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Science, technology and innovation ecosystem transformation toward society 5.0

Kayano Fukuda

Department of Industrial-Academic Collaboration, Japan Science and Technology Agency K's Goban-cho, 7 Gobancho Chiyoda-ku, Tokyo 102-0076, Japan

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ABSTRACT

Society 5.0 is the vision of a new human-centered society in the fifth stage launched by Japan. This paper explores a prospective model of science, technology and innovation (STI) activities in Society 5.0 from an ecosystem perspective. STI policy review and statistical analysis are conducted in comparison with Germany and the United States to describe the historical transformation of Japan's STI ecosystem. Major socio-economic risks on Japan's STI ecosystem can be classified as labor, capital and spatial risks. Shifting from a push-based STI ecosystem to a pull-based STI ecosystem and increasing the system resilience through value creation for society are essential to reduce three risks and to revitalize productivity and growth in Society 5.0.

1. Introduction

The Government of Japan has launched the vision of what it calls "super-smart society", or "Society 5.0" on April 2016 (CSTI, 2016). It is defined as a new society in the fifth stage which follows four earlier stages: the hunting society, the agrarian society, the industrial society and the information society. It aims to create a human-centered society in which products and services will be readily provided to satisfy various potential needs as well as to reduce economic and social gaps so that all the people live a comfortable and vigorous life.

The vision is based on the recognition of the current global trends. The pace of technological, economic and social change has been accelerating, and business and communities struggle to keep up with the speed. Fast progress of information and communications technology (ICT) in recent years has brought about an unprecedented explosion of digital data and the emergence and growth of cyberspace. Rapid globalization has expanded various economic and social activities beyond national borders, and also has been changing the process of creating new ideas for innovation. It is now recognized that the new ideas are generated through different sources and significantly contribute to competitive advantage.

In such the chaotic era of drastic change, Japan looks beyond Industry 4.0 toward Society 5.0, while paying particular attention to other countries' policies, including Germany's Industry 4.0 and the United States' Advanced Manufacturing Partnership. It strives to take the transformation beyond industry and to build a super-smart society in which new knowledge and values are continuously created to contribute to economic growth and social welfare.

This paper explores a prospective model of science, technology and innovation (STI) ecosystem in Society 5.0. The concept of an ecological approach chosen in this paper was introduced by Moore (1993) to describe business environments, and is widely adopted to describe STI environments (Council on Competitiveness, 2005; Adner, 2006; Fukuda and Watanabe, 2008; Carayannis and Campbell, 2009; Traitler et al., 2011; Zygiaris, 2013;Organisation for Economic Co-operation and Development, 2015). Better analysis of both the economic and social impacts of STI requires a deeper understanding of STI ecosystem which includes the interaction between the actors, their technologies and their business models, and the dynamics that structure this ecosystem (Organisation for Economic Co-operation and Development, 1997; Jackson, 2011). Historical changes in Japan's STI ecosystem is examined with a focus on productivity and growth in comparison with two leading countries, Germany and the United States, which take the lead in the new industrial revolution to discuss a transformation path for the future.

The rest of the paper is organized as follows. Section 2 reviews the brief history of the national STI policies in three countries; Japan, Germany and the United States. Section 3 assesses changes in Japan's STI ecosystem over the past two decades compared to the above two countries. Sections 4 describes the historical transformation of Japan's STI ecosystem in the post-World War II era. Section 5 then discusses an expected STI ecosystem for the future. Finally, Section 6 presents a conclusion.

E-mail address: kfukuda@jst.go.jp.

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2. Political background

In the late 1990s, when rapid development of ICT, including mobile phones and the internet, accelerated globalization of the world economy, innovation become more important for economic growth (European Commission, 2013). As interaction between various stakeholders have become more important for innovation and innovation systems, STI policy has been reformed in each country.

In the middle 2000s, The United States clearly declared the shift of the innovation concept from the linear model to systemic model in which innovation emerges from a complex ecosystem of relationships and interactions (Council on Competitiveness, 2005). Germany, as well as Japan, also implemented the national comprehensive policy founded on the systemic model.

All those countries perceive AI as a key technology for the future economic growth and social prosperity. While various policy measures are adopted in each country to strengthen technological advantage and develop the workforce, there is increased need for data governance. Japan proposes the creation of a framework for discussing global data governance among the G20 countries.

2.1. Japan

Japan's national STI policy is guided by the Science and Technology Basic Plan which has been compiled every five year since 1996, following the enactment of the Science and Technology Basic Law in 1995. The Basic Law's objective is to switch from catch-up growth to cutting-edge growth by promoting science and technology through development and implementation of well-integrated and well-planned policies (Government of Japan, 1995; NSF Tokyo Office, 1996).

The Basic Plan identifies important research fields to address social and economic challenges and the aspirations for systems reform relating to STI rather than prioritized research agenda on a detailed level (NSF Tokyo Office, 2003; MEXT, 2015). It is drawn up by the Council for Science, Technology and Innovation (CSTI) in coordination with related ministries. CSTI was launched in 2014 by the reorganization of the Council for Science and Technology Policy (CSTP) which was established with the January 2001 government reorganization in order to function as “a control tower to promote science and technology” in Japan.

The First Basic Plan for the period from 1996 to 2000 (Cabinet Office, 1996) was adopted by the Cabinet in June 1996. Several key provisions were intended to bring about long-term improvements in the national science and technology system. The most important of these was that the government was committed to invest 17 trillion yen over the five years of the plan ended on March 31, 2001, aiming to increase the government investment on research and development (R&D) to the same level as major European countries and the United States on the basis of gross domestic product (GDP).

The Second Plan for the five-year period from 2001 to 2005 (Cabinet Office, 2001) and Third Plan for the period from 2006 to 2010(Cabinet Office, 2006) sought to adopt a strategic approach to government research investments. As a principle means for implementing this objective, four mission-oriented research themes as principal priority areas for emphasis during its five-year time span, and four themes as secondary priority areas were identified.

The Fourth Basic Plan for the period from 2011 to 2015 (Cabinet Office, 2011) emphasized the need for Japan to push innovations in science and technology. It first announced the STI concept which aims to shift from discipline-based approach to a problem-oriented approach in order to address the real challenges such as the aging population, the high national debt and the devastating effects of the Great East Japan Earthquake of March 2011. CSTP was reorganized as CSTI to strengthen its role, and launched two new programs, the Strategic Innovation Promotion Program (SIP) and the Impulsing Paradigm Change through Disruptive Technologies Program (ImPACT), designed to improve cross-ministerial coordination and high-impact innovation.

The Fifth Basic Plan for the period from 2016 to 2020 (Cabinet Office, 2016a) envisages the creation of Society 5.0. This vision of the future is defined as a human-centered society in which products and services will be readily provided to satisfy various potential needs and also to reduce several gaps such as regional, generational, gender, linguistic ones so that all the people live a comfortable and vigorous life. It intends to tackle several economic and social challenges by going beyond just advanced use of ICT, artificial intelligence (AI) and robots towards the transformation of society.

The Artificial Intelligence Technology Strategy was released in March 2017 to promote inter-ministerial strategic research, development and implementation of AI as a key technology for creation of Society 5.0 (Strategic Council for AI Technology, 2017). One of five pillars of the strategy is ethics and regulation of AI development while the IT giants known as GAFA have been reported to collect huge amounts of customer data to improve their business as have the Chinese giants known as BAT (Lucas, 2017; Shigeta, 2019; Galloway, 2017) to provide them to the government. With increasing global awareness of importance of data sharing rules, the government called for launching to the work to create a global rule, and released the Social Principles of Human-centric AI in March 2019 (CSTI, 2019).

2.2. Germany

STI policy in Germany is governed by the federal government and the 16 federal states (OECD, 2016a). After a long period of stagnation coincident with the German reunification after the fall of the Berlin Wall in 1989, Germany has revitalized its economy and competitiveness since the early 2000s (Bastasin, 2013).

The federal policy has been guided by the High-Tech Strategy since 2006 to bring key STI stakeholders together in a common purpose of developing new technologies. Most programs within the framework promote partnership between different project partners. Some new instruments have been introduced to strengthen cooperation between enterprises, universities and research institutions.

The High-Tech Strategy in the first phase (2006–2009) was the first comprehensive national strategy for all its ministries to puts STI policy front and center in government activities. While it focused on key technologies to create lead markets, the High-Tech Strategy 2020in the second phase (2010–2013) intended to overcome major social challenges through technological innovation (EFI - Commission of Experts for Research and Innovation, 2015).

The new framework in the third phase started in 2014, the High-Tech Strategy 2020Action Plan, identified 10 Future Projects as the critical STI policy objectives to be addressed. One of them is the “Industrie 4.0” which refers to the technological evolution from embedded system to cyber-physical system. It represents the digital transformation of manufacturing, leveraging the Internet of Things and related technologies to realize connected factories, smart decentralized manufacturing, self-optimizing systems and the digital supply chain in the cyber-physical environment of the fourth industrial revolution.

The latest High-Tech Strategy 2025released in September 2018 set out twelve missions, and one of them is “Rolling out AI” which aims to make Germany one of the world's leading center for research, development and application of AI. (Bundesministerium für Bildung und Forschung (BMBF), 2018). Following the release, the Federal Government's Artificial Intelligence strategy, dubbed “AI Made in Germany”, was announced in November 2018 (The Federal Government, 2018) which put its focus on the AI technologies as an essential driver promoting smart industrial process in manufacturing and other sector and thus taking “Industries 4.0” to the next level.

2.3. United States

The United States has reshaped its STI policy in the beginning of the twenty-first century, facing serious competitive challenges posed by the globalization (Thota and Munir, 2011). Two reports entitled “Innovate America” (Council on Competitiveness, 2005) and “Rising Above the Gathering Storm” (National Academy of SciencesNational Academy of Engineering& Institute of Medicine, 2007) played a crucial role to develop the America COMPETES Act enacted by the Bush Administration in 2007. The Act focuses on three primary areas of importance to maintaining and improving the national innovation capacity: i) increasing research investment, ii) strengthening educational opportunities in science, technology, engineering and mathematics from elementary through graduate school, and iii) developing an innovation infrastructure.

The Obama Administration laid out the Strategy for American Innovation which was first issued in 2009, and updated in 2011 and 2015 (NEC and OSTP, 2011; 2015). The Strategy sought to ensure that our economic growth is sustained and to bring greater income, higher quality jobs, and improved health and quality of life to all the nation's citizens.

One of the federal government's major priorities was to transform and reinvigorate advanced manufacturing in the United States after a steep decline in its manufacturing sector in the 2000s (OECD, 2017a). In July 2011, President Obama launched the Advanced Manufacturing Partnership (AMP) which aims to bring academia, industry and government together and catalyze development and investment in the emerging technologies, such as additive manufacturing/3D Printing technologies, which will create high quality manufacturing jobs and enhance our global competitiveness. Subsequently, the National Network for Manufacturing Innovation (NNMI) program was proposed by the Obama Administration proposed in January 2013 (Exective Office of President, 2014).

The NNMI is modeled after the German Fraunhofer Institutes, and is composed of competitively selected, independently managed manufacturing innovation institutes (Sargent, 2014; OECD, 2017a). The institutes serve as regional hubs which provide shared facilities to local start-ups and small manufacturers to help them scale up new technologies, accelerate technology transfer to the marketplace and facilitate the adoption of innovative developments across supply chains. They also act as ‘teaching factories’ to build workforce skills at multiple levels and to strengthen business capabilities in large and small companies. The NNMI has 14 manufacturing innovation institutes at the beginning of 2017.

The Trump administration unveiled a National Strategic Plan on Advanced Manufacturing in October 2018 which focuses on developing new manufacturing technologies, strengthening manufacturing workforce, and expanding the capabilities of the domestic manufacturing supply chain (Office of Science and Technology Policy, 2018). In February 2019, the American AI Initiative was announced to boost the US AI industry by some measures including promoting sustained R&D investment, developing the American workforce for AI. (The White House, 2019).

3. Changes in science, technology and innovation ecosystem

This section analyzes changes in Japan's STI ecosystem over the two decades using statistical data compared to Germany and the United States.

3.1. Statistical data analysis

The focus of the analysis is put on productivity and growth since innovation has been a major force in economic growth which rises the level and growth rate of productivity in the long run (Ahn, 2002). The data of growth and productivity was extracted from the Organization for Economic Co-operation and Development (OECD) database (OECD, 2017b) which meet the international standards for economy-wide and industry-level productivity measurement established by the OECD (Jorgenson, 2011).

The following Cobb-Douglas production function is introduced to compute marginal productivity of technology:

$$Y = Z^{\eta}R^{\alpha}e^{\mu t} \tag{1}$$

where Y is total production, Z is production factors except for stock of technological knowledge, R is stock of technological knowledge, μ is rate of technical progress, and α and η are the elasticities of production factors. Taking logarithm and differentiating totally both sides of equation yields:

$$\dot{Y}/Y = \mu + \eta\cdot(\dot{Z}/Z) + \alpha\cdot(\dot{R}/R) \tag{2}$$

Equation (2) leads to MFP growth rate (MFPG) which is represented as equation (3):

$$\mathrm{MFPG} = \dot{Y}/Y - \eta\cdot(\dot{Z}/Z) = \mu + \alpha\cdot(\dot{R}/R) \tag{3}$$

Here, the elasticity α is represented as follows:

$$\alpha = \partial Y/\partial R\cdot R/Y \tag{4}$$

Thus equation (5) is obtained:

$$\mathrm{MFPG} = \mu + \rho\cdot(\dot{R}/Y) \approx \rho\cdot(E/Y) \tag{5}$$

where ρ is marginal productivity of technology, and E is expenditure on R&D since the change of stock of technological knowledge equals expenditure on R&D on the assumption that stock of technological knowledge is not depreciated.

3.2. Key economic changes

3.2.1. GDP per capita

The compound average growth rate of GDP per capita growth in Germany had declined from the late 1980s to the early 2000s during the rapid globalization initiated by ICT development, as shown in Fig. 1. The growth rate in Japan also declined from the late 1980s to the late 2000s, the five-year period longer than Germany. It recorded a sharp decrease from the late 1980s to the early 1990s, and a negative rate in the late 2000s after the slight recovery from the late 1990s to the early 2000s. Contrary to these two countries, The US recorded the highest rate of 3.1% in the late 1990s followed by the 2.7% in the late 1980s. After the depression in the late 2000s, every growth rate in three countries changed to increase in the early 2010s while big data analytics emerged as a key issue for leading innovation.

3.2.2. Productivity

Total hours worked in Germany and Japan caused the stagnated productivity growth in the 1990s and the 2000s (Fig. 1.) as the innovation process became more interactive. It dropped to negative rates from the early 1990s to the early 2000s in Germany, from the early 1990s and to the late 2000s in Japan as well as over the 2000s in the United States.

The decline of multifactor productivity (MFP) is another factor in stagnation of productivity growth in two countries. Especially in Japan, both steep falls from the late 1980s to the 1990s and from the early 2000s to the late 2000s have halved the growth rate on a percentage point basis. Such a clear relationship is not apparent in the United States while it more than doubled over the two decades from the late 1980s to the early 2000s followed by shrinking by almost two-third in the latest two decades.

3.2.3. R&D investment

Each country strengthened its investment on R&D in the recent decade (Fig. 2.). Japan steadily grew the expenditure on R&D from the late 1980s to the late 2000s. Germany and the United States has increased their expenditure since the early 2000s as the innovation process model made the shift from linear to open.

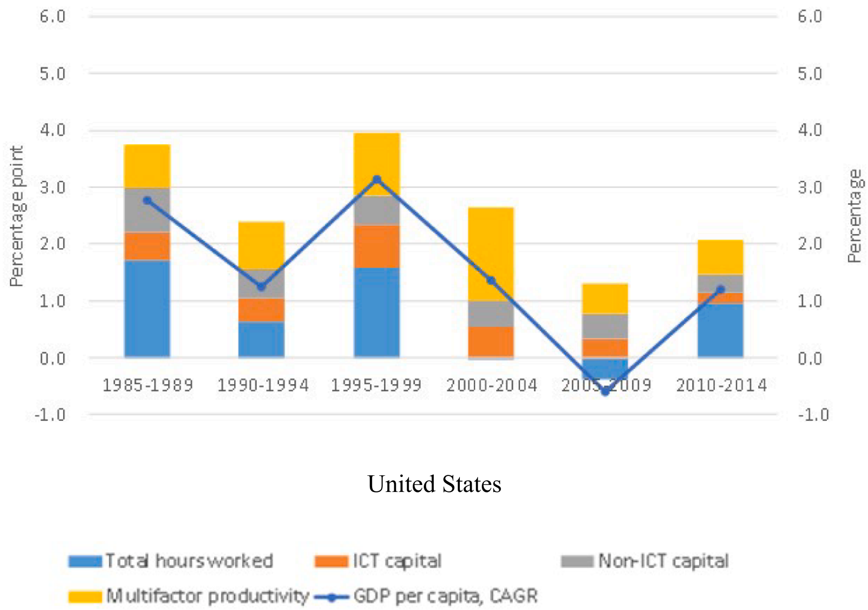

Fig. 1. Contribution of four factors to GDP growth (percentage point, 5-year average) and compound average growth rate of GDP per capita (percentage, 5-year period) in three countries, 1985–2014.

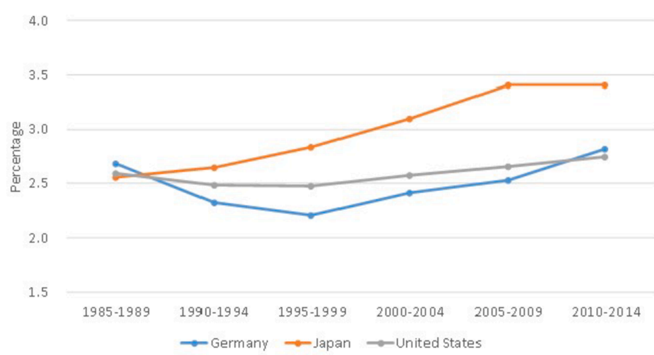

Fig. 2. Gross domestic expenditure on research and development (percentage of GDP, 5-year average) in three countries, 1985–2014.

3.2.4. *Marginal productivity of technology*

Germany continued to decrease its marginal productivity of technology from the early 1990s to the late 2000s (Fig. 3.). Japan also dropped its marginal productivity sharply in the late 1980s, and it turned to negative in the late 2000s. Contrary to these two countries, the United States increased its marginal productivity from the late 1980s to the early 2000s while the innovation process became more globally collaborative by means of rapid development of ICT. It stagnated in the early 2010s whereas two other countries increased as AI and other technologies were emerged.

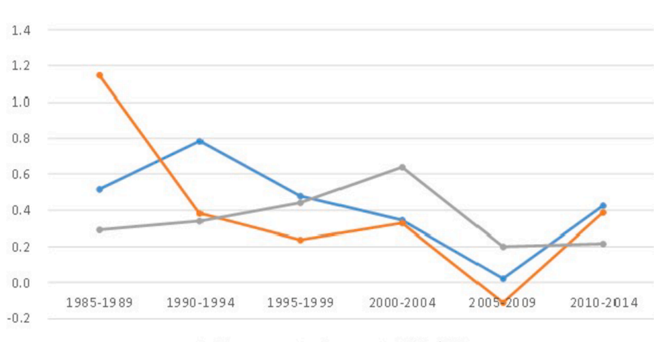

Fig. 3. Marginal productivity of technology (5-year average) in three countries, 1985–2014.

3.2.5. *Contribution to GDP by economic sectors*

Information and communication increased its share in the early 2000s in each country (Fig. 4.) amid rapid technological advances in this sector. Manufacturing maintained its contribution of almost 20% of GDP in Germany and Japan, and of 12% in the United States in which service activities made a large contribution of around 36–38%. Service activities grew in Japan by 2.5 percentage point over the two decades while it slightly decreased in Germany and the United States.

3.2.6. *Trade in services*

Three countries have grown service exports and imports over the two decades (Fig. 5.) while ICT transforms the process of value creation where two-way communication between customer and producer enhances user participating in product and value co-creation. Germany recorded the largest growth and more than tripled the exports to diminish its trade deficit. Japan also decreased its deficit while its exports was doubled during the same period. The United States maintained and increased its trade surplus over the period from the late 1980s to the early 2010s.

3.2.7. *Gross fixed capital formation*

The share of gross fixed capital formation in GDP in Germany slightly declined over the past two decades (Fig. 6.) as products and services began available through digital channels. Japan apparently dropped the share from the early 1990s to the early 2010s. The share in the United States also fell by two percentage point from the early 2000s to the early 2010s. On the other hand, intellectual property product grew its share in GDP in each country over the past three decades.

3.2.8. *Household final consumption expenditure*

The share of household final consumption expenditure in the final consumption expenditure in Japan continued to fall from the early 1990s to the early 2010s as shown in Fig. 7. Germany also decreased the share by two percentage point over the past two decades along with business model transformation to deliver personalized customer experiences and maintain customer engagement. Contrary to these two

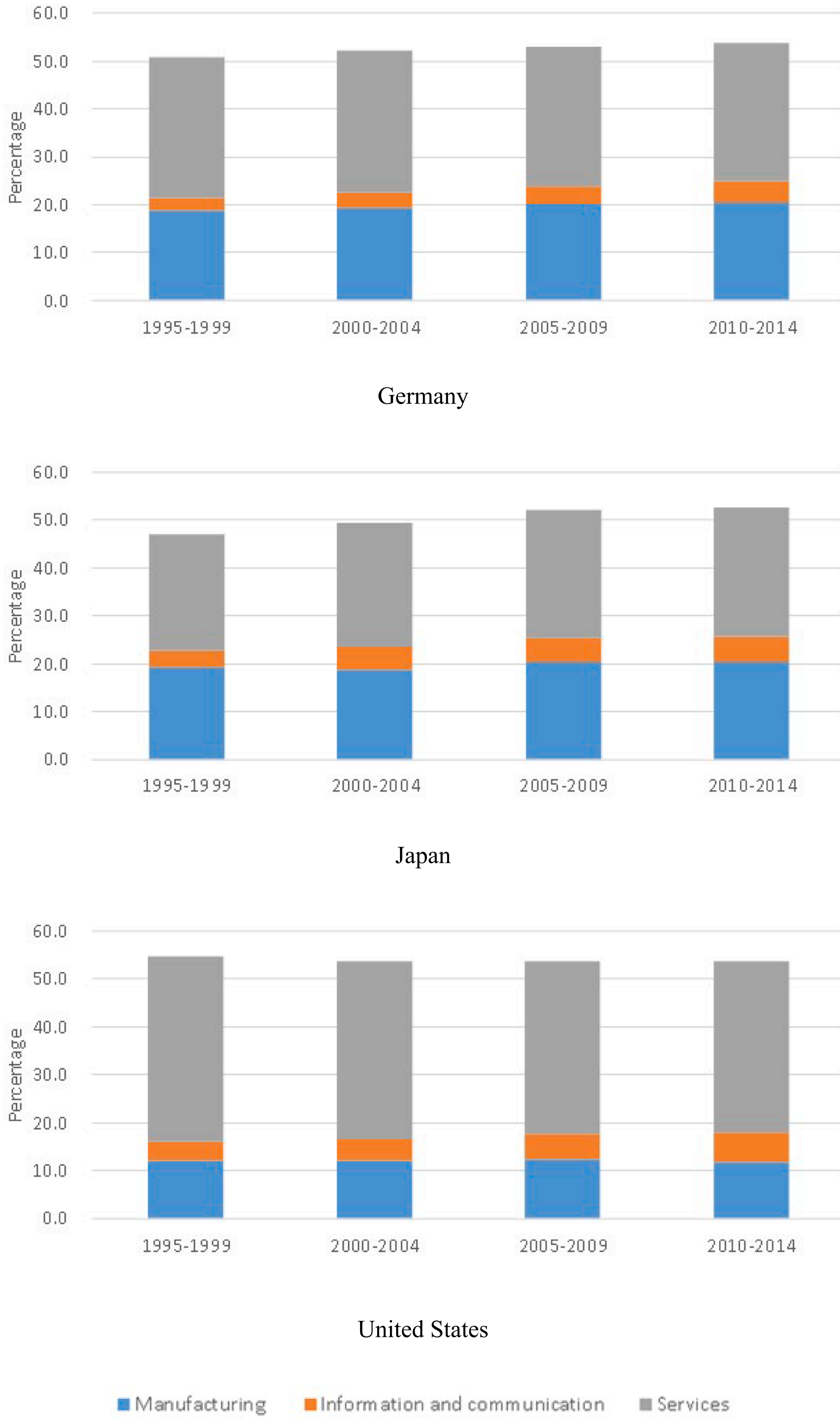

Fig. 4. Contribution of three selected sectors to GDP (percentage of GDP, 5-year average) in three countries, 1995–2014.

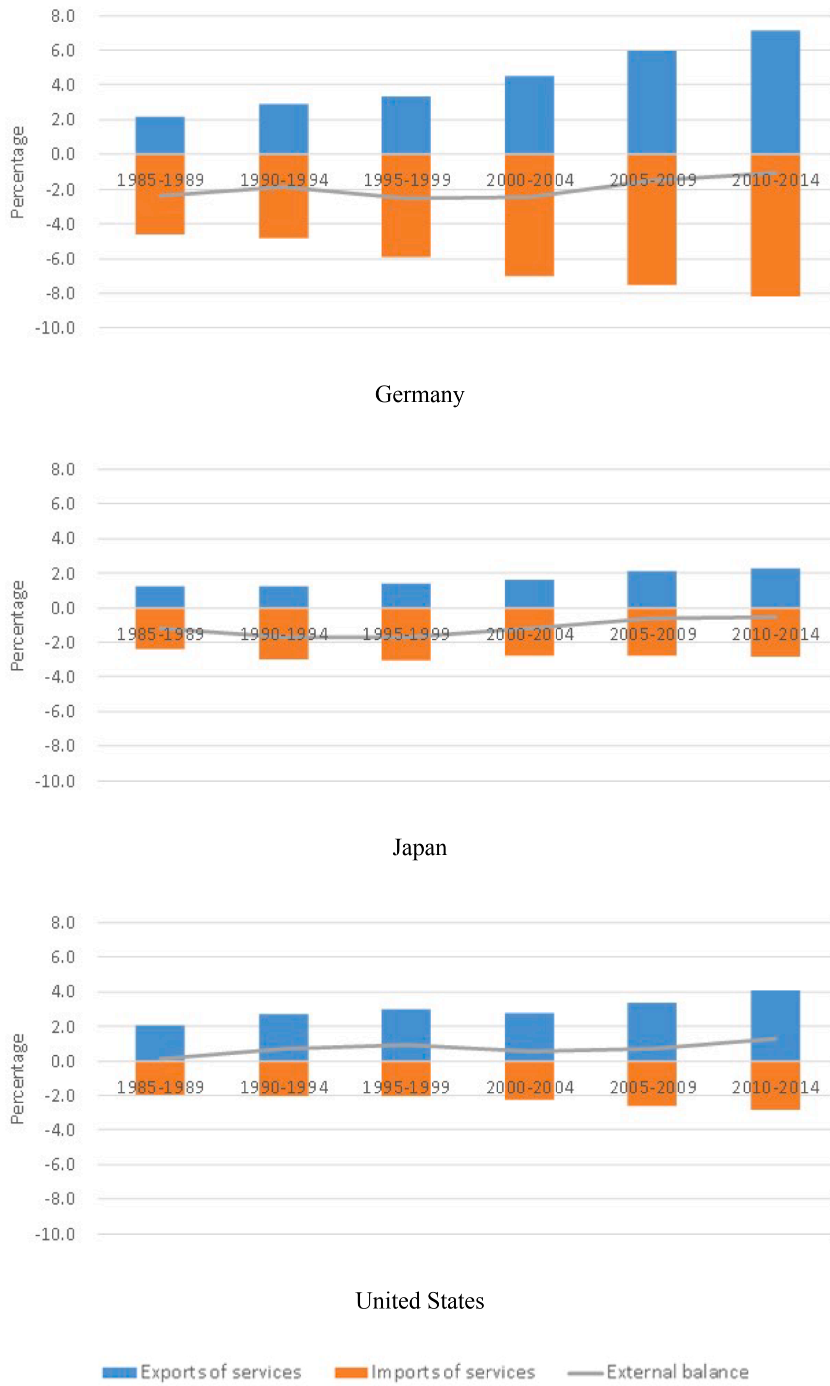

Fig. 5. Exports and imports of services and its external balance (percentage of GDP, 5-year average) in three countries, 1985–2014.

countries, the United States increased the share steadily from the early 1990s to the early 2010s.

4. Japan's science, technology and innovation ecosystem transformation

The above observations indicate the historical transformation of STI ecosystem in Japan as follows.

4.1. Post-world war II period by the late 1980s

Japan tried hard to catch up with other industrialized countries by importing advanced technologies after the end of World War II. These efforts drove the high economic growth from the mid-1950s to the early 1970s and the subsequent stable economic growth from the early 1970s to the early 1980s. After the three-decade long “economic miracle”, Japan experienced its “bubble economy” in which stock and estate prices soared to great heights in the late 1980s (Ohno, 2006). With the bubble burst in the early 1990s, however, the Japanese economy plunged into a long recession.

4.2. The 1990s

Japan sharply decreased MPF growth over the 1990s whereas the United States increased its growth from the early 1990s to the early 2000s. A key factor of this contrast is ICT investment (Fukao et al.,

Fig. 6. Gross fixed capital formation (percentage of GDP, 5-year average) in three countries.

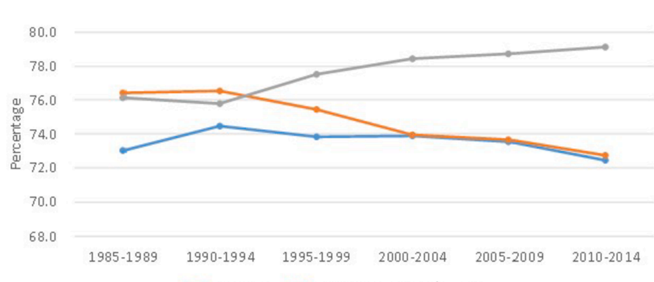

Fig. 7. Share of Household sector in final consumption expenditure (percentage, 5-year average) in three countries, 1985–2014.

2006; Colecchia and Schreyer, 2001). The US strong investment in ICT capital made a great contributed to large capital accumulation in the business sector and led to the positive effects on economic growth. On the other hand, Japan suffered low contribution of ICT investment to economic growth while it increased R&D investment under the First Science and Technology Basic Plan. Germany also reaped few benefits from the positive effects of ICT investment on economic growth and declined MFP growth in the late 1990s.

The low levels of ICT investment caused lower contribution of labor input to economic growth in the 1990s and the 2000s. Japanese firms were reluctant to introduce ICT for saving unskilled labor input because of the high job security in Japan. They also have provided limited training opportunities for temporary or part-time workers while the percentage of these workers in total workers has been increased (Fukao et al., 2014).

In addition, rapid ICT development brought radical changes to the production and delivery of goods and services and also supported the emergence of a globalized market (European Commission, 2016). Businesses are significantly expanded through computer-based logistics systems that help firms manage complex globalized supply-chains, or through software that facilitates the organization of business activities in dispersed locations. These new globalized production chains enable enterprises to specialize in what they are good at and contract out what they are not good at.

These changes have enhanced the adoption of modular designs in many industries in the United States (Baldwin and Clark, 1997; Sturgeon, 2002). Some major firms, including Hewlett Packard and IBM, led the way to break up of vertically integrated corporate structures and to aggregate cast-off activities in suppliers. Contrary to such efforts by the US firms, Japanese firms struggled to adapt to the new business environment due to their established corporate structures. The tight linkages between lead firms and suppliers have been identified as a source of competitive advantage for Japanese firms (Dyer, 1996; 21PPI, 2015) whereas suppliers are able to work with multiple firms because of the high degree of product modularity in the new business environment. Such a mismatch resulted in the dramatic economic slowdown over the 1990s.

4.3. The 2000s

Rising global trade volumes associated with ICT development boosted growth in developing countries in the late 1990s and accelerated its growth rates in the 2000s (Cubeddu et al., 2014). Their rapid growth threatened competitive advantages of developed countries, and also rose severe global challenges such as climate change, energy and food security risks, and water crises. These emerging challenges drove a paradigm shift in national strategies for STI in major developed countries over the 2000s. As reviewed above, Germany launched the High-Tech Strategy in 2006, and the United States enacted the America COMPETES Act in 2007.

Japan also strengthened the approach to problem solving which encourages to open up the innovation process (Fukuda and Watanabe, 2008). This approach represents the concept of open innovation which has taken off in the early 2000s (Chesbrough, 2003; Van Der Zee et al., 2015). The open innovation model is dynamic and non-linear in its approach, and seeks to leverage both external and internal sources for innovative opportunities through multiple channels, including alliances, collaborations, spin-offs and outsourcings (Docherty, 2006).

Some Japanese lead firms made efforts to overcome the “Not Invented Here” syndrome in the early 2000s (21PPI, 2015). Toray Industries, Inc. Launched Project New TORAY21 (Project NT21) in April 2002 to improve the corporate governance, just after falling into the red in the March 2002 settlement for the first time since its foundation. This project intended to strengthen the corporate structure and to recover the lost revenue. On the agenda included promoting R&D innovation which encouraged leveraging external resources. In the same year, Kyoto University and five lead companies have established a comprehensive and integrative industry-academia partnership for innovation. This partnership aimed to create new businesses through the research and development of next-generation innovative technologies in organic electronic materials and devices.

The government also introduced some measures to catalyze collaboration between academia and industry since the role of research universities have received a lot of attention from many research-intensive firms as sources of new scientific and technological knowledge and of the skilled technical personnel (Feller, 2009). National research institutes and national universities were incorporated in 2001 and 2004, and launched their intellectual property offices to enhance collaborative activities with industry.

These efforts contributed to recovery of MFP growth in the early 2000s. However, the growth turned into negative in the late 2000s while Germany and the United States sustained the positive rates despite the severe economic conditions which led to the bankruptcy of Lehman Brothers in 2008 and its consequences. Japan had benefited little from the positive effects of ICT investment on economic growth since the 1990s as mentioned above, and this experience led to the continuous decline in gross fixed capital formation over the 2000s.

Furthermore, Japan struggled with the long-term fall in household consumption and shift in demand from goods and services. These trends represent a new paradigm shift in production from “making things” to “making stories”, or from “monozukuri” to “kotozukuri” in Japanese (Keizai Doyukai, 2013; Ministry of Internal Affairs and Communications, 2013). Japanese firms provided value-added products with high standards and quality achieved through their manufacturing excellence from manufacturers’ perspective. They utilized ICT to avoid product commoditization and to make their products more attractive than others over the 1990s. However, a relationship between consumer and producer was changed as the usage and adaptation of the Internet by businesses and consumers extremely grew over the 2000s. Any consumer became a content creator in collaboration with other consumers or producers while they had been a viewer of content provided by producers (Cormode and Krishnamurthy, 2008). This change required producers to seek new models of added-value creation for customers. Komatsu Ltd., a lead manufacturer of construction and mining machinery in Japan, created a business model to provide machine data through its remote monitoring system called KOMTRAX, and to proactively schedule and perform maintenance at times that work best for an owner or a maintenance engineer. Despite such advanced efforts, many Japanese firms strived to establish relationships with customers.

4.4. The 2010s

The STI value chain has continued to expand in the 2010s, and offering an integrated solution for customers by bundling the products and services is the key to success in innovation. The shift from product-focused to customer-centric approach accelerates as ICT and its applications permit a precise segmentation, profiling and targeting of customers (Gurău et al., 2003; Priem, 2007; Keizai Doyukai, 2013; MIC, 2013). Martinez et al. (2010) identify the five pillars which form a supporting foundation necessary for manufacturing organizations to become product-service providers: embedded product-service culture, delivery of integrated offering, internal processes and capabilities, strategic alignment and supplier relationships. Japanese lead manufacturing firms take advantage of their vertically integrated structures and long-term trust relationships with their suppliers to strengthen their performance. Their recovery leads to improvement of Japanese economic performance in the early 2010s subsequent to two lost decades.

The government put Internet of Things (IoT), big data, robotics, and AI at the heart of its revitalizing strategy. Collaborative activities across public and private sectors are encouraged to integrate functionality derived from these technologies into existing manufacturing products. However, the technologies carry some risk and present policy challenges along several dimensions including jobs, safety and regulatory rules. To realize the human-centered Society 5.0, the government proposed setting up international guidelines on AI R&D, and continues to lead international discussions about frameworks for the development and utilization of the cutting-edge technologies to protect consumers.

5. Science, technology and innovation ecosystem for the future

5.1. Rise of data-driven innovation

Two lost decades eroded Japan's confidence and competitiveness (Desvaux et al., 2015). In addition to accelerate the pace of economic recovery, Japan is eager to prepare to Society 5.0 which is coming through data-driven innovation. The generation and use of huge volumes of data are leading from the confluence of several trends, including the increasing migration of economic and social activities to the Internet and the decline in the cost of data collection, storage and processing. These large data sets, or "big data", are becoming a core asset in STI ecosystem which enhances productivity, fosters new industries and create economic competitive advantages and social welfare benefits (Organisation for Economic Co-operation and Development, 2015; Arai, 2016).

Data-driven innovation begins to transform all industrial sectors (Organisation for Economic Co-operation and Development, 2015; Ministry of EconomyTrade and Industry, 2017; MEXT, 2016). In manufacturing, firms are increasingly using sensors mounted on production machines and delivered products to collect and process data on the machines' and products' operation. One of the enablers is the IoT where sensor equipped machines with connectivity transmit data to other machines and computer systems, automating many processes and also gathering vast quantities of new types of data. Benefits of data-driven innovation in healthcare include new insights into the natural history of diseases and their diagnosis, prevention and treatment, and greater opportunity for further development of personalized therapies. Health data can be used to improve patient care, to understand the burden of illness and quality of life of the population, and to manage and evaluate public health interventions, including for health promotion and prevention. In transportation, matching demand and supply in real time allows shaving peak demand by redistributing it in space, reducing road congestion. This can save people time and money and reduce pollution and emissions in cities. (Organisation for Economic Co-operation and Development, 2016b).

Data-driven innovation is described as a sequence of phases from data collection and generation to data analytics and decision making (Organisation for Economic Co-operation and Development, 2015). This process is not linear but can be seen as a cycle which involves feedback loops at several phases of the value creation process. The heart of the process lies data, and online platforms play an increasingly central role. Online platforms cover a wide range of activities such as online marketplaces, communications services, internet search services, and social media and creative content outlets. They facilitate interactions between producers and consumers to create the community, to collect and even generate data through these interactions, and to maximize the total values for their members (Martens, 2016; Van Alstyne et al., 2016). Such online platforms reshape markets and industries into interconnected business environment so that industry boundaries will dramatically blur (Ministry of EconomyTrade and Industry, 2017; MEXT, 2016).

Data-driven innovation may induce structural change in labor markets since it enables the automation of an increasing number of cognitive and manual tasks (Organisation for Economic Co-operation and Development, 2015; Ministry of EconomyTrade and Industry, 2017; Takigawa, 2017). The rapid progress in artificial intelligence enables machines to carry out a broad range of job, and begins to hollow out of mid-level skills jobs. This trend raises job polarization in which middle-skill jobs are declining and the workforce is divided into two groups: highly paid, skilled workers and low-paid, unskilled workers. Furthermore, rising life expectancy makes most people more conscious of their lengthening working lives while data-driven innovation is changing the way of working (Gratton and Scott, 2016, 2017). In response to the pressures resulting from longer working lives, individuals are starting to explore different career structures. Working longer secures a reasonable retirement income, but at the same time, requires the individual's intangible assets which includes skills and knowledge, strong mental and physical health, and diverse networks which support personal change and transitions.

5.2. *Socio-economic risks in Japan's science, technology and innovation ecosystem*

Data-driven innovation comes with major economic and social challenges which most countries will face. Japan needs mitigate the following three major socio-economic risks to maximize the benefits of data-driven innovation and revitalize its productivity and growth toward Society 5.0.

5.2.1. *Labor risks*

According to the United Nations (United Nations Statistics Division, 2017), the population of Japan had shrunk by 0.7 million people in five years from 2010 to 2015, and is expected to decline by 22.1 million people to 2050 (Fig. 8.). Its population of working-age from 15 to 64 has been in decline since the early 2000s. It had shrunk by 4.2 million people in five years from 2010 to 2015, and is estimated to plunge by almost one-third to 2050. The working-age population of Germany is expected to fall down slower than Japan from 2015 to 2050 whereas the United States will continue to increase by 22.3 million over the same period. It is also a serious agenda for Japan to accelerate progress towards gender equality. On the report of the Global Gender Gap Index (World Economic Forum, 2015; 2016), Japan has maintained much lower positions than Germany and the United States in both rankings by the global index and the category of economic participation and opportunity as shown in Fig. 9. With its workforce shrinking and wide gender gap, Japan has to rely on productivity as its primary catalyst for growth.

5.2.2. *Capital risks*

Significantly less risk money available to entrepreneurs is one of the problems to be addressed in risk-averse Japan. The venture capital represents a very small percentage of GDP in Japan as well as Germany and other many countries (Organisation for Economic Co-operation and Development, 2016c). The United States is the exception in which the venture capital industry is more mature and represents 0.33% of GDP in 2015 (Fig. 10.). Its amount is very huge and accounted for 85% of total venture capital investments in the OECD countries in 2015. The ratio of later stage venture capital is much smaller in Japan than in two other countries. Japanese venture capital is most invested in startups at the early stage in which the idea has been transformed into a product and is being produced and sold, but is less invested in startups at the seed stage in which they seek for funding for the ideas or the expansion and pre-IPO (initial public offering) stages in which they try to expand the market share or go public (VEC, 2016). Another problem is huge corporate savings (Cabinet Office, 2016b). The savings of Japanese corporation has increased since the early 2000s and has reached 20 percent of GDP in the early 2010s (Fig. 11.). This ratio is higher than around 13.0% in Germany and around 10.0% in the United States.

5.2.3. *Spatial risks*

It is estimated that the working age population aged 15 to 64 will fall down in each region as shown in Fig. 12 (IPSS, 2013). The rate of municipalities which more than half the population are not of working-age will increase in all the regions. Especially in Hokkaido and Tohoku which are located in the northern part of Japan, the rate will exceed 40% in 2025 and 70% in 2040. Such demographic projections indicate that economic activities in Japan will be distributed more unevenly and the regional divide will be widened in the next few decades.

5.3. *Managing socio-economic risks*

The following three measures are required to effectively tackle the above socio-economic risks.

5.3.1. *Deploying next generation technologies*

Deploying next generation technologies contributes to improving labor productivity. The survey was conducted by the Cabinet Office to clarify impacts of technology implementation on labor productivity in Japanese firms, focusing on five technologies consisting of IoT or big data, AI, robots, 3D printing, and cloud computing (Cabinet Office,

Fig. 8. Population trends in three countries by age (millions), 1980–2050 (five year intervals). Data from United Nations Statistics Division (2017).

Fig. 9. Trends in three countries' rankings in Global Gender Gap Index (global index, category of economic participation and opportunity), 2006–2016. Data from World Economic Forum (2015, 2016).

2017). In the survey, an ordinary least squares (OLS) regression analysis was conducted on the respondent firms (n = 1466) to determine the impact of technology implementation on productivity increase (Table 1). The dependent variable is productivity increase which is defined as a change rate of nominal value added per regular employee from the fiscal year 2012 to the fiscal year 2015. The explanatory

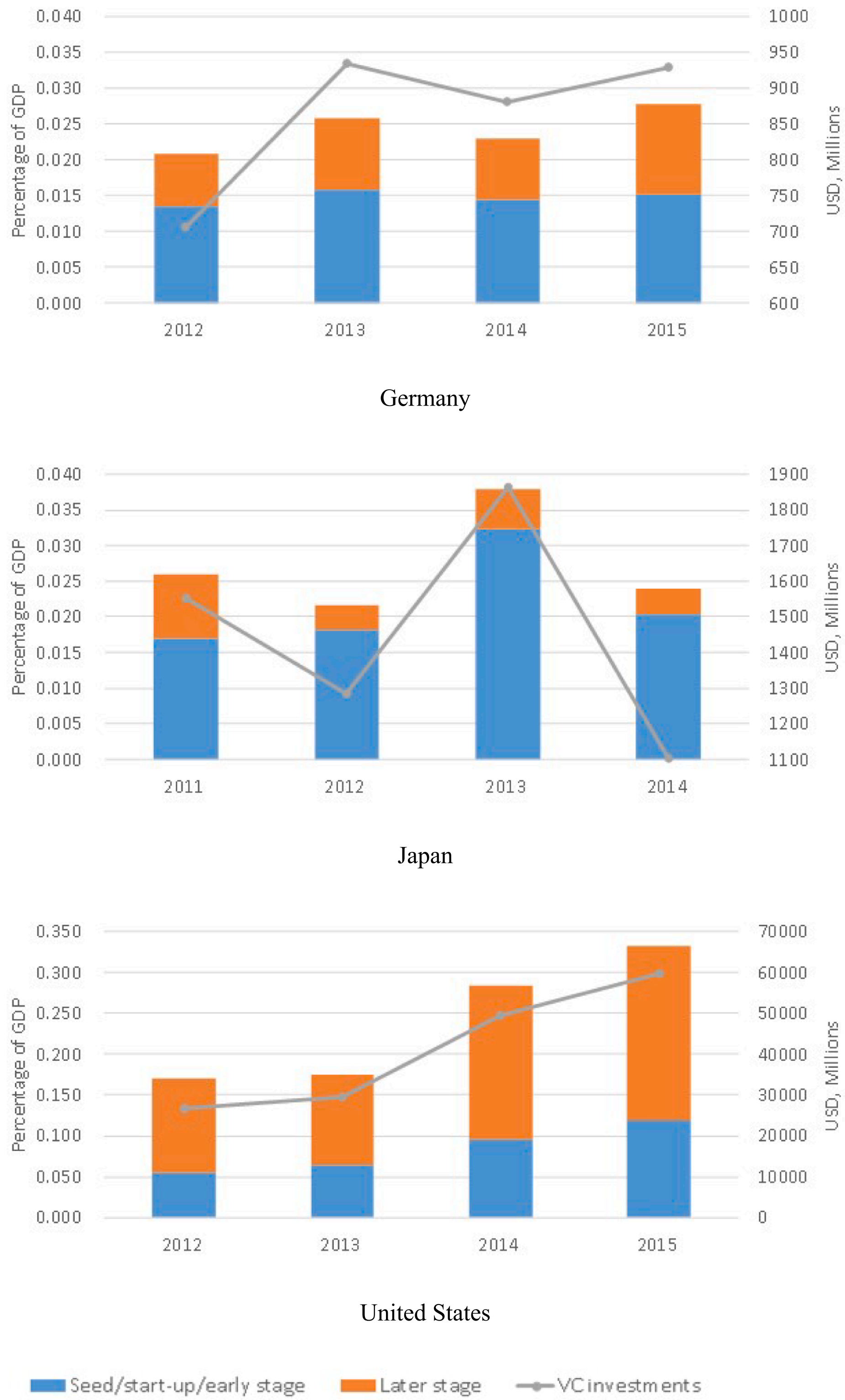

Fig. 10. Venture capital investments in three countries (each stage as a percentage of GDP, total amount as million US dollars), 2012–2015. Data from Organisation for Economic Co-operation and Development (2016c).

variables include technology implementation (coded as 0 = none of five technologies implemented, 1 = one or more of five technologies implemented), the capital to labor ratio, and industry dummy variables. The causal effect of technology implementation on labor productivity was also estimated by using a decentralized level of decision-making as an instrumental variable (IV). The results of both OLS and IV methods suggest that technology implementation makes a statistically significant contribution to productivity increase when taking account of the reverse causation, that is, a firm with higher productivity is more likely to implement new technologies.

Increased automation through deploying next generation technologies will affect jobs in many industries. However, it is predicted that the pursuit of new growth markets and a projected decline in Japan's labor force could cushion the net impact on employment (Desvaux

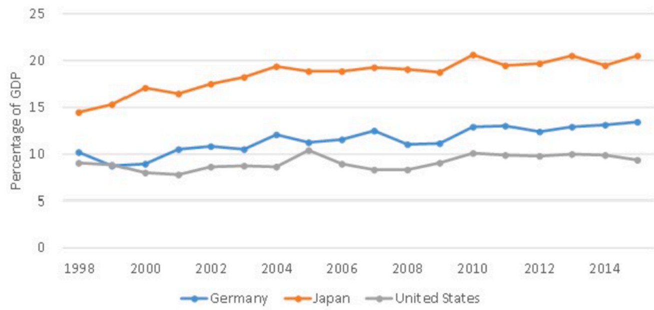

Fig. 11. Gross savings of non-financial corporations in three countries (percentage of GDP), 1998–2015. Data from OECD (2017b).

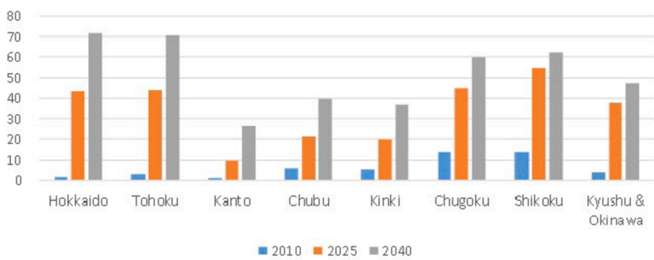

Fig. 12. Rate of municipalities which more than half the population are not of working-age in each region in Japan, 2010–2040 (15 year intervals). Data from IPSS (2013).

et al., 2015). One big trend is a collaborative robot, or so-called “a cobot,” which are designed to work alongside human workers, assisting them with a variety of tasks. Collaborative robots are gaining popularity since sensors and computer power have become so cheap that they decrease the cost of the robots and make them more available to businesses of all sizes including small and medium-sized enterprises (Tobe, 2015; Prodhan, 2016). A significant surge in demand for cobots having a payload capacity between 5 and 10 kg is observed recent years as they are the safest robot for a majority of factory automation tasks and can be substitute for heavier robots. The cobots having this payload capacity range are provided by some major companies including KUKA AG in Germany and FANUC Corporation in Japan as well as by many emerging startups in the United States and Europe including Veo Robotics, Inc. and Osaro, Inc. Such cobots startups are expected to contribute to the rapid market growth in next few years while incumbents are catching up with the market trend (CB Insights, 2018).

5.3.2. *Corporate governance reforms*

Organizing for discipline and performance is effective in improving capital productivity. The corporate governance reform has been performed in Japan to evolve its traditional economic management system characterized by the union of lifetime employment and seniority-based workplaces (Cabinet Office, 2016b; Ministry of EconomyTrade and Industry, 2017). The Corporate Governance Code which took effect in June 2015 seeks to make companies more transparent and responsive to shareholders. The Practical Guidelines for Corporate Governance Systems was released as a supplementary document to the Code in March 2016 which details practical approaches to effective corporate governance and productive actions to boost the earnings. These efforts are expected to encourage a manager to develop a positive mindset and take investment risks, and then result in higher productivity and profitability in Japanese economy.

5.3.3. *Value creation for cities and communities*

The gap between urban and rural economies has one of the critical challenges to be addressed in Japan. Toyama (2015) points out that Japanese economy is divided into two spheres with different players: the global sphere with large firms competing for a share of the world market and the local economic sphere with community-based small and medium-sized companies putting a focus on customer-facing services. It is necessary in the global sphere to develop and distribute products and services globally and at the same time to optimize them for local consumers. However, a different approach is effective in the local sphere, which starts to innovate for people in local community and then distribute these innovations globally (Govindarajan and Trimble, 2012).

Despite the difference between the strategic approaches in the global and local spheres, expectation of creating values for the society is growing in both spheres while rising inequalities in earnings and in wealth is a major concern in many countries (OECD, 2017c). Firms are required to think and align the interests of shareholders and societies for mutual benefit in the long-term (Porter and Kramer, 2006; Kramer and Porter, 2011). In Japan, many projects on value creation for cities and communities have been launched supported by both public and private funds:

- Kashiwa-no-ha Smart City (Mitsui Fudosan, Co., Ltd., 2016): The Kashiwa-no-ha area, located outside Tokyo, is home to the University of Tokyo, Chiba University, and national research institution campuses. As part of the Kashiwa-no-ha International Campus Town Initiative, the goal is to build a city on this foundation which is integrated with the environment, promotes long and healthy lives, and cultivates industrial innovation. The project promotes accessibility by public transportation and enhance the environment for bicycle use by building cycling paths and bicycle sharing systems in order to reduce the use of automobiles. Preceding initiatives have been undertaken to visualize energy usage to heighten the sense of engagement among residents and electricity sharing between districts through Japan's first case of distributed power sourcing. Some guidelines are also adopted which require new buildings to provide a certain level of environmental performance.
- Town of Tamaki, Mie Prefecture (Town of Tamaki, 2016): Tamaki is one of municipalities coping with the inconvenience of living in

Table 1
Impacts of technology implementation on productivity increase in Japanese firms.

	(1)		(2)	
	OLS	IV	OLS	IV
Technology implementation	0.059** (2.14)	0.264** (1.98)		
Technology implementation index			0.044*** (3.13)	0.118** (2.02)
Capital to labor ratio	0.116*** (4.36)	0.121*** (4.43	0.116*** (4.41)	0.120*** (4.51)
Constant	0.416*** (8.60)	0.354*** (5.92)	0.414*** (8.58)	0.380*** (7.18)
Observations	1466	1466	1466	1466

Technology implementation codes: 0 = none of five technologies implemented; 1 = one or more of five technologies implemented.
t or *z* statistics in parentheses.
$^{***}p < 0.01$, $^{**}p < 0.05$, $^{*}p < 0.1$.
Note: From Figs. 3–1-12 (1) ‘Impacts of technology implementation on productivity increase’ (Cabinet Office, 2017, p.177, p.177).

sparsely populated areas in aging Japan. The town introduced a demand-responsive transport system developed by the University of Tokyo in 2009 to give senior citizens free rides in minivans. The system eliminates the need to call an operator, and optimizes dispatch and route planning so that new passenger reservations do not disrupt or delay services to already-booked passengers (OECD, 2016d). The on-demand bus service supported by the system encourages elderly residents in Tamaki to go out and participate in community events, and contribute to reducing medical costs per users compared to those per non-users.

- Agricultural Production Corporation GRA Inc. (Ministry of Internal Affairs and Communications, 2014 MIC, 2014): GRA was established at Town of Yamamoto, Miyagi Prefecture, in July 2011, just after devastated by the 2011 he Great East Japan Earthquake. The GRA Group has developed the computer-aided facilities for strawberry farming. Their objective was to revitalize the key industry in Yamamoto through combining the wisdom of farmers with the precision of technology. The facilities support the management of cultivation processes and products, and also contribute to building a strong brand image. Their strawberry-farming system has been implemented to India since 2012 to help the local agricultural industry in collaboration with the local non-governmental organization.

6. Conclusion

STI ecosystems are subjected to short-term shocks, such as economic bankruptcy and a technological breakthrough, and are also subjected to slowly changing long-term stresses, such as demographic changes and globalization. System resilience enables STI ecosystems to recover its stable state after short-term shocks and long-term stresses, and plays an important role in maintaining conditions which sustain STI activities as a major force in growth and productivity improvement.

Japan's STI ecosystem has been severely affected by rapid ICT development in the 1990s which brought the radical changes to the production and delivery of goods and services and the emergence of a globalized market, and also caused the changing business environment which required agility and flexibility. The ecosystem became vulnerable to these shocks and stresses, and decreased the system resilience while the process of value creation has shifted from independent to interactive, from close to open, from stable to dynamic. This system damage resulted in the dramatic economic slowdown over the decade in Japan.

In the 2000s, Japan's STI continued to suffer from the shocks and stresses bought by rapid ICT development and consequences which include a paradigm shift in production from “making things” to “making stories”. However, it has gradually recovered the system resilience through strengthening the approach to problem solving which encourages to open up the innovation process, to offer an integrated solution for customers by bundling the products and services, and the shift from product-focused to customer-centric approach.

The recovery of the system resilience leads to improvement of Japanese economic performance in the early 2010s subsequent to two lost decades. However, Japan's STI ecosystem faces of the next shocks and stresses as AI and other cutting-edge technologies are emerged. This recognition encourages Japan to look beyond industry 4.0 toward Society 5.0 which is coming through data-driven innovation.

Japan's STI ecosystem is shifting from a push-based system to a pull-based system. Whereas the actors offer efficient solutions to problems to be addressed in a push-based system, a new push-based ecosystem brings value source from the inside and outside of the system. The key functional service of the system is to facilitate value creation for Society 5.0 in which all the people live a comfortable and vigorous life. Expanding this functional service depends on keeping the resilient STI ecosystem. The risk mitigation measures mentioned above, such as deploying next generation technologies, corporate governance reforms, and value creation for cities and communities, could contribute to increasing the system resilience. The public and private sectors will have to work together to create the right environment for growth, focusing on labor market frameworks, entrepreneurship, competition, and talent and skills development as well as safety and regulatory of data sharing. These efforts could maximize the benefits of data-driven innovation and revitalize its productivity and growth in Society 5.0.

This paper reviews relevant topics to STI activities in three countries, but provides a balanced overview of topics and essentials for the future from an ecosystem perspective. Further study is required to understand historical complex dynamics of STI ecosystem and develop practical approaches to increase the system resilience.

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