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International Comparison and Trade Effects of Digital Innovation[1]

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I. Introduction

The fourth industrial revolution is the on-going industrial revolution driven by intelligent information technology. The digital innovations related to artificial intelligence, big data analysis, cloud computing, and the internet of things are driving hyper-connectivity between all products and services through global networks, thereby advancing the data-driven economy. In particular, the data-driven technologies combined with new technologies and established industries and services contribute to the new business models, thereby bringing about the so-called digital disruption.

The recent digital innovation has been accelerated by the market needs to the extent that the mass production system of the established industries needs to be changed into a personalized production system. All the materials and phenomena in the physical world with analogue characteristics have been transformed into digital data to a substantial degree, in terms of speed as well as magnitude. In addition, artificial intelligence systems which can find optimal solutions through data analysis have been utilized widely in various socio-economic areas. The digital innovation taking place in the wake of the fourth industrial revolution is having disruptive effects on products, production processes, and business models of the established industries.

II. Digital Innovation and Trade Pattern

Digital innovation will bring about revolutionary changes in all activities in the social and political sphere, not to mention the areas of technology, industry, trade, and other economic transactions. In a recent research, the OECD (2018) presents the following future scenarios: the “iChoose” scenario, where individuals will play a leading role in economy, politics, and societal activities through deregulation and innovations by the governments and corporations; the “platform government” scenario, where governments are changed into a platform government to manage the mutual relationships among the citizens, corporations, and societal organizations; the “Tech Titans” scenario, where the large companies leading global technology innovation will play pivotal roles in all

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economic activities, providing better personalized services for the general public than the governments; and the "Artificial Invisible Hands" scenario, in which artificial intelligence replaces the many coordination functions of governments and corporations, guiding the people to make better choices in improving their welfare.

The information on production and consumption collected through the internet of things will be conducive to an optimal production system and smarter consumer choices through big data analysis and artificial intelligence, bringing about fundamental changes in the world economy. In particular, digital innovation will have various impacts on international trade patterns according to technology characteristics and different levels of technology development. Let us take the example of a smart factory. In the embryonic stage of the smart factory, the international trade pattern will be determined by the individual levels of technology because the digital innovations are not differentiated from the previous production systems. In the growth stage of a smart factory, the reshoring of the production activities will be facilitated by the comparative advantage in terms of technology and location, changing the trade pattern substantially. In the maturity stages of the smart factory, the factories will be located in the consumer markets by a distributed manufacturing system. The trade pattern will be transformed toward the servicification of manufacturing.

III. International Comparative Analysis of Digital Innovation

In this study, we analyzed the level of digital innovation and digital utilization by country and industry. The level of digital innovation – measured by number of patent grants, number of citations, and H index – is analyzed using data on utility patents related to digital innovation technology, among those reported to the U.S. Patent and Trademark Office (USPTO), while the analysis for the level of digital utilization uses both industrial robots data in the World Robotics Reports and ICT access and usage data in the OECD.Stat database.

According to the results of our analysis, significant improvement was made in the world's digital innovation (number of patents), led by the U.S. and Japan, showing a stair-step increase in the years of 1998 and 2010. However, the number of patents in Japan has remained relatively flat since 2000, while the number in China and India has increased rapidly since the mid-2000s.

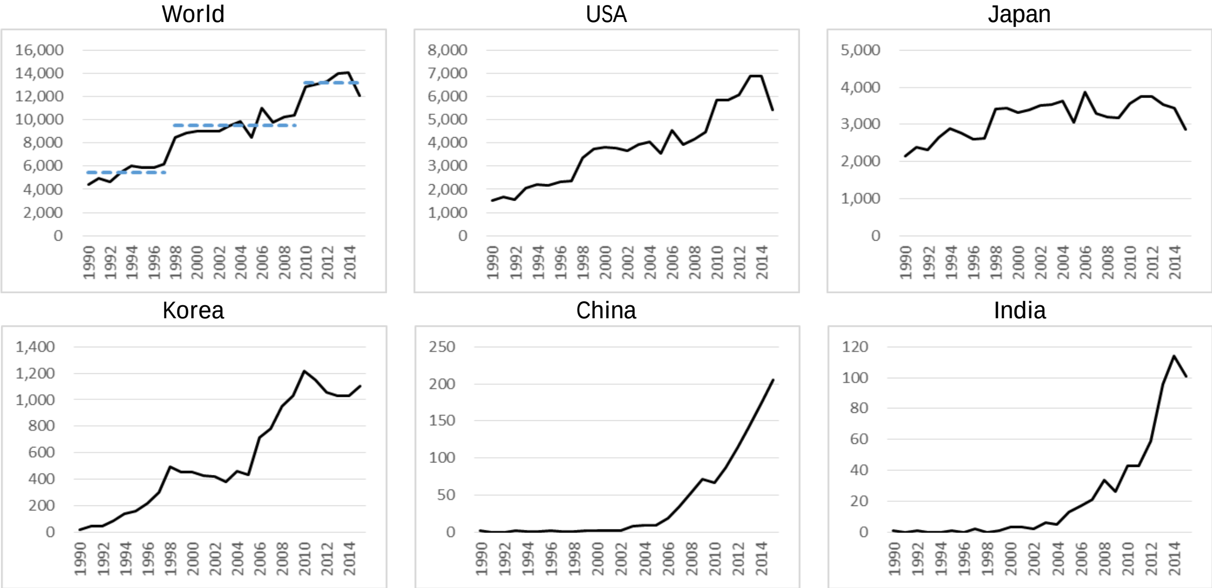
The quantitative and qualitative level of Korea's digital innovation is steadily rising, but still relatively lags behind the U.S. and Japan. In particular, considering the recent decline in Korea's rank on the H index, and the improvement in the level of digital innovation shown in China and India, Korea is likely to experience the same decline as the EU member states.

By industry, the level of digital innovation is focused in the category 26 (computer, electronic and optical products), 28 (machinery and equipment n.e.c.), and 62 (computer programming, consultancy and related activities) industries. Among these industries, category 62 industries have shown dramatic increase recently. When comparing the level of digital innovation in major countries (USA, Japan, Korea, Taiwan, China, India) within the period of 2010–15, it was found that all category 26 and 28 industries were at a high level in all major countries. Korea's level of digital innovation by industry is currently positioned between the U.S., Japan, China and India, according to the analysis by country. In the category 62 industry especially, Korea is at a lower level than India.

Overall, industrial robots indicate an increase in the level of digital utilization. Around 72% of the world's industrial robots are installed and operated in the U.S., Japan, Korea, China and Germany. Korea has installed the third most robots in the world, and operates the fourth largest number of industrial robots actively. In particular, the number of robots in operation per 10,000 workers in Korea is 631, the largest rate recorded in 2016.

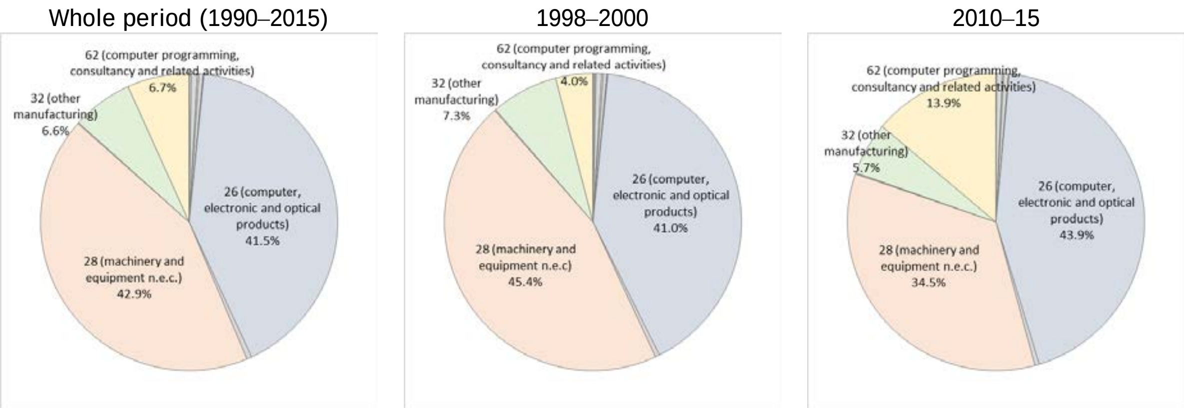
Figure 1. The Trend of Patent Grants by Major Countries

Unit: number of utility patent grants



Source: Author's calculation based on USPTO DVD-ROM.

Figure 2. The Ratio of Patent Grants by Industry



Source: Author's calculation based on USPTO DVD-ROM.

Table 1. Major Countries' Number of Patent Grants Related to Digital Innovation Technology by Industry (2010–15)

Unit: number of utility patent grants

Major Industries		USA	Japan	Korea	Taiwan	China	India
code	name						
20	Chemicals and chemical products	207	135	31	21	6	1
26	Computer, electronic and optical products	14,376	8,314	4,730	1,655	405	340
27	Electrical equipment	177	67	33	43	14	0
28	Machinery and equipment n.e.c.	11,010	10,237	1,245	786	272	39
32	Other manufacturing	1,437	1,703	431	345	51	1
62	Computer programming, consultancy and related activities	9,413	245	63	26	28	75
Industry Total		36,939	20,889	6,591	2,909	792	456

Source: Author's calculation based on USPTO DVD-ROM.

Many of the robots that were installed and in operation during 2011–16 are used in the manufacturing of automotives, electrical and electronics, metal, plastics and chemical products. Korea uses a large number of robots in the electrical and electronics sectors, unlike other major countries that use many robots in the automotive sector.

Lastly, as for the other indicators of digital utilization, the usage of ICT at enterprises is not very high in Korea, with the exception of RFID utilization, despite the very high usage rate of high-speed internet at enterprises (99.3%) and households (99.5%).

IV. The Impact of Digital Innovation on International Trade

This chapter examines the impact of digital innovation on international trade. Digital innovation denotes new products and processes based on data and software codes. Since it is widely known that there is a positive correlation between innovation and productivity, it is natural to conjecture that digital innovation would have an impact on international trade due to changes in fundamental productivity. We select a structural approach rather than a reduced-form econometric approach due mainly to the paucity of relevant data.

A. The model

The world comprises N countries and J sectors, in which a particular country is denoted by $n, i \in \{1, \dots, N\}$ and a particular sector by $j, k \in \{1, \dots J\}$. Consumers in each country supply their labor inelastically at wage rates w_n in country n and demand consumption baskets according to Cobb-Douglas preferences with country-sector specific share α_n^j over their consumption of final output bought at prices P_n^j in all sectors. Given prices and income, consumers maximize their utility subject to the budget constraint.

We add fundamental productivity into a multi-country and multi-sector Ricardian model with input-output linkages, trade in intermediate goods, and sectoral heterogeneity in order to quantify the trade effects from digital innovation. Representative firms in each country and sector produce a continuum of varieties of international goods. Following Eaton and Kortum (2002) and Caliendo and Parro (2015), we model efficiencies as random variables so that firms producing intermediate goods differ in their productivity level z_n^j drawn randomly from a Frechet distribution. Given the realization of productivity level at intermediate good sector j in country n, we introduce fundamental productivity T_n^j to the production function for intermediate goods as follows.

$$y_n^j(z_n^j) = z_n^j \left(T_n^j l_n^j(z_n^j)\right)^{\gamma_n^j} \prod_{k=1}^{J} m_n^{k,j}(z_n^j)^{\gamma_n^{k,j}}$$

Where l_n^j is the labor demand, $m_n^{k,j}$ is the demand for material inputs by firms in sector j from sector k, $\gamma_n^{k,j}$ is material share from sector k in the production of sector j and lastly $1 - \gamma_n^j = \sum \gamma_n^{k,j}$. The structure of production technology shows input-output matrix for each country. From cost minimization, unit cost bundle c_n^j is derived.

Final goods or composite intermediate goods in sector j, Y_n^j, is produced by Ethier (1981). We assume that the final goods cannot be generated by assembling intermediate goods from different sectors other than sector j. The optimal demand function for intermediate goods is derived from final good producer's maximization problem.

International trade is costly. A unit of any intermediate good in sector j shipped from country i to j requires producing $\kappa_{ni}^j \geq 1$ units in country i. Final good producers search for the lowest price of intermediate goods across all locations and assemble them to provide their buyers in their own country. Using some properties of the Frechet distribution, we calculate bilateral trade share π_{ni}^j and total expenditures X_n^j for all countries and sectors.

On equilibrium under trade costs and exogenous variables, a wage vector and prices satisfy equilibrium conditions, including a number of optimal behavior of consumers and producers and market clearing conditions in each country.

B. Changes in equilibrium and data

We highlight the link between digital innovation and productivity and between productivity and international trade on a general equilibrium setting to answer counterfactual questions. In order to perform the counterfactual analysis, we first calculate changes in equilibrium following the popular hat calculus.

Cost bundles ($N \times J$ equations)

$$\hat{c}_n^j = \hat{w}_n^{\gamma_n^j} \prod_{k=1}^{J} (\hat{P}_n^j)^{\gamma_n^{k,j}}$$

Price index ($N \times J$ equations)

$$\hat{P}_n^j = \left[\sum_{i=1}^{N} \pi_n^j (\hat{c}_n^j \hat{\kappa}_{ni}^j)^{-\theta^j} (\hat{T}_n^j)^{\theta^j \gamma_n^j}\right]^{-1/\theta^j}$$

Bilateral trade share ($N \times N \times J$ equations)

$$\hat{\pi}_{ni}^j = (\hat{T}_n^j)^{\theta^j \gamma_n^j} \left[\frac{\hat{c}_n^j \hat{\kappa}_{ni}^j}{\hat{P}_n^j}\right]^{-\theta^j}$$

Total expenditures ($N \times J$ equations)

$$\hat{X}_n^j X_n^j = \sum_{k=1}^{J} \gamma_n^{j,k} \sum_{i=1}^{N} \hat{X}_{in} X_{in} + \alpha_n^j (\widehat{w_n L_n}) w_n L_n$$

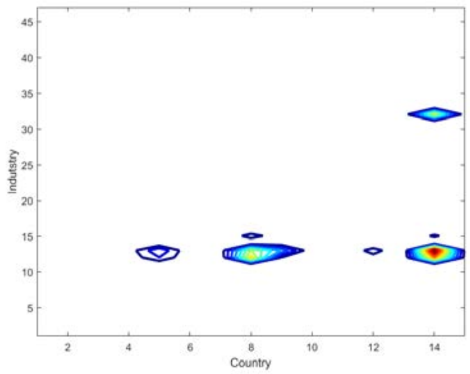
where it is assumed that the world trade is balanced.

Given a system of equations as above, we next measure digital innovation by extracting patents data pertinent to new technology such as Artificial Intelligence, Big Data, Machine Learning, Cloud Computing, and others recorded in the United States Patent and Trademark Organization from 2011 to 2015 (Figure 3).

Next, we proceed to concord the extracted patents data to International Standard Industrial Classification Revision 4. Then, we use the constructed patents data (Figure 3) to generate changes in fundamental productivity at sector-level to examine the trade impact of digital innovation. In addition, we consider changes in fundamental productivity at country-level of estimates from previous studies (e.g., Craft 2004; Craetz and Michaels 2015; O'Mahony and Timmer 2009; McKinsey Global Institute 2017).

In all cases, we use data from the World Input-Output Table released in 2016 to calculate exogenous variables such as input-output coefficients, value-added share, and share of consumption expenditures for the model.

Figure 3. Patents Records Relating to Digital Innovation at Country-industry Level



Note: Author's calculation. Brighter color represents higher number of patents for digital innovation. Such patents are concentrated in the computer, electronic, and machinery sectors in the US, Japan, Korea, and EU.

C. Counterfactual Results

We consider ten different scenarios depending on productivity shocks (changes in T_n^j) from sector-level and country-level. However, we can only show part of the main results in Table 2 due to space limitation.

Table 2. The Impact of Digital Innovation on Trade Volumes: Counterfactual Predictions

(unit: million US$)

Country	Industry-level	Country-level(2% uniformly)		
		US only	Leading countries	The world
Total	157,033	155,222	372,620	681,369
	(100.0)	(100.0)	(100.0)	(100.0)
U.S.	65,736	76,148	109,805	144,603
	(41.9)	(40.6)	(21.0)	(16.3)
Japan	27,842	3,951	29,896	37,193
	(17.7)	(2.1)	(5.7)	(4.2)
E.U.	24,621	16,807	93,440	126,816
	(15.7)	(9.0)	(17.9)	(14.3)
Korea	4,918	2,472	21,540	26,321
	(3.1)	(1.3)	(4.1)	(3.0)

Note: Author's calculation. The figures in parentheses show the share out of 'Total'. Parameter values are calculated based on WIOT and tariffs are from WITS. Leading countries include the US, EU, Japan, Korea, and China.

Counterfactual analysis based on a variant of the Ricardian model shows that digital innovation is beneficial to international trade. In other words, if digital innovation boosts fundamental productivity, it triggers growth in international trade at both sector-level and country-level. If countries/sectors have higher productivity due to digital innovation, those become much more competitive in producing goods or services, affecting trade share, price, expenditure, and many others within the model. As fundamental productivity induced by digital innovation becomes higher and the number of countries that experience enhanced productivity becomes larger, the model predicts that world trade volumes will grow larger accordingly. However, the growth in trade volumes is uneven. Although digital innovation contributes to the growth of world trade volumes, the increases in world trade are concentrated in certain countries and/or sectors that lead digital innovations.

V. Conclusions

This study provides the following implications for Korean private companies and its government. First, Korean private companies need to expand their R&D investments in software and programming related to Artificial Intelligence (AI), internet of things, and big data – areas in which the quantitative as well as qualitative level of Korean patents are relatively low compared to the U.S. and Japan. They need to strengthen their competitiveness in digital innovation technologies. For its part, the government must step up wide-ranging deregulation measures to facilitate digital innovations related to data flow and technical interoperability.

Second, efficient policy governance needs to be set up to systematically support digital innovation in private sectors. This is because the digital policies in the age of the fourth industrial revolution are expected to have wide-ranging effects on the economy as well as society. According to an OECD study (2017) on national digital strategy governance, OECD member countries have allocated respective responsibilities to various ministries. A systematic governance system needs to be established to lead development, and to monitor and co-ordinate implementations.

Third, the Korean government needs to cooperate with WTO member countries to revise the international trade rules related to digital trade. In particular, trade rules such as the Technical Barriers to Trade (TBT), Intellectual Property Rights (IPR), and Telecommunication Agreements need to be urgently revised through WTO negotiations. KIEP

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