30 billion facility from China Development Bank (Dalton, 2011).
Sina	An IoT-based app to turn on air conditioners using Weibo. Teamed up with Ayla Networks to develop Wi-FI Weather Station to get block-by-block weather reports	October 2016: Weibo had 282 million active users (Pickrell, 2016).	First license to publish online news (2000), first license to operate as an ICP (2001), first license to operate BBS (Chen, 2016). In designing Weibo, it worked closely with regulators (economist.com, 2011).
Tencent	WeChat launched an open hardware platform and a nationwide competition.	# 20 in MIT Technology Review's 50 Smartest Companies 2016 (MITTechnologyReview, 2016). Shenzhen: $599 million project with a campus-like atmosphere for an urban setting: beta test its IoT platforms (Fenner & Chen, 2016).	Headquartered in Shenzhen Political favor: allowed to enter into other sectors that the government wants to shake up and make more efficient.
ZTE	150 smart city projects in China: offers smart metering, smart lighting, smart parking. IoT business is oriented toward telecoms operators, corporations and governments.	2011: 10,000 m^2 global R&D center in Nanjing, 3000 R&D staff. Telecoms operators segment: joint innovation center with China Mobile to explore IoT in 2013: test NB-IoT.	Headquartered in Shenzhen. 2009: received a $25 billion credit line from the state-owned China Development Bank and China

	IoT platform in South Africa with local operator MTN. ZSmart solutions in over 70 countries (Tomas, 2016).	Working with China Telecom (Tomas, 2016).	Export-Import Bank (Dalton, 2011)..

3.3.1. Demand side factors

3.3.1.1. Huge potential market size

Indicators such as social media users, e-commerce, mobile commerce, mobile payments (Table 1) point to a big potential IoT market size in China. Diverse sectors such as transportation, retail, energy, logistics, utilities, manufacturing can benefit from the IoT's deployment in real-time information processing in order to increase efficiency, lower costs and manage infrastructures.

To take an example, China is the world's fastest-growing automotive market. Increasing traffic congestion and safety concerns in the country have escalated the demands of cars with advanced navigation technologies and safety features (Bushell-Embling, 2015). These factors are likely to lead to a high demand for connected cars with IoT capabilities. Capitalizing on such opportunities, in the early 2015, Alibaba invested US$160 million in a joint venture with Shanghai Automotive Industry Corp (SAIC) to develop a connected car (Bloomberg News, 2015). The ‘Internet Car’ based on the IoT was launched in the mid-2016. Alibaba provides its YunOS for Car operating system, cloud computing, digital entertainment, maps and financial data. Alibaba wants to use YunOS to power televisions, home-air conditioning systems, refrigerators, microwave ovens, game consoles, smart watches, and robotic vacuum cleaners (De Feijter, 2016). Likewise, China Mobile was reported to be seeking collaborations with over a dozen carmakers such as Beijing Auto, BYD, Audi and BMW. The idea is to integrate mobile data and web services into the operating system (OS) of the next generation of cars (Chen, 2015).

Looking at the M2M as a proportion of total connections, while Chinese IoT market is more mature than the world average, it is less mature than the U.S. (Table 1). The huge market size, however, has been the source of China's power on the IoT front.

3.3.1.2. Fewer legacy issues

Developing economies such as China have fewer legacy issues to grapple with and thus have the potential to leapfrog the industrialized world in some areas of IoT applications (Bughin, Chui, & Manyika, 2015). For instance, consider the primary sector of the Chinese economy. One estimate suggested that 266 million or 35% of workers in China are employed in the primary sector. A study indicated that output per farmer in South Korea is 40 times higher than that of in China (Badkar, 2012). One key factor behind higher farming productivity in South Korea concerns farmers’ heavier utilization of machinery (Badkar, 2012). The fact that most Chinese farmers do not utilize machinery makes the IoT-related innovations more attractive for them.

However, fewer legacy issues could be an indication that developing economies such as China may exhibit a low level of national capabilities in the assimilation of technologies and associated

organizational practices (Cohen & Levinthal, 1990). This may hinder efforts to adopt technologies such as the IoT widely and deeply.

3.3.1.3. Firms far from the frontier: higher degree of incremental benefit

Various indicators related to low agricultural productivity, severe environmental pollution and inefficiency in healthcare services and operations point to the fact that Chinese firms far from the frontier in the technology space. Due to this, Chinese firms' IoT deployment may be associated with higher incremental benefits than those in industrialized countries.

Consider, agriculture, which is arguably entering the third stage of development or Ag 3.0 (Lohr, 2015). Ag 3.0 involves exploiting data from diverse sources such as sensors embedded on farm equipment and plants, satellite images and weather tracking. It is argued that in the not too distant future, the use of water, fertilizer and other input is likely to involve detailed measurement and monitoring, sometimes on a plant-by-plant basis (dimsums.blogspot.ca, 2014). Some progress has already Bughin et al. 2015, Chinese agricultural authorities signed a deal to deploy "agricultural cloud" technology provided by AKOL for fish farms. Through the AKOL system, fish farmer operators can access in-depth information, gathered via sensors and analyze. The system tells fish farmers regarding appropriate times to clean pools, the amount and time to feed fish and other information (Shamah, 2015). In 2012, China's Anhui province began using AKOL's Agro Cloud solution in order to quantify total food production. AKOL's solution, which was developed with IBM, allows local officials to monitor the production of fruit, vegetable, dairy, poultry and meat (Shemer, 2013).

China is the world's biggest emitter of carbon dioxide due to its rapid economic growth and increased energy consumption. Due to high energy costs and a desire to reduce pollutants, there is a big push for energy conservation (Higginbotham, 2014). There is thus high demand of environmental sensors such as air quality and purifiers. It was reported that as of August 2013, the IoT was used to automatically monitor over 15,000 key pollution sources (Louchez & Thomas, 2014).

3.3.1.4. Increasing manufacturing sophistication

The manufacturing sector, which is one of the fastest growing sectors in the Chinese economy, is reported to be one of the major drivers of the IoT market. According to IDC, Chinese manufacturing enterprises' IoT spending will reach US$127.5 billion in 2020 (IDC, 2016).

The combination of the IoT and big data analytics will allow firms in the manufacturing industry to benefit from low-cost sensing, real time, and more efficient data collection and advanced data analysis. Machine learning can also facilitate faster and more accurate data analysis for firms in the manufacturing industry, which will be in a better position to integrate functions such as R&D, production, operation, marketing and management (IDC, 2016).

Chinese manufacturing firms have started using RFID tags to track and monitor the flow of the manufacturing process (prnewswire.com, 2015). The IoT will greatly facilitate and improve manufacturing as well as distribution of products (Bughim et al., 2015). Services and capabilities

offered by Chinese manufacturers have expanded rapidly. Not long ago, Chinese manufacturers played relatively minor roles in the supply chain. Products used to be designed in the U.S. or Europe and shipped to Taiwanese companies. Taiwanese firms, on the other hand, shipped them to China for cheap, volume manufacturing. In recent years, Chinese firms have shifted into a higher gear and are performing activities that involve higher value added and more complex technologies and more sophisticated products. China is becoming a less attractive destination for low-cost manufacturing. The country is developing its own brands and next generation of technologies (Voigt, 2012). One example is Yifang Digital Technology, whose Nextbook is the fifth largest selling tablet in the U.S. and eighth worldwide. The company's NexTurn home control platform is soon likely to be sold in the U.S. (Friedman, 2014) Chinese companies manage industrial design, design-for-manufacturing, as well as the manufacturing process (Friedman, 2014). The increasing sophistication of the manufacturing base and the willingness of foreign retailers to promote or adopt Chinese brands are likely to act as forces that may accelerate the diffusion of the IoT in manufacturing.

3.3.1.5. Diffusion of complementary technologies

The growth of the IoT market in China is associated with and facilitated by the diffusion of complementary technologies such as cloud computing, big data, cellphones, mobility and low cost sensors. Tags are being increasingly used on merchandise in stores due to the decline in the cost of readers and an expectation that most smartphones in the future will have built-in RFID readers (Swedberg, 2015). Many types of RFID tags cost just a few cents (McLellan, 2013).

In view of the current economic and societal trends, the IoT may provide rich experience, information and economic benefits to Chinese businesses and consumers. In order to illustrate this point, we consider the IoT's possible use in fighting counterfeit products. Chinese merchants and consumers are concerned about counterfeit products in industries such as food, apparel, medications and electronics. To address such concerns, stores have begun deploying RFID, which allows consumers to verify products’ authenticity. Brands have started tagging products to facilitate this process. For instance, a hot sauce maker has deployed RFID tags, which enables customers to use a store's RFID reader to authenticate products (Swedberg, 2015). A liquor company uses RFID to tag and track high-value products. A store receiving the liquor company's products uses RFID interrogator to capture the ID number encoded to a bottle's tag. The store can then access the liquor company's server to confirm that the ID matches to that of a genuine product. Manufacturers of apparel, furniture and food products have made similar uses of RFID.

3.3.2. Supply-side factors

3.3.2.1. Entrepreneurial firms with capabilities to identify opportunities and develop businesses with unconventional models

Prior research has suggested that the rapid diffusion of mobile Internet has stimulated entrepreneurial activities and innovative business models in China (Xia, 2016b). Mobile Internet-led entrepreneurial activities have been key drivers of the IoT sector. The private sector has been the biggest innovator and driver of the Chinese IoT market. This can be partly attributed to the

Chinese government's favorable policies to support domestic companies in electronics and high technology industries (Fig. 1).

The IoT development in China is being driven by Internet companies such as Baidu, Alibaba, Tencent, JD.com, and Sina, many of which started as or are primarily social media platforms (Table 2). Leading mobile operators such as China Mobile, China Telecom and China Unicom are also looking for opportunities to use the IoT to increase market share and revenue.

In many aspects, China's mobile payment platforms and e-commerce markets are more developed than in the west (Table 1). The IoT is the obvious next step for Chinese companies in these sectors. This is because China's Internet companies can tap into a huge user base (Table 1) to create and capture value with new IoT-based offerings such as smart chopsticks, weather apps and blood pressure monitor (Schuster, 2014).

China's Internet companies are launching new products and are providing IoT services to manufacturers on their own as well as in partnership with foreign companies (Friedman, 2014). For instance, Sina and U.S.-based startup Ayla Networks developed Wi-FI Weather Station, which is a new cloud-connected device to get block-by-block weather reports with the same levels of details as provided by Google Maps (Baker, 2013). In 2014, the Chinese e-commerce firm JD.com launched a cloud platform to help manufacturers in the IoT sector to develop products for online shoppers. The company noted that it would use big data to help manufacturers understand consumers' needs (Hong, 2014).

The IoT is a multifaceted phenomenon, which encompasses diverse areas such as infrastructure, hardware, software, applications, and services (Sterling, 2013). Not all these areas are in the domain of a single company's activities. Firms thus need to expand their capabilities to successfully compete in this environment. For instance, consider, Xiaomi, which overall ranked #2 (#1 among technology companies) on the MIT Technology Review's 2015 list for 50 Smartest Companies (technologyreview.com, 2015). As of the mid-2015, Xiaomi had over ten connected devices based on the IoT such as wristbands, air purifiers and blood pressure monitors and smart TV (Griffiths, 2015). Other major IoT players shown in Table 2 are also highly innovative.

3.3.2.2. Lean firms focusing on multiple products and industries

China's Internet companies have flexible and lean organizational structure. Chinese innovation ecosystems often involve the co-development of collaborative environment and creation of network effects around the core. By engaging in collaborative activities, the core company can overcome the capability gaps and exploit new opportunities in adjacent industries (Hendrichs, 2015). For instance, Xiaomi's core business is based on smartphones, for which the Mi User Interface (MIUI) software (also known as firmware) is a key part. In order to enter into the IoT realm, Xiaomi expanded its capabilities by acquiring, investing and forming partnerships with over 30 companies in a range of industries such as wearable devices, home appliances, online video content and streaming sites. Xiaomi's acquisition and partnership activities have been centered on the MIUI software (Hendrichs, 2015). Smartphones have played a key role in the IoT revolution involving a range of connected devices (Schwartz, 2015). In this way, the IoT is not completely unrelated to the company's core business activities.

Likewise, Alibaba's core business operations include e-commerce, big data and cloud computing. In April 2015, as a part of its overall IoT strategy, Alibaba announced its entry into the smart appliance market with the establishment of a smart living unit. Its cloud computing service provides storage. The Baichuan program, which offers infrastructure support to mobile phone app developers helps in the software development process. Its business-to-consumer (B2C) online retail unit, TMall will be the main sales channel. Alibaba's revenue from Internet-connected smart products incorporating IoT is increasing rapidly. In order to strengthen its market position, Alibaba has introduced cheap Wi-Fi and Bluetooth products, which can be used to connect appliances to the Internet (wantchinatimes.com, 2015a, 2015b).

Alibaba is taking initiatives to build an IoT ecosystem into online marketplaces to sell the IoT-enabled products, operating systems to run them, cloud services for manufacturers (Brennan, 2016). It was reported that over 10 million smart devices were sold during Alibaba's 2015 Singles' Day on November 11 (11.11) (Brennan, 2016). Manufacturers of smart home appliances can use Aliyun cloud services and Taobao's login systems and payment mechanisms and developer platforms (Hong, 2014). Alibaba's YunOS is used in smart products and home appliances such as cellphones, watches and TVs (Brennan, 2016). Alibaba has also planned to develop a smartphone app Ali Smart, which will function as a universal remote control for compatible devices of different manufacturers (Brennan, 2016).

Alibaba and Xiaomi have thus expanded from their respective bases in e-commerce and smartphones into the IoT. The IoT has a significant link to the companies' core business operations. The IoT has been integrated into their core business activities in such a way that it positively affects performance and competitiveness by enhancing the value delivery process. Political favors provided by the Chinese government to innovative companies has partly facilitated this process (Fig. 1).

As a further example, in July 2014, WeChat, which is a mobile text and voice messaging service developed by Tencent, launched an open hardware platform and a nationwide competition. It allowed hardware manufacturers to register accounts to promote their ideas and development, and launch their products. As of August 2015, over 2,400 hardware manufacturers had registered accounts on the platform, which focused on eight areas such as toys, routing, smart homes, television, healthcare and wearables (Huifeng, 2015).

3.3.2.3. Local skill and technological base

Prior research has suggested that local skill and technological base have played a major role in the diffusion of new and emerging technologies in China (Kshetri, 2016c). Chinese firms in the IoT sector have engaged in substantial R&D activities. China Mobile launched cloud research program in 2007. In 2014, it set up an R&D center in Suzhou, which is expected to have a team of 3000–4000 people (ofweek.com, 2014). Many Chinese universities have started offering IoT-related courses such as a bachelor's degree in IoT engineering (N° 6, 2013).

Nonetheless the lack of big data manpower with a high level strategic thinking capability has been a challenge. For instance, China has a rich endowment of technology human resources

thanks to an abundant supply of engineers. It, however, lacks experts at the executive level (Swanson, 2015).

3.3.2.4. Competition among state-owned telecom operators

In the past, state-owned enterprises (SOEs) were often reluctant to compete with each other. This mindset has changed in recent years. Indeed, the government is encouraging SOEs to compete with each other. In the mid-2015, Premier Li Keqiang urged the three leading mobile operators-- China Mobile, China Telecom and China Unicom-- to change their service plans to provide cheaper and faster mobile data services. One key area of competition for them has been the IoT (Chen, 2015). They are moving from a business-to-business focus and are offering more sophisticated consumer-oriented products and services via partnerships with automotive makers, wearables companies and other companies (Dinham, 2015).

To take an example, China Mobile IOT is a subsidiary of China Mobile, which focuses on wearable devices, smart homes, smart cars, and mobile payment. As of March 2016, China Mobile's IoT connections exceeded 60 million (cn.net, 2016). It has launched two IoT platforms, which target enterprises. During Consumer Electronics Show 2015, it announced the IoT business management platform and OneNet device cloud platform. The IoT business management platform combines statistical analysis and an API interface, which allows businesses to build hardware and software tools. It was stated that the platform was tested on networks comprising a real-time management scenario of about five million devices. The OneNet device cloud platform connects terminals and applications. China Mobile also displayed energy consumption monitoring platform (which uses data obtained via a wireless sensing device to dynamically adjust related equipment to promote optimal allocation of energy), smart community platform (which integrates residential properties, family security services, household services and location based service applications in order to create a secure environment), and communication module for enterprise users (chinatechnews.com, 2015). In March 2016, it was reported that in the energy-saving management projects of elevators, lighting and engine room in the industrial plants, energy consumption reduced by over 30% (cn.net, 2016).

3.3.2.5. Foreign companies in the IoT sector

The Chinese IoT sector has also benefitted by the various mechanisms associated with MNCs' technology globalization noted above (Archibugi & Michie, 1997; Iammarino & Michie, 1998). IBM's China Research Laboratory has led the Green Horizon effort. It is utilizing the expertise, knowledge, experience and resources of IBM's 12 global research labs and partnering with government, academia, and the private sector. In December 2015, IBM announced two more partnerships in China to deploy Green Horizon: (Baoding and Zhangjiakou) (Howard, 2015).

As noted above, Israel's AKOL is another high-profile foreign firm operating in China, which utilizes the IoT in the agricultural sector. In 2014, China's Yuanda Group bought the Israeli company AutoAgronom for US$20 million. Using smart irrigation with sensors and "tensiometer" to measure plants' needs at the roots, AutoAgronom's tools can increase the effectiveness of fertilization and irrigation. The tools can save 50% water and 70% fertilizer by

delivering only where they are needed. AutoAgronom reportedly can reduce water consumption per acre as much as 500 t (Kloosterman, 2014).

There are also instances of Chinese firms' collaboration with foreign firms in which the former engage in activities that involve higher value added and more complex technology and more sophisticated products. For instance, Aliyun's IoT platform is used by the Dutch electronics company, Philips to host its healthcare and smart home products such as a connected air purifier (Business Cloud News, 2014). Using Aliyun IoT platform, smart air purifier send alerts to consumers' mobile devices when the indoor air quality levels are not acceptable and filters need replacement. The platform also supports smart lighting systems, which can be controlled from mobile devices to improve energy efficiency.

Huawei has partnered with GE to develop solutions for the industrial IoT. Huawei solutions will use GE's Predix, industrial OS for building applications that connect to industrial assets, collect and analyze data, and report in real time. There are over 300 smart city initiatives in China (De Grasse, 2016).

3.3.3. Institutional factors

Formal and informal institutions affect the development of the IoT sector directly as well as indirectly via the effects on demand and supply side factors (Fig. 1). Some key features of Chinese formal and informal institutions from the standpoint of technology standardization have been examined in Kshetri et al. (2011). Their analysis indicated that China's formal institutions such as regulatory bodies (e.g., the CCP) and existing laws and rules are likely to favor domestic technologies and standards. A weak rule of law and the state's deep entrenchment in the economy leads to a high degree of favor for a domestic technologies over foreign ones. Concerning informal institutions, nationalism, patriotism and perception of national security and economic threats from foreign countries are found to be important triggers that lead to Chinese bias towards domestic technologies and the desire to achieve technological superiority (Kshetri et al., 2011; Kshetri, 2007; Xia, 2016a).

3.3.3.1. Formal institutions

Favorable policies to support domestic companies in electronics and high technology industries.

Regarding the state's role (Mazzucato, 2011), the success of China's major IoT players can be traced to favorable policies that were originally designed for helping domestic companies in electronics and high technology industries. For instance, Huawei, Tencent and ZTE have headquarters in Shenzhen, which is a purpose-built city to develop the Chinese electronics industry. The city was designated as China's first Special Economic Zones, which experienced virtually no interference from the Chinese government. It allowed Shenzhen to practice market capitalism "guided by the ideals of Chinese socialism" (Branwyn, 2015). China offers tax breaks and relaxed labor and environmental standards for these companies (Gilbert, 2015).

A European Commission report found that telecommunications equipment makers such as Huawei and ZTE benefit from significant Chinese government support. Such supports include huge credit lines from state-owned banks (Table 2; Dalton, 2011).

Just like China's other major technology sectors (Kshetri, 2016c), the IoT has been a high-priority policy issue. In 2014, the Chinese government invested US$1.6 billion in IoT (GSMA, 2015b). The country's plan is to invest more than US$600 billion by 2020 in M2M solutions and other fields in this sector (Silbert, 2014).

A comparative analysis of China's IoT policies with other major economies can provide key insights into the development of this new industry. For instance, since 2010, the European Commission started cooperating with Member States and third countries in the development and deployment of the IoT. In March 2015, the European Commission initiated the Alliance for Internet of Things Innovation (AIOTI) in order to work closely with all concerned stakeholders (Europa.eu, 2016). It is, however, argued that the IoT industry lacks a strong political support in Europe (Sterling, 2013). The Brookings Institution examined the strategic plans of each federal agency of the U.S. government. The results suggested that the U.S. federal government lacked policy initiatives to benefit from the IoT (Fedorschak, Desouza, & Dawson, 2015). IoT-related policies in the U.S. are mainly formulated at the city level (Sterling, 2013). On the other hand, the IoT has been the focus of significant policy interest of the Chinese government since at least as early as other major world economies started their initiatives in this area.

As noted above various IoT initiatives have been developed to drive economic modernization, which is related to the CCP's political ideology (Kshetri, 2007; Xia, 2012a, 2012b). For instance, in 2010, the Chinese government established a national IoT center in Shanghai and funded a R&D program in IoT in 2010 (Camhi, 2015). China's five-year plan (2011–2015) included the IoT as a national strategic priority and recognized it as a major direction of the new generation of IT innovation and development (chinadaily.com.cn, 2015). In his speech to the 2014 National People's Congress, Premier Li Keqiang proposed “Internet Plus” strategy to “integrate the mobile internet, cloud computing, big data and the internet of things with modern manufacturing, to encourage the healthy development of ecommerce” (Clover, 2015).

As of September 2015, China had formed four IoT industry centers in Yangtze River Delta, Pearl River Delta, Bohai Rim, and central and western China (english.gov.cn, 2015). It also established state-owned enterprise zones such as the Chengdu Internet of Things Technology Institute in Sichuan province (harborresearch.com, 2014).

The “Made in China 2025″ strategy aims to promote domestic integration of digital technologies and industrialization. The German and Chinese governments have established high-level dialogue and partnership to develop the Industrial Internet (fmprc.gov.cn, 2014).

In addition to the funding for filing patents, the Chinese government has also provided funding for RFID deployments (Claire, 2015). There are also local and national initiatives to support research on IoT and apps that are likely to lead to adaptation of the technology to local conditions and circumstances (itu.int, 2015).

3.3.3.1.1. Regulations that favor the IoT industry

China is also planning to implement sector-specific regulations, policies and incentives. For instance, the country's national healthcare policies are likely to drive the IoT market's growth. The National Plan for Medical and Healthcare Service System (2015–2020) has envisioned the deployment of the IoT and other emerging ICTs to improve medical services. An estimate suggested that China's healthcare IT solution market will reach about US$2.2 billion by 2019 (idc.com, 2015b).

Other key priority areas, as noted earlier, are food safety and environmental protection. The Chinese government is especially interested in applying the IoT to deal with food safety and healthcare in remote areas (harborresearch.com, 2014).

Local officials are also encouraging the adoption of the IoT through new building codes and other incentives (Friedman, 2014). These initiatives broadly reflect the national IoT policies. As of 2014, over 90% of China's provinces and municipalities had listed the IoT as “a pillar industry” (ckgsb.edu.cn, 2015). Smart cities are another area where China would rely on IoT applications to make infrastructure and services more interconnected and efficient (N° 6, 2013). In 2013, China released plans for building 103 smart cities, districts and town (Ran, 2013).

3.3.3.1.2. Political favors to innovative companies

It is argued that the rise of some of China's big companies can be attributed to government policies that have made difficult for foreign companies to enter (Einhorn, 2014). The industries in which these companies operate have been insulated from foreign competitors. Especially the success of China's biggest Internet giants-Baidu, Alibaba and Tencent (BAT) could be credited to China's web filters (the Great Firewall). Blocking of sites such as YouTube, Twitter and Google provided these companies with the space needed to grow (Chen, 2015). Global Times noted: Without the firewall “China would become the realm of Google China, Yahoo China and Facebook China” (Chen, 2015). Innovative Chinese companies receive political favors.

In exchange for political favors, China's Internet companies help the government achieve political control. They work with the CCP's propaganda apparatus to censor and filter user-generated contents (finance.yahoo.com, 2013). It is also a common practice among big Internet firms to seek for the government's input before launching a product or service. In this way, they involve the regulators in the product development process. It was reported that, when Sina was designing Weibo, it worked closely with the regulators (economist.com, 2011).

3.3.3.1.3. The government's commitment to transform troubled industries

Some of China's IoT players have been ranked among the world's most innovative companies (Table 2). These companies have been allowed to invest in industries outside their core businesses, which the Chinese government wants to transform. China's state banks, for instance, lacked the ability to adapt. The telecom sector is dominated by three state firms. The government believes that Computer networks are compromised by U.S. spying (WSJ, 2014). Major Internet companies, which are also IoT players, offer something new in these industries.

To take a non-IoT example, in 2014, the China Banking Regulatory Commission (CBRC) approved a pilot scheme, which allowed five private banks to operate (Xiang, 2014). In 2015 Alibaba's online bank, MYbank and Tencent-backed private lender, WeBank were launched. These and other big data companies are carrying out an increasing number of traditional banking functions. In 2013, Alipay launched a money-market fund despite objections from traditional banks. The Chinese government has provided special approval to these companies to operate in troubled industries. These players, however, mostly remain outside the regulated sector. For instance, Alibaba-owned AliFinance makes loans much bigger than its registered capital would allow in the regulated banking sector (Rabinovitch, 2013).

As a specific example of the IoT consider food safety, which has been a top priority of the Chinese government. Businesses are responding by developing products that monitor food safety. For instance, Baidu announced a plan to launch a pair of smart chopsticks that can detect contaminants in food (Higginbotham, 2014).

3.3.3.1.4. Low privacy- and security-related regulatory barriers

Some factors that have acted as barriers to the adoption of the IoT are less pronounced in China. Due to privacy and security concerns, Western countries are likely to experience regulatory barriers to the IoT's diffusion. For instance, the U.S. Federal Trade Commission's first workshop on IoT held in November 2013 focused on privacy and security (Sterling, 2013). As noted earlier, China is not concerned as much as the U.S. about the IoT's privacy and security issues.

Nonetheless, given recent media concerns about the use of IoT as a potential spying tool by government agencies, this technology raises genuine privacy concerns. For instance, in February 2016, the U.S. Director of National Intelligence, James Clapper reportedly said: “In the future, intelligence services might use the [IoT] for identification, surveillance, monitoring, location tracking, and targeting for recruitment, or to gain access to networks or user credentials” (WashingtonsBlog, 2016, para. 4).

Such concerns are even more serious when we consider the authoritarian nature of the Chinese government. In 2011, the Chinese government announced a plan to introduce an "information platform of real-time citizen movement". The stated goal of the plan was to tackle congestion by monitoring the flow of people. Human rights activists expressed concerns that the regime may use the information to suppress activists. For instance, cell phones of activists have already been allegedly tracked by security forces, which is used to locate activists and know whether others going there (theguardian.com, 2011). Compared to more democratic societies, civic societies hold positions of less power in the discourse in China.

3.3.3.1.5. Government agencies’ use of IoT

Public procurement is among the regulative forces that can facilitate the development of an industry related to a new technology (King et al., 1994; Montealegre, 1999). Public procurement practices that ask for leading edge products and services can facilitate an innovation's success (Dosi, 1982). In China, government agencies are key users of IoT products and services. For

instance, the Chinese government tracks police uniforms with RFID tags. Likewise, vehicles are tagged for toll collection (Claire, 2015).

3.3.3.2. Informal institutions

3.3.3.2.1. Consumers less concerned about privacy and security

Asian societies arguably have a lower degree of concern about privacy, which is one of the main factors behind the development of South Korea's New Songdo City (NSC), the world's first greenfield smart city (Kshetri, 2016d). An intriguing aspect of NSC is that most of the core technologies were developed in the U.S. (Kshetri, Alcantara, & Park, 2014). Anthony Townsend, a research director at the Institute for the Future noted that the technology was implemented in South Korea due to fewer social and regulatory obstacles. NSC makes an extensive use of RFID. For instance, using RFID, public recycling bins credit when a resident recycles a bottle (Regine, 2005).

In general, privacy concerns are less visible and pervasive in Asia (Rozek, 2007). Recent research has noted that the public's awareness of their right to privacy has increased in China (Kshetri, 2014). Despite this, however, understanding of privacy among Chinese consumers and the level of data privacy awareness is much less developed than in the West (Kshetri, 2014). China thus may have an institutional advantage compared to many other countries in the domains of the IoT. In China's case, an example is an algorithm developed by the U.S.-based ZestFinance, which reportedly uses “tens of thousands of data points” to assess potential borrower's ability to repay loans. China's JD.com was reported to be the first customer of ZestFinance (Kshetri, 2016c). In the context of the IoT, consider a study of the media agency Mindshare conducted in 19 economies to assess consumers’ attitudes towards connected devices. Only 20% of Chinese consumers were against sharing data with companies because they "find it creepy". The global average was 38% (Warc.com, 2016).

3.3.3.2.2. Low degree of trust in government agencies

Another key component of informal institutions in China concerns the level of trust in the government. The high demand for environmental sensors in China can also be considered to be a result of a low degree of trust in the government. Households are installing environmental sensors such as air quality and purifiers because they consider government's reported statistics on environmental pollution to be untrustworthy (Higginbotham, 2014).

4. Discussion and conclusion

Among developing countries, China arguably is the most successful country in achieving a rapid diffusion of telecommunications services (Harwit, 2008). Despite many constraints and setbacks associated with the government's policy measures, the Chinese telecommunications industry has grown rapidly (Wu, 2009). Just like other technology domains such as cloud computing (Kshetri, 2016c), China's IoT market is a result of a number of contradictory and conflicting forces. Factors related to demand, supply and institutions have interacted in a unique manner that has determined China's IoT trajectory. Table 3 compares China and the U.S. in terms of key

determinants of the IoT industry and market. Regarding the demand, it can be argued that China's trajectory associated with non-IoT technologies is less powerful (Table 3). Looking at the IoT-led technical progress, which can be defined in terms of a shift of the production possibilities curve, and/or increase in the number of producible goods (Dosi, 1982), compared to industrialized countries, the adoption of the IoT is likely to lead to more significant technical progress in China. For instance, a large proportion of the population lacks access to basic healthcare and safe food.

Table 3. A comparison of China and the U.S. in terms of key determinants of the IoT industry and market.

	China	**The U.S.**
Demand side factors	• Bigger market size but less mature than that of the U.S. • Less powerful non-IoT trajectory (current use of relatively primitive technologies in most areas)	• Smaller market size but more mature than China • More powerful non-IoT trajectory
Supply side factors	• More developed mobile payment platforms and e-commerce markets allow Chinese companies to develop IoT-based offerings. • High degree of innovative activities but questionable quality • Availability of technical manpower but lack of experts at the executive level	• Mobile payment platforms and e-commerce markets are less developed • High quality innovations of firms (e.g., Qualcomm as the leader in the IoT domain whereas ZTE ranked #13 (LexInnova, 2013)).
Institutions	• IoT as a high priority policy area • Low privacy- and security-related regulatory barriers • Consumers are less concerned about privacy • IoT may make censorship and surveillance more effective.	•Lacks a federal policy on the IoT (Fedorschak et al., 2015; Sterling, 2013). •High privacy- and security-related regulatory barriers •Consumers are more concerned about privacy issues associated with IoT

Factors such as the integration of sensors and RFID in diverse range of products and the continuous reduction of the costs of censors provide favorable conditions for the rapid growth of the IoT industry and market in China. Overall, the IoT is likely to produce a highly dramatic effect in developing countries such as China, which are currently using relatively primitive technologies in most areas. For instance, developing world-based farmers can directly leapfrog into ag3.0 from ag1.0. The Green Horizon and other examples suggest that the IoT has the potential to produce beneficial effects in various sectors of the Chinese economy. China thus has more incentives and opportunities to adopt the IoT.

Concerning supply side, a review of performance indicators related to innovative activities in IoT indicates that Chinese technology firms need to be evaluated in terms of the track record of breakthrough achievements. A study of the management consulting firm, McKinsey indicated

that Chinese companies that rely on customer-focused and efficiency-driven innovation such as household appliances perform relatively well. However, they are not yet global leaders in science-based industries (McKinsey Quarterly, 2015). Likewise, China arguably is three to five years behind the U.S. in software (chinainnovatin.com, 2014). Chinese firms thus may face barriers to achieve breakthrough IoT innovations.

In order to illustrate this point, let us go back to the point about IoT-related patent activities in China. As noted earlier, ZTE ranked #1 in terms of the number of IoT patents filed. The consulting firm, LexInnova, which focuses on patent research and analysis, identified Qualcomm as the leader in the IoT domain in terms of "high patent portfolio quality as well a good patent filing activity" (LexInnova, 2013, p. 3). Indeed, in terms of LexInnova's overall score, which considers factors such as claim broadness, citation, geo score (coverage across major markets) and tech score (coverage across multiple technology domains), ZTE ranked #13 (LexInnova, 2013).

Despite unproven quality, Chinese firms have developed and deployed a wide range of IoT applications in order to enhance operational efficiency and create business opportunities. Chinese technology companies can capitalize on a huge user base (Table 1) to develop new IoT-based offerings. For instance, Baidu reported that about 26 million people search for medical information on its website. Baidu uses the information to track disease, which can help hospitals to make vaccines or schedule personnel (news.xinhuanet.com, 2015) and to design platform such as Dulife discussed above.

Technologies and expertise provided by foreign multinationals such as AKOL, IBM and Philips have played crucial roles in China's deployment of IoT technologies in key activities such as environment and agriculture. This research highlights the complementary roles of local and foreign firms in the creation and deployment of IoT-related innovations in China. Industrial world-based organizations' resources and technological capabilities are key to the success of some of the IoT-related innovations generated and deployed in China. For instance, when AKOL was founded in 1978, the Internet did not exist in the way we know it today. In the pre-Internet era, AKOL's online databases and applications were used by farmers in Israel to improve productivity. The company is regarded as the main force behind the development and achievement in Israel's agricultural success. AKOL is re-engineering its ag-tech process and capitalizing on its experience to operate in the Chinese agricultural IoT market. Chinese technology firms such as Alibaba, ZTE, JD.com and Xiaomi, on the other hand, are generating a variety of IoT-related innovations and applications focusing on new areas.

Regarding formal institutions, the government's proactive policies and other interventions in order to create an appropriate IoT environment have played a key role in the evolution of the IoT. China currently is in a position to invest more than most other economies. Institutions-, demand- and supply-related factors provide favorable conditions for the creation and diffusion of IoT-related products and services. Nonetheless, innovation-friendly policy has not necessarily translated into high quality IoT innovations.

An observation on formal institutions is that China's strong state cuts both sides. While China's supports to the development of the IoT industry are encouraging, it may also use the technology

to pursue political goals. Cyber-control has been one of the principal motivations of the Chinese government. China is trying to monitor, control and censor the Internet. It is thus in the Chinese government's interest to develop IoT products to make censorship and surveillance more effective (Voigt, 2012).

In some cases, friendly informal institutions have been a key driving force in the adoption of IoT products. For instance, while some IoT products that track and monitor people are likely to face hostility and lack of support in the West, Chinese consumers are generally more indifferent towards such issues and activities. Nonetheless some changes may hinder the use of IoT. For instance, there has been an increased public awareness and activism regarding the handling of personal information by Chinese technology companies (Kshetri, 2016c). Misuse and abuse of personal data and information are reported to be key problems facing Chinese consumers who receive credits from big data companies. TMTpost cited a China Youth Daily poll, which showed that 75.9% of respondents believed there was abuse of consumer privacy (wantchinatimes.com, 2015). This means that while China has leapfrogged in some domains of the IoT, there are various obstacles that stand in their way.

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