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The Faster-Accelerating Digital Economy

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The Faster-Accelerating Digital Economy

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Abstract: The digital economy is one of the most important features of the knowledge-based society of the future. Based on information and communications technology (ICT), it grows faster than and eventually overtakes the traditional industrial economy. The fundamental driving forces of the digital economy's faster economic growth are as follows. First, ICT converges with and improves the efficiency of traditional industries. Second, the production function of the ICT industry shows increasing returns to scale. Third, the development of ICT stimulates not only demand and supply but the entire expansive reproduction system, resulting in faster-accelerating economic growth. This paper investigates the essentials, causes, and patterns of the faster economic growth of the digital economy, and forecasts its future on the basis of real-life examples from the US, Finland, and Ireland. Furthermore, the core of the IT paradox is revisited, so that the potential of the digital economy can be reaffirmed.

Keywords: Knowledge-based society, digital economy, new economy, economic growth, faster acceleration, technological change, IT paradox.

JEL Classification Numbers: L16, O11, O47.

1. Introduction

The term ‘digital economy’ was first used by the US Department of Commerce in its 1998 annual report to describe an economy that grew much faster than previous societies accelerated by ICT innovation. One important property of this economy is its inclusion of knowledge and information in main production factors, besides three major production factors - labour, capital, and land – of an industrial society. The digitalization of core economic activities including production, distribution, and consumption of goods and services is another main property of the digital economy [1].

Brynjolfsson and Kahin [2] also defined the digital economy with digitalization of information. They emphasized that every part of the economy has experienced recently a transformation to digitalization and the digitalization of information was crucial in further growth of an economy.

Lyotard [3] insisted that the development of IT technologies and the universal diffusion of knowledge make it possible to exchange knowledge as a good in the marketplace. The development of IT technologies is regarded as a critical factor for the establishment of the digital economy. Advanced IT technologies have led to the advent of new media, sucha as network based databases, and the development of computer networks and the Internet have made it easy to collect information and knowledge from all over the world. Information or knowledge intensity enabled by IT technologies have increased the importance of information and knowledge as production factors of an economy.

The digital economy is considered as a step toward the knowledge-based society. Drucker [4] and Bell [5] defined the knowledge-based society in concrete terms by stating that knowledge would be the basis of policy decision and knowledge workers who created and used information would become more important. They insisted that theoretical knowledge is necessary to innovate and manage technologies and policy systems that became more complex and changed comprehensively as time passed. Moreover, they asserted that the supply of knowledge workers would increase because of the growing population of well-educated personnel. Therefore, the entire society would move from a material-oriented to a knowledge-oriented economy as knowledge industries develop.

This paper is organized as follows: Section 2 describes the faster-accelerating characteristics of the digital economy—its role in improving traditional industries, the nature of its production function, and its influence on overall social change. Section 3 examines the structure and principles of the faster-accelerating distal economy. Section 4 demonstrates the faster-accelerating growth of the digital economy with three concrete examples. The IT paradox is revisited and the limitation and potential of the digital economy are examined in Section 5. Lastly, Section 6 concludes the paper, arguing that the digital economy is the driving force for the creation of a new economic paradigm.

2. Characteristics of the Digital Economy

2.1. Efficiency Improvement in Traditional Industries

The development and diffusion of ICT has increased the convergence between ICT and existing technologies in other industries. The technological advancement due to increasing ICT use in traditional industries has resulted in raising the added value and improving the productivity of traditional industries.

Computerization and digitalization of industries have influenced the entire production process, introducing faster and more efficient procedures. Solow [6] provoked the productivity paradox dispute, but Brynjolfsson and Hitt [7] refuted his statement by showing that ICT does lead to productivity improvement. They contend that computerization changes the industrial structure, leading eventually to productivity improvement. However, computerization by itself does not automatically bring about productivity improvement. As computerization matures, productivity improvement accelerates, and so does economic growth.

Many traditional industries, including the automobile, mechanical, and shipbuilding industries, attempt to improve their added values by developing new convergence technologies that graft state-of-the-art ICT into the existing systems. Table 1 shows some important examples of technology convergence between traditional industries and ICT.

Table1. Examples of technology convergence between traditional industries and ICT.

Industry	Major convergence technologies
Automobile industry	Web-based automobile, Integrated modularization of components, Intelligent safety system, Engine control, Gas emission control
Mechanical industry	MEMS[a], jOpen PC-NC, Industrial robots, IMS
Shipbuilding industry	Automatic sailing system, Automatic ship identification system, Integrated control system, Super-luxury passenger ship (car ferry), Special vessel-building technology
Textile industry	High-performance industrial textile (conductivity textile, smart textile, intelligent textile, etc.)
Construction industry	Intelligent construction system, Construction robots, Construction CALS/EC, Contractor integrated technology and information system (CITIS)
Health-care industry	Next-generation intelligent medical equipments, Sensory functions recovery devices for the disabled, Speedy EMS, Operating robots, Micro autonomous endoscope

[a]MEMS = micro-electronic-mechanical system, IMS = intelligent manufacturing system

2.2. Production Function of the Digital Economy

An economy driven by digital industries grows much faster than an economy based on traditional industries because of the increasing-returns-to-scale (IRS) production function of ICT industries. Whereas the traditional manufacturing industries of industrial societies show DRS, the production function of the digital economy has the IRS characteristic [8] [9]. IRS refers to a certain trend in which the more the units of the input factor, the greater the output per unit of the input factor. Ray et al. [9] insisted that IRS appears in the knowledge-based society due to the substitution of material capital for knowledge capital and its self-reinforcing nature in the process of knowledge accumulation as the driving force. Computer and software industries are representative examples that show the IRS production function. IRS reflects the continual increase of productivity due to the decrease of marginal cost to produce additional outputs. The marginal production cost of the software industry is considered to be close to zero [10]. Besides, Romer [8] claimed that technology development can lead to continuous economic growth, and many economists believed that the phenomenal economic growth of the New Economy in the US had been built on ICT technologies [11] [12].

Arthur [13] mentioned that the economic growth of the digital society accelerated faster than that of the traditional industrial society. Arthur [13] explained the acceleration effect of the digital economy based on the IRS characteristic in production and the path-dependent economy. Shy [14] theoretically proved the network effect observed in the computer hardware and software industries. His research on the distinctive feature of markets according to the different characteristics of software products (e.g. ease of reproduction and network effects) indicated that the software market, unlike the traditional product market, is not a competitive one but is dominated by a single technology. This kind of tipping effect in production is the basis of the technology-oriented accelerating growth of the digital economy. Harrington and Reed [15] also mentioned the virtuous cycle of e-commerce growth, which represented the accelerating increase of e-commerce revenue well, when e-commerce was regarded as one of the production indicators of the digital economy. According to them, the faster-accelerating growth of the digital economy is significantly different from the economic growth trend of the traditional industrial societies, which have the DRS production function.

Section 3 further explains how the IRS production function influences the faster acceleration of economic growth.

2.3. Social Changes in the Digital Economy

Not only does the ICT-based digital economy affect the economic area, it also brings about all-round social change. The digital economy brings about economic and social transformation, which accelerates economic growth by stimulating the cycle of the expansive reproduction system (ERS)[1]. In this section, we will look at five examples of such changes. The digital economy creates new demand for digital products, allows flexible economic structures, helps manage fluctuation in prices, restructures firms and employment types, and facilitates the emergence of the digital generation.

First, the digital economy creates new demand generated by new products, enabled by digital technology. The advances in computers and information technologies created tremendous opportunities for the production of new products [16]. For example, as the Internet is widely used, the need for online identifiers has arisen and the market for identity management systems (IDMs) followed [17]. The development of a portable music player and MP3 (MPEG Audio Layer-3) created a market for online music stores. Apple's iPod and iTunes are symbols of the new market [18]. As in these examples, the digital economy contributes to creating new demands that have not existed in traditional societies and expanding existing demands.

Second, the digital economy allows more flexible economic structures. With the development of ICT, the entry and exit of firms become easier, and consumers have a larger role. With the help of Internet-based e-commerce, entrepreneurs can start their businesses with a small amount of labour and capital. Small businesses in the digital economy have a potential for high growth due to the digital economy's IRS feature. Furthermore, as consumers can directly contact producers and send their messages via the Internet, they have a greater influence on producers. Producers, for their part, can obtain information about the consumers' needs and carry out efficient production based on the information. The development of ICT helps producers forecast the diffusion and demand of products more precisely so that producers can flexibly handle the fluctuation of demand as forecasted and reduce the amount of inventory. For example, Dell could make enormous profits by allowing customers to order PCs on the Web site. This initiative eliminated several factors that raised the product cost, and reduced the burden of inventory cost [19] [20].

Third, the digital economy mitigates price fluctuation. In the US, ICT goods and services contributed to decrease the inflation rate. For example, without the ICT industries, the inflation rate would be 3.1% in 1997. However, due to the continuous and remarkable price reduction by ICT industries, the overall inflation rate (i.e. with ICT industries included) dropped to 2% [19]. Kahn et al. [21] concluded that the advances in information technology reduced the fluctuation of outputs and inflation. To derive the results, they compared real-world data with simulated data based on the general equilibrium model, which considers the production function and utility function along with inventory and includes the optimal fiscal policy.

Fourth, the digital economy transforms the structure of firms and employment type, and creates new employment. Large companies are reorganized to small companies or subsidiary companies, and outsourcing is used. E-commuting and flexible working schedules made fixed places and times of work unnecessary, which triggered the creation of various goods and small businesses. More flexible working conditions enabled by out-of-office businesses such as e-commerce contributes to the changes of employment structures. Besides, the development of ICT industries led to an increasing demand for skilled people in this area. In the US, the number of people employed in the ICT industries was estimated as follows: 557,000 in 1985, 1,200,000 in 1996, and 2,500,000 in 2006 [19]. According to the 2009 statistics of the US Bureau of Labor Statistics, the number of persons employed in computer-related areas of the US in 2008 was estimated at about

3,200,000. If the entire ICT industries are considered, the impact of ICT industries on employment will be even larger.

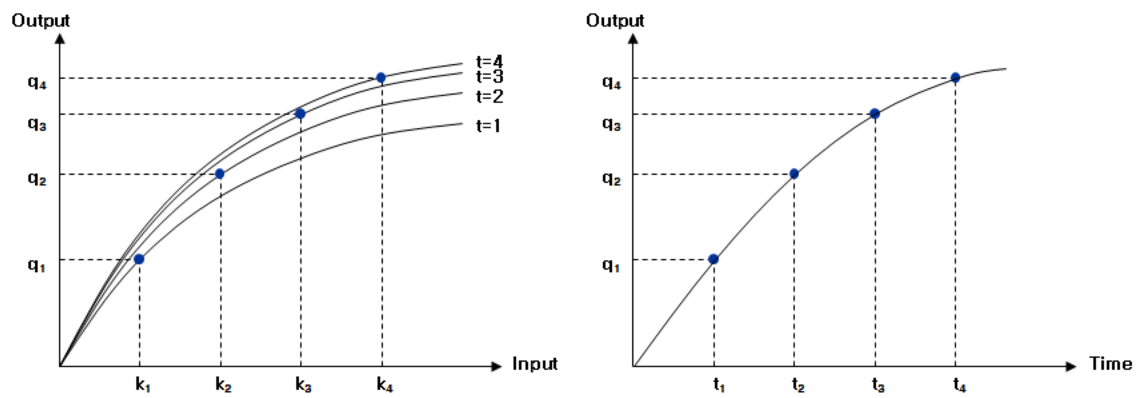
Lastly, the digital economy prompted the emergence of the digital generation. Tapscott [22] [23] insisted that the digital generation was clearly distinguished from other generations in the matter of values and lifestyle, since it was the first generation that grew with the development of digital media. The digital generation actively participated in using digital media for communication, entertainment, learning, working, and thinking, and formed new values. The digital generation tended to maximize individual utility, and acted as prosumers, who affected the production process and were at the same time consumers of the products [24] [25]. Since the digital generation is actively involved in the production and consumption of new products, it contributes to stimulating the cycle of ERS.

3. Structure of the Digital Economy's Faster Growth

3.1. Time-Output Relationship in the Digital Economy

As already mentioned, the production function of the digital economy shows IRS. Prior to describing the shift of IRS production function over time, we first see how the time-output relationship is observed for the DRS production function, which is generally considered as a production stereotype of previous industrial societies.

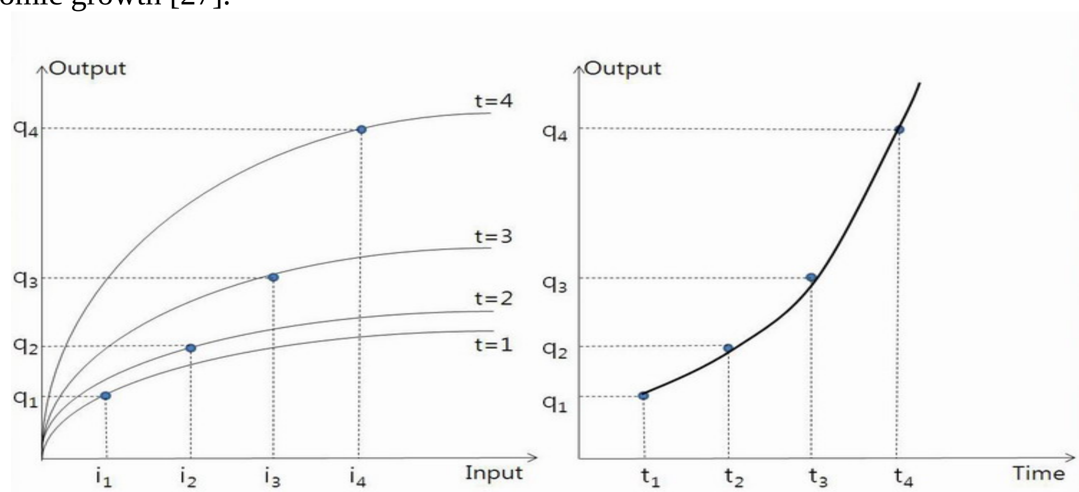
Figure 1(a) shows the positions of DRS aggregate production functions (APFs) at different time frames (t = 1, 2, 3, 4). Each APF reflects the technology level at the time. As time passes, technological innovation occurs and shifts the APF upward, though the range of technological change gets smaller. Figure 1(b) is a long-term time-output path, which follows the points of input-output intersection observed at each point of time. We define this path as an APF production expansion path, which means the production records of the APF observed at each point of time as an APF moves according to technological changes [26]. Figure 1(b) indicates that the economic growth of the society which has this kind of an APF production expansion path tends to gradually decelerate in the long run. A pure agricultural society before the Industrial Revolution falls under this category, where the economy stagnates over time because of slow technological changes.



(a) (b)

Figure 1. Time-output relationship with DRS production function and slow technological change.

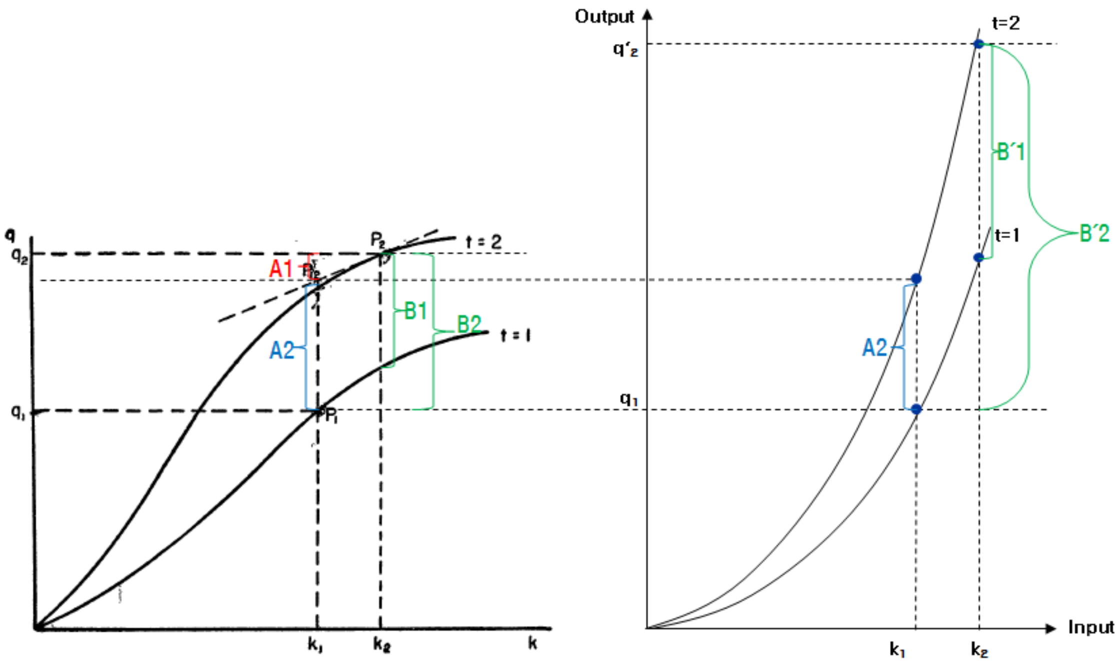
The next case is a situation in which the production function has the DRS characteristic, but technological changes are fast. As seen in Figure 2, when we connect the input-output intersections, the curve shifts upward at each point in time when technological innovation happens; this case shows the accelerating growth pattern in the long run. Modern industrial societies after the Industrial Revolution achieved this pattern of economic growth [27].



(a) (b)

Figure 2. Time-output relationship with DRS production function and fast technological change.

Lastly, we will examine how the output levels will change with time when the production function shows IRS, similar to the digital economy. First, we examine a test case that assumes the same technological progress as in Figure 2; however, the production function changes from the DRS to the IRS type. Figure 3 shows the time-output relationship for this case.



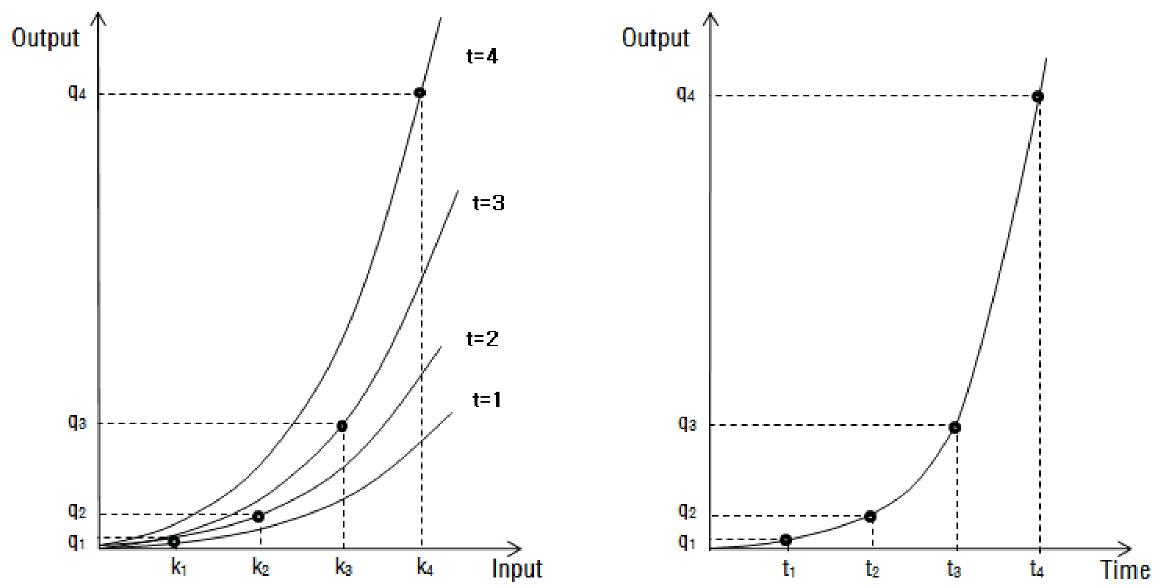
(a) (b)

Figure 3. Time-output relationship with IRS production function; the speed of technological change is the same as in Figure 2. (Source: (a) Solow, 1957, p. 313, chart 1 [28])

In order to estimate the technological progress in Figure 2, which measures how fast the production function shifts, the difference between the two time frames of a production function needs to be divided into two parts as in Figure 3(a): increase due to input changes and increase due to technological changes. Solow [28] explained that because of the time lag between the two observed production points, the output movement along the production function and the shift of the production function itself are mixed in the shift of the production function estimated from the two sets of observations. Of the two movements, the shift of the production function itself is only related to the technical change between the two production points. In order to calculate the technical change, Solow [28] drew a tangent line at P2, which was the input-output point at t = 2, and found P12, at which the tangent line met the input level of t = 1. Then, he calculated the technical change from the difference between P1 (the output level of t = 1) and P12 (the output at t = 2 adjusted to the input level of t = 1). Figure 3(a) illustrates this process. As regards the difference between the production functions at t = 1 and t = 2, the output increase due to an input increase at the same technology level, that is, along the same production function, is expressed as A1; the change of the production function itself from technological advancement is indicated as A2. B1 represents the difference between the outputs with and without technological innovation at t = 2. B2 measures the output difference between t = 1 and t = 2.

When the DRS production function of the industrial economy changes to the IRS production function of the digital economy, it is generally assumed that technical progress becomes faster. However, even if the technical progress is assumed to be the same as with A2, the output increase would be much bigger (see Figure 3(b)). Even if the production function only changes to the IRS type, the difference between the outputs with and without technological innovation at t = 2 (B´1) is much wider than with the DRS type of production function (B1 < B´1). As a result, the difference between the total outputs q = 1 and q = 2, at t = 1 and t = 2, respectively, is also much larger with an IRS than a DRS (B2 < B´2) production function.

Finally, the shift of the digital economy's APF with time appears to be similar to Figure 4(a). Looking at Figure 4(b), which traces the output according to the time frame of Figure 4(a), the long-run output curve of the digital economy accelerates faster than in Figure 2(b), which represents the industrial society.



(a) (b)

Figure 4. Time-output relationship in the digital economy.

In the digital economy, not only does the production function change from a DRS to an IRS type, but also the technological progress becomes faster than in industrial societies. Therefore, the output increase over time is much bigger than in industrial societies, and its acceleration rate of economic growth is also much faster.

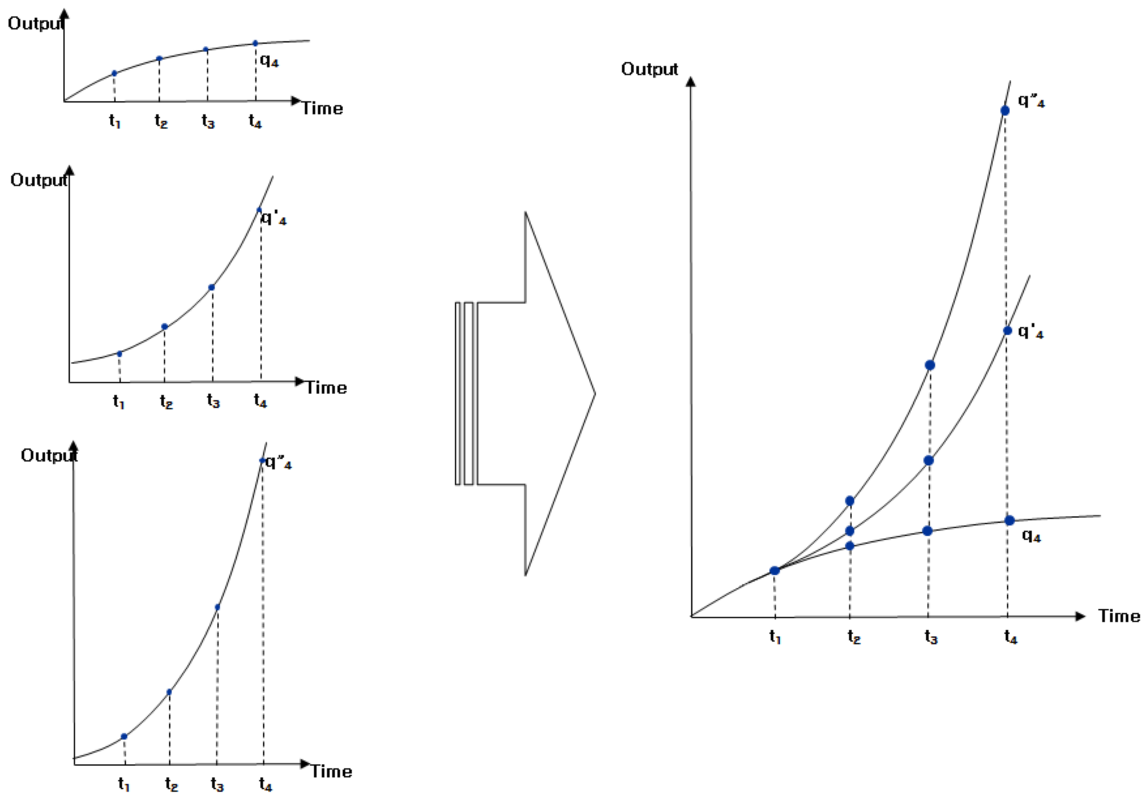


Figure 5. Comparison of shifting APF patterns over time among agricultural, industrial, and digital economies

Figure 5 compares the shifting patterns of APFs over time among the agricultural, industrial, and digital economies, as illustrated in Figures 1 to 4. On the assumption that the shift in each APF starts at the same time (t1), the pattern of each society's economic growth can be compared in one graph. In other words, we will compare the decelerating agricultural society with the industrial society and the digital economy that diverged from the agricultural society at t1. Although the agricultural and industrial societies have a DRS-type production function in common, the range and pace of technological changes in the long run are different for the two societies. This causes the economic growth path of the two societies to diverge; the former becomes a decelerating and the latter an accelerating society. As for the digital society, its long-term growth trend is similar to that of the industrial society, but it accelerates much faster. Therefore, the economic growth of the digital economy is faster than that of the industrial society. This difference occurs because the acceleration mechanism and the pace of the digital economy's economic growth are based on the IRS production function, which is quite different from the DRS production function of the industrial society. For this reason, it is more appropriate to consider the faster acceleration system of the digital economy not as a continuation of the former industrial society's economic growth but as the emergence of a new economic system.

3.2. ERS of the faster-accelerating digital economy

Figure 6 illustrates three principles of the digital economy, represented by paths ①, ②, and ③, which help the virtuous cycle of the ERS of the industrial society to circulate more efficiently and faster with ICT developments.

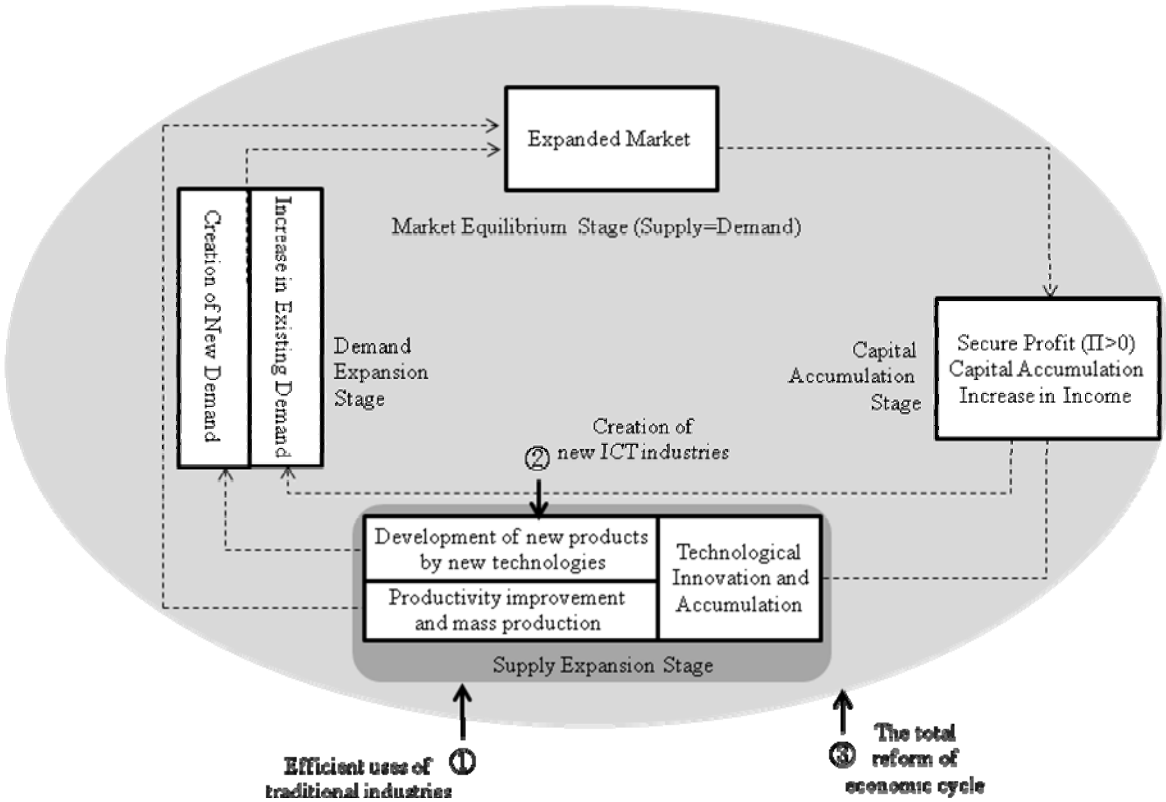


Figure 6. Restructured ERS in the digital economy.

The ERS of traditional industrial societies shows the virtuous cycle of economic growth, in which supply and demand increase by capital accumulation and technological innovation and then the increased supply and demand create an expanded market equilibrium. It also explains the accelerating growth of an economy over time [27].

ICT developments in the digital economy have similar effects as do technological innovation and accumulation in traditional industrial societies, but the spillover effects influence all types of industries and the entire cycle of the economy, in addition. Thus, as the driving force of the digital economy is based on the developments and utilization of ICT, we need to treat the effects of ICT developments not as part of industrial technologies in the ERS of the industrial society but as new independent technologies, in order to understand exactly the virtuous cycle of ERS in the digital economy.

The digital economy based on ICT has a different impact on economic growth compared to previous industrial societies in three respects. First, ICT contributes to efficient uses of traditional industries, which stimulate the development of new ICT convergence products. Furthermore, productivity improves, and the production cost reduces. As a result, technological innovation and accumulation in traditional industries are reinforced. Such effects are represented by arrow ① in Figure 6.

Second, ICT industries themselves have a key role in supply. The development of ICT created new industries such as ICT manufacturing or ICT service that provide new goods and services that did not exist in previous industrial societies. This effect not only stimulates the expansion of supply in the ERS by experiencing the production expansion in IT industries at the industry level but also creates new demands as well as new industries. This kind of ripple effect is different from the previously mentioned ICT spillover effect for efficient uses of traditional industries. This involves the creation of new ICT products and the productivity improvement of ICT industries. This relationship is represented by path ② in Figure 6.

Lastly, the impact of ICT developments on the virtuous cycle of ERS is not just confined to the production part. As we already saw in Section 2.3, ICT developments generate positive effects on the entire economy. Arrow ③ represents this relationship in Figure 6. Overall social change that occurs in the digital economy causes the cycle of ERS to accelerate faster. Likewise, ICT developments exert mitigating influences on the management cycle of macroeconomics and improve its efficiency, leading to an overall market equilibrium.

The faster-accelerating production expansion curve of the digital economy is a result of the weighted average of the pure market creation effect by ICT industries and the productivity improvement effect by ICT-infused traditional industries. The weights used here can vary according to the proportion of digital industries and goods in the entire economy. The larger the proportion, the faster is the accelerating growth of the digital economy.

4. Case studies

First, we present the New Economy of the US, the leader of industrial societies. Next, we consider Ireland and Finland, both early digital economies of Europe. Their economic growth surpassed that of other industrial countries in Europe, even though they lagged behind other countries during industrialization. Analyzing ICT-producing industries' labour-productivity and GDP data, we examine if these cases have digital economy attributes such as the traditional capital deepening and new-industry creation. We do not include the overall social changes generated by ICT to test if the cases are relevant examples of the digital economy, because this effect is difficult to be quantified and captured in the early stages of the digital economy, though it is possible to glimpse it through some macroeconomic indices like GDP. This investigation is left for future research.

4.1. The digital economy in leading industrialized countries

The economic growth of the US, though a technology leader, is often predicted to be slower than other countries adopting its innovation. However, in the middle and late 1990s, the US enjoyed the highest GDP per capita and the fastest economic growth among major industrial countries. In the Economic Report of the President [29], this period of high economic growth of the US during this period was described as the 'New Economy'. The report mentioned that a notable feature of this period was the rapid growth of ICT industries.

During the New Economy period, the US grew faster than any other country, and ICT played a remarkable role in this rapid economic growth. Table 2 shows that in comparison with the EU total productivity recorded marked improvement in the US and the role of ICT increased rapidly between the early 1990s and the late 1990s, a period considered to be part of the New Economy phase. This means the US was one step ahead of the EU in its transition to a digital economy during this time.

Table2. Rate of productivity increase and contributions from ICT: the US and the EU. (Source: Van Ark et al., 2002 [30])

	1990–1995		1995–2000	
	US	EU15[a]	US	EU15[a]
Total Economy	1.08	1.88	2.52	1.41
ICT Producing	0.51	0.33	0.75	0.47
ICT Using	0.43	0.42	1.42	0.42
Non ICT	0.23	1.10	0.36	0.48

[a.] EU 15 includes Austria, Belgium, Denmark, Finland, France, Germany, Greece, Ireland, Italy, Luxembourg, Netherlands, Portugal, Spain, Sweden, and the United Kingdom.

Figure 7 depicts the change of GDP per capita for the US and OECD-Europe [2] from 1960 to 2006. The US economy grew rapidly from the middle of the 1990s. From 1995 to 2000, the GDP per capita increased annually by 3.87% on average [3]. In the same time frame, the GDP per capita for OECD-Europe increased annually by 3.13% on average, which resulted in an expanding gap between the US and OECD-Europe. We can see that the New Economy left a large gap between the US and the EU in terms of economic growth.

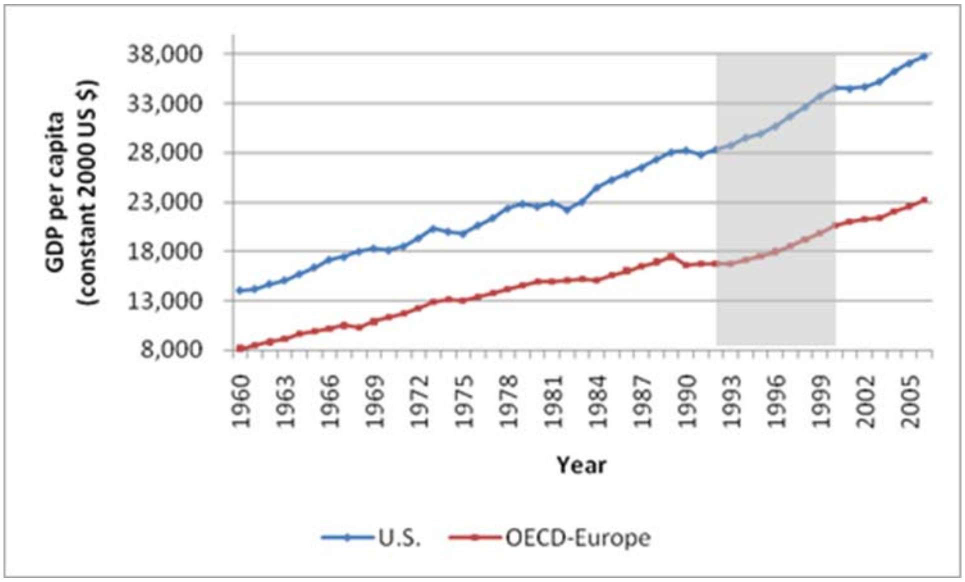


Figure 7. GDP per capita for the US and OECD-Europe (constant 2000 US$). (Source: World Development Indicators Database, 2008 [31]).

Figure 8 describes the change of labour productivity in the US nonfarm business sector from 1977 to 2006. Whereas the rate of increase of labour productivity on annual average was 1.7% for the whole period, it increased to 2.3% for the period 1995 to 2000. These data confirm the remarkable increase of labour productivity during this period. Many studies pointed out in common that ICT is the main cause explaining the rapid increase of labour productivity in the New Economy after the mid-1990s [32] [12] [33] [34].

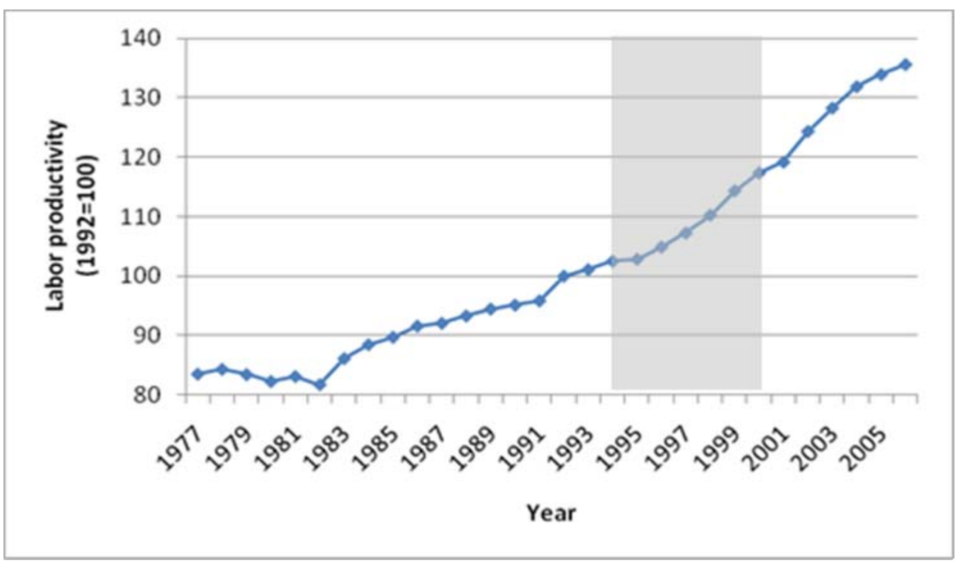


Figure 8. Labour productivity of nonfarm business in the US (1992 = 100). (Source: The Bureau of Labor Statistics, 2010 [35])

In order to look into this phenomena in detail, we will review Oliner and Sichel's [36] research, which estimated ICT contributions to labour productivity growth in the US from 1974 to 2001, categorized into ICT capital and ICT production (Table 3). Contributions from ICT capital was calculated by the capital deepening effect due to ICT assets, including computer hardware, software, and communication equipment. Contributions from ICT production was measured by multifactor productivity (MFP) from industries that produce ICT products, including semiconductors, computer hardware, software, and communication equipment. In other words, contributions from ICT capital are related to efficient uses of traditional industries by ICT, and contributions from ICT production are relevant to the creation of new industries by ICT. As the transition to the digital economy progresses, the proportion of its contribution to the improvement of labour productivity increases. ICT contributions to the growth of labour productivity for 1974–1990, 1991–1995, and 1996–2001 are estimated at 0.68, 0.87, and 1.79, respectivly, which translates to 50.0%, 56.5%, and 73.6% of the total growth of labour productivity resulting from ICT capital and production. On the basis of this analysis, Oliner and Sichel [36] concluded that the the accelerating growth trend of labour productivity in the New Economy after 1995 comes from ICT. In particular, the effect of ICT capital is noteworthy.

Table3. Contributions to the growth of labour productivity in the US. (Source: Modified from Oliner and Sichel, 2003, table 1 [36])

		1974–1990	1991–1995	1996–2001
Growth of labour productivity[a]		1.36	1.54	2.43
Contributions from	Capital deepening	0.77	0.52	1.19
	Labour quality	0.22	0.45	0.25
	MFP	0.37	0.58	0.99
Contribution from ICT	Total	0.68	0.87	1.79
	ICT capital	0.41	0.46	1.02
	ICT production	0.27	0.41	0.77

[a]In the nonfarm business sector, measured as the average annual log difference for the years shown multiplied by 100.

The GDP trend of ICT-producing industries[4] in the US that influence the creation of new industries is drawn in Figure 9. The GDP of ICT-producing industries in the US grew rapidly after the mid-1990s and reached about 4.2% during 1995–1999. During the same period, contributions from ICT to the economic growth of the US reached about 30% [29]. Although the size of ICT industries is relatively small, they play a key role in economic growth as its driving force.

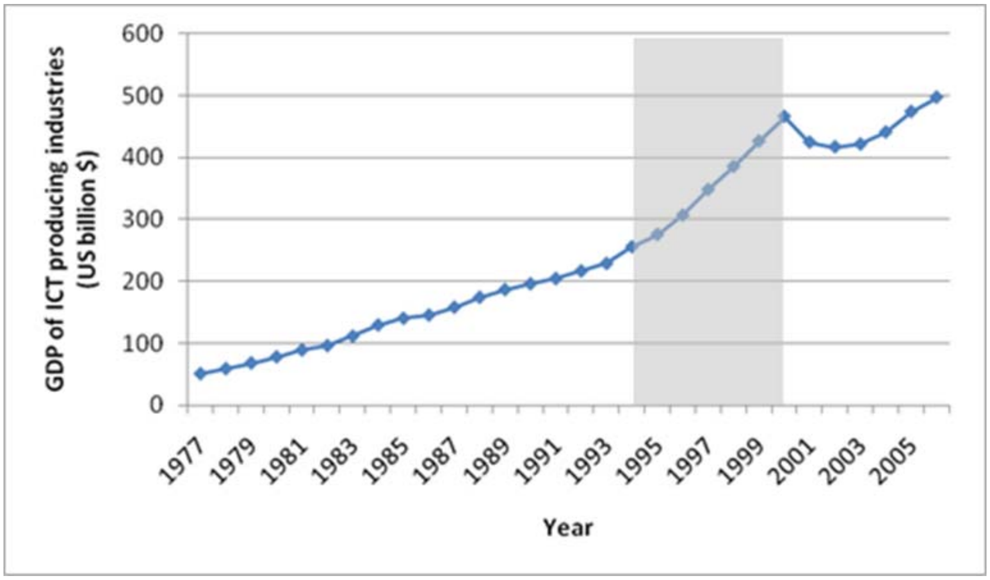


Figure 9. GDP of ICT-producing industries in the US (in billion $).
(Source: The Bureau of Economic Analysis, 2010 [37])

Later, similar to the IT productivity paradox pointed out by Solow [6], ICT contributions to economic growth were challenged since the GDP share of ICT-producing industries in the US dropped heavily in the early 2000s. Regarding this issue, the Economic Report of the President [38] explained that the ICT sector declined because the overheated stock market driven by the rapid growth of ICT calmed down, and the demand for ICT capital decreased after the heavy investments by companies in 2000 to prepare for Y2K were no longer needed. Oliner and Sichel [36] and Martinez et al. [39] refuted the IT paradox and showed that ICT contributed to the growth of labour productivity even after 2000. The decline of ICT in the early 2000s was only temporary, and ICT is still the key growth engine for the US economy.

4.2. Digital economy in industrialized following countries

Despite the polarization in industrial societies, it is possible that following countries will overtake the leading countries if they adopt and develop a digital economy ahead of other countries. Figure 10 illustrates the process by which a faster-accelerating economy overtakes an accelerating industrial economy.

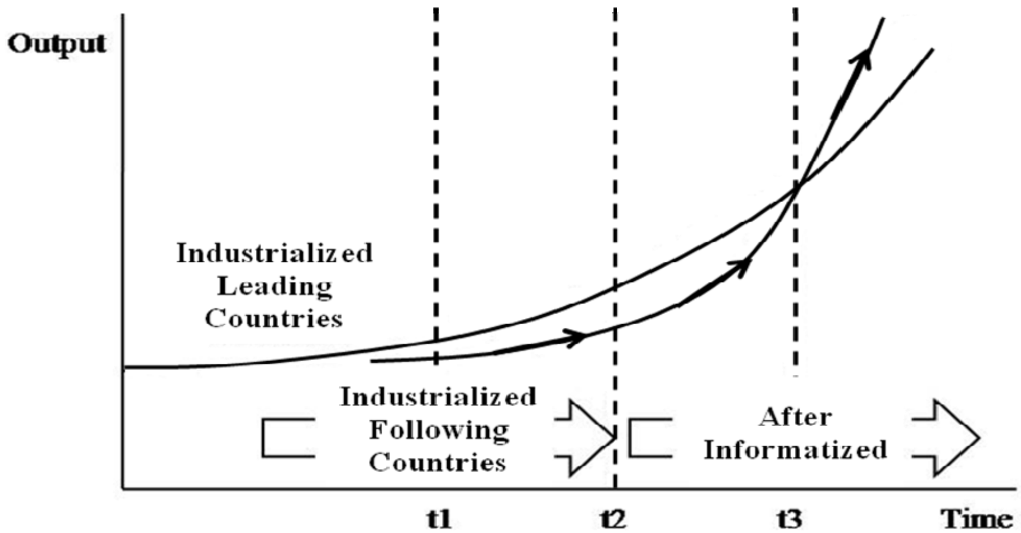


Figure 10. Overtaking model of the digital economy.

The speed of accelerating economic growth is measured by the slope of the time-output curve in Figure 10. If the leading countries' economies are ahead in informatization, the gap between the leading and following countries will go on widening. However, if the following countries intensively invest in ICT to establish a faster-accelerating digital economy, the gap can be closed. In Figure 10, the gap is broadening until t2 in the process of industrialization. When the following countries enter the digital economy at t2, the slope of economic growth becomes faster, and eventually the following countries overtake the leading countries at t3. This paper presents two real-world examples among the following countries that show an outstripping economic growth curve: Ireland and Finland.

4.2.1. Ireland

Ireland experienced a serious financial crisis in the 1980s because of political instability and excessive government expenditure, and its GDP per capita dropped below 70% of the European average. In the 1990s, however, Ireland intensively promoted ICT industries and, as a result, achieved a rapid 9% annual growth, on average, in the mid- and late 1990s. This growth rate was the highest among OECD countries at that period of time. As shown in Figure 11, Ireland grew remarkably faster than other economies, starting from the early 1990s. In the late 1990s, Ireland's GDP per capita surpassed the OECD and EU-15 (listed in Table 2) averages, and the country emerged as one of the richest in Europe. In 2006, its GDP per capita, at $30,736, ranked ninth in the world.

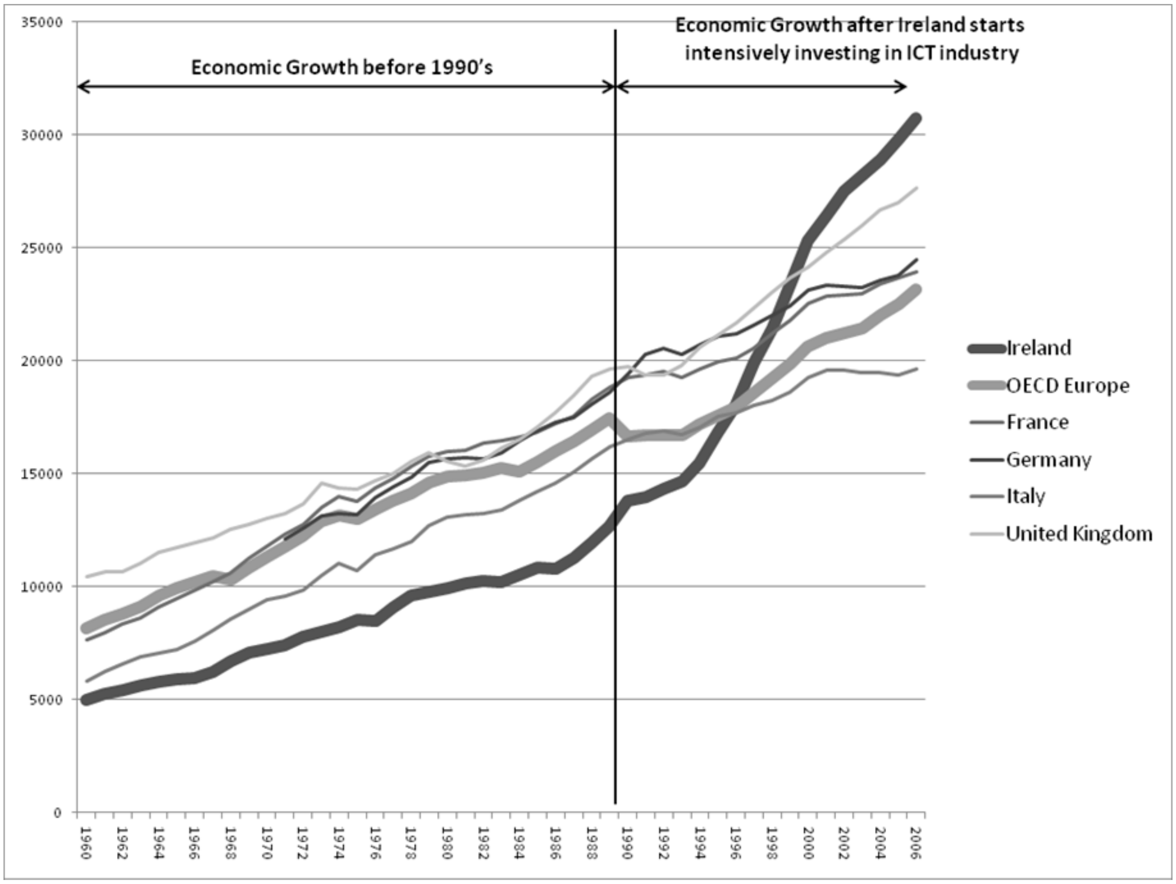


Figure 11. GDP per capita of Ireland, OECD Europe (average), and other European countries. (Source: World Development Indicators Database, 2008 [31])

Government policies that fostered software companies and focused on high-value-added ICT industries were the one factor that led Ireland into rapid economic growth. The country's domestic companies are technically inadequate, and the domestic market relatively small. From the 1990s, therefore, Ireland concentrated on policies that developed ICT industries by attracting competitive foreign companies. The Industrial Development Authority (IDA) offered various incentives such as tax benefits and financial support to attract foreign investments. As a result, many software companies, in particular, moved in and made considerable investments in Ireland. The development of ICT industries played an important role in the economic growth of Ireland, and the country achieved an annual average 4–5% of economic growth, which was higher than the OECD average until the mid-2000s. However, Ireland began to experience economic downturn from the first half of 2008[5]. According to IMF [40], though, the main causes of the economic bubble lie in the finance and construction sectors.

Table 4 shows the average contributions from each component to Ireland's GDP growth during 1990–1994 and 1995–1999. The total gross value added increased 2.27 times from the first to the second half of the 1990s. Moreover, contributions from ICT capital during this period increased 2.84 times, exceeding those from other components. The table confirms that the economic growth of Ireland accelerated as ICT industries matured, and the proportion of ICT capital's contribution to this growth continued to increase.

Table4. Contributions to gross-value-added growth in Ireland. (**Source: EU KLEMS, 2009 [41]**)

	1990–1994	1995–1999
Gross-value-added growth	3.99	9.07
Contribution of capital input growth	1.37	3.51
(Contribution of ICT capital)	(0.25)	(0.71)
(Contribution of non-ICT capital)	(1.12)	(2.80)
Contribution of labour input growth	1.37	3.24
Contribution of multi-factor productivity growth	1.25	2.32

ICT also contributed substantially to the improvement of Ireland's labour productivity after the 1990s (see Table 5). Van Ark et al. [30] estimated the ICT industries' contributions to the improvement of Ireland's labour productivity in the 1990s under three categories, following the international standard industrial classification of all economic activities (ISIC Rev. 3): ICT-producing, ICT-using (where the ratio of ICT capital is relatively high), and non-ICT industries. Contributions from ICT-producing industries represent the effects of ICT on the creation of new industries, and those from ICT-using are none other than ICT's effects on efficient uses of traditional industries. According to their analysis, the role of ICT industries, particularly the producers, was crucial to the improvement of Ireland's labour productivity.

Table5. ICT industries' contributions to labour productivity growth in Ireland. (Source: Van Ark et al., 2002 [30])

	1990–1995		1995–2000	
	Labour productivity growth	**Contributions to productivity growth**	**Labour productivity growth**	**Contributions to productivity growth**
Total economy	3.0		5.3	
ICT-producing industries	11.2	0.89	23.5	2.75
ICT-producing manufacturing	17.1	0.82	42.3	2.77
ICT-producing services	2.2	0.07	-0.2	-0.02
ICT-using industries	1.4	0.42	2.9	0.89
ICT-using manufacturing	6.1	0.37	8.7	0.56
ICT-using services	0.2	0.05	1.4	0.33
Non-ICT industries	2.6	1.48	2.7	1.65

The relatively high proportion of ICT industries in its economy helped Ireland achieve a faster-accelerating economic growth compared to the established industrial societies such as the UK, Germany, France, and Italy. Figure 12 shows the GDP trend of Ireland's ICT-producing industries.

Figure 12. GDP share of ICT-producing industries in Ireland. (Source: The Groningen Growth and Development Centre, 2005 [42])

4.2.2. Finland

Figure 13 compares GDP per capita of Finland with the average GDP per capita of OECD Europe during 1950–2001. Finland experienced high economic growth compared to OECD Europe in the early 1980s, as financial institutions became free to raise and manage funds after financial and capital liberalization policies were applied. However, this period is also characterized by careless management of finances with financial institutions buying real estate and providing loans excessively (Figure 13, A). In addition to this problem, the collapse of the Soviet Union, which was the most important export market, caused Finland to face a serious financial crisis after the late 1980s (Figure 13, B). The foreign exchange shortage and the severance of trade with the Russian Federation forced the industrial structure of Finland to change. As a result, ICT industries, including the mobile phone and other hardware-manufacturing sectors, were developed as key industries. Fuelled by ICT, the economy of Finland has been growing faster than OECD-Europe ever since (Figure 13, C).

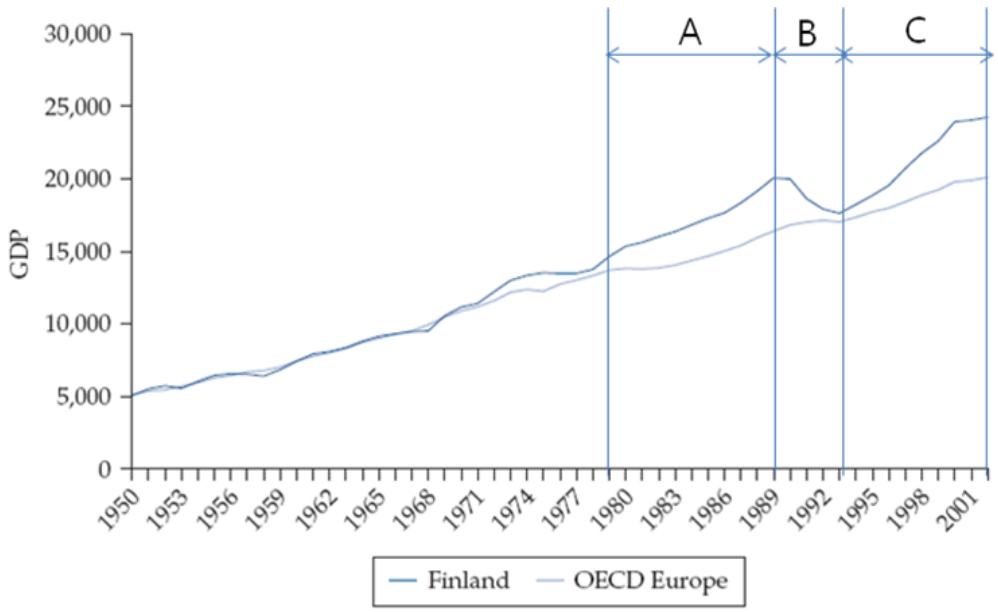


Figure 13. GDP per capita in Finland and OECD Europe, at 1995 prices and purchasing power parity (PPP) exchange rates. (Source: Carl et al., 2006 [43])

Statistics reveal that the GDP growth from 1995 to 2001 was 5%, on average, compared to 3.5% from 1950 to 2001 [44]. In order to overcome the economic crisis, Finland announced an ICT promotion policy in 1994, before other countries did so. The government proposed a new policy aimed at 'education, training and research in the information society', and pursued the adoption and development of information technologies as the key national policy. As a result of these policies, Finland enjoyed a high economic growth and is now one of the most competitive countries among EU members.

Jalava and Pohjola [45] divided the period between 1980 and 2004 into two sub-periods, 1980–1990 and 1990–2004, and analysed factor contributions to the output growth of Finland for each sub-period (Table 6). Regarding the effect of each component on GDP growth, contributions from ICT to GDP were investigated by three categories: ICT production, ICT capital, and spillovers from the use of ICT capital. ICT production includes ICT manufacturing for electrical and optical equipments, and post and telecommunication services. ICT capital refers to the assets invested in ICT industries. The spillover effects by the use of ICT capital are estimated by investigating 21 industries—including agriculture, mining, manufacturing, gas, and water—classified by Nordhaus [46]. In other words, these three categories correspond to the previously mentioned impacts of the digital economy on the ERS: ICT production is an equivalent term for the creation of new industries by ICT, and ICT capital and spillovers from the use of ICT capital represent the efficient uses of traditional industries.

Table 6 shows ICT's total contribution to GDP growth from 1990 to 2004 was almost three times the 1980–1990 rate. Contributions from ICT production increased 3.5 times, but the increase from ICT capital was not significant. Even if the spillover effect is excluded, the contributions from ICT production and ICT capital to GDP growth from 1990 to 2004 increased almost 2.5 times (about 3 times if the spillover effect is included).

Table6. Factor contributions to the output growth of the Finnish non-residential market sector. (Source: Jalava and Pohjola, 2008, pp. 270–287, table 3 [45])

		1980–1990		1990–2004	
		(a)	(b)	(a)	(b)
Growth of real gross value added at basic prices[a]		3.15	3.15	2.53	2.53
Contribution[b] from	Capital	1.10	1.32	0.37	0.53
	Labour	0.57	0.57	-0.35	-0.35
	Multi-factor productivity	1.48	1.26	2.51	2.35
Total contribution from ICT[b]		0.48	0.66	1.54	2.09
Contribution from ICT capital		0.22	0.44	0.24	0.43
Contributions from MFP	ICT production	0.26	0.22	0.91	0.89
	Spillovers from the use of ICT capital	—	—	0.39	0.77
Memoranda					
Income share of ICT capital[c]		2.45	2.62	4.63	4.62
Volume growth of ICT capital[a]		8.80	17.00	3.92	7.83
Output share of ICT production[c]		5.53	5.53	10.06	10.06
MFP growth in ICT production[a]		4.76	3.97	9.05	8.75

Notes: (a) Estimates based on non-hedonic ICT prices
(b) Estimates based on hedonic ICT prices
[a] in per cent, [b] in percentage points, [c] in per cent

According to Jalava and Pohjola [47], Finland's labour productivity grew 2.87% from 1995 to 2005. Table 7 shows ICT's contributions to labour productivity. The data confirm that the influence of ICT on the creation of new industries is substantial. The ICT impact on total labour productivity, which is the sum of ICT capital and ICT-related contribution, was found to be about 65%.

Table7. Average growth of labour productivity and its components in Finland, 1995–2005. (Source: Jalava and Pohjola, 2007, pp. 463, table 2 [47])

	Share of GDP (%)	Volume growth (ln %)	Contribution (ln %)
GDP at market prices	100.00	4.06	4.06
Hours worked		1.19	1.19
Labour productivity		2.87	2.87
Capital deepening	34.62	1.86	0.66
Dwellings	9.92	1.15	0.13
ICT capital	3.27	13.95	0.46
Other capital	21.42	0.01	0.07
Labour quality	65.38	0.22	0.14
Multi-factor productivity		2.07	2.07
ICT related contribution			1.41
Other contribution			0.66

Notes: Numbers may not sum to totals due to rounding.

Figure 14 illustrates the GDP share of the ICT sector in Finland. The proportion of the ICT sector increased at an accelerating rate from the early 1990s and doubled by the early 2000s to reach 10%. On the other hand, the percentage of the forest industry, which was traditionally strong, dropped lower and lower, to nearly 3%. The figure reveals the effects of the creation of new industries by ICT, and shows that ICT was the driving force of the rapid growth of Finland in the 1990s.

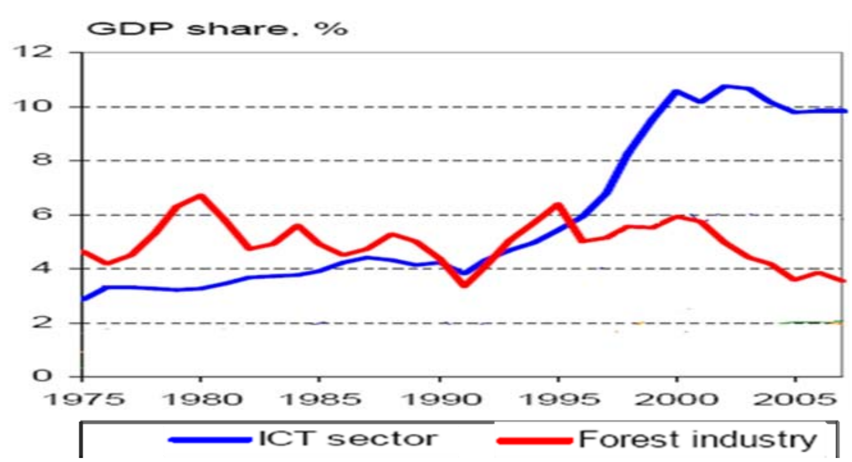


Figure 14. Changes in the GDP shares of ICT sector and forest industry in Finland. (Source: Pohjola, 2008 [48])

5. IT paradox of the digital economy revisited

In the cases presented in the previous section, we saw that ICT contributed a substantial part of economic growth. However, some researchers argue that the New Economy of the 1990s ended unsuccessfully in the US. Finland and Ireland also have recently gone through economic crises. According to the OECD report of 2007, ICT capital accounted for not more than 20% of GDP growth in an average country. From these arguments, it is still debatable whether ICT has a direct effect on improving productivity and accelerating economic growth. Actually, these doubts have existed for a very long time.

The term IT productivity paradox can be traced to what Solow said in 1987: 'You can see the computer age everywhere but in the productivity statistics.' There are largely two arguments about why the IT productivity paradox provokes controversy: First, some scholars argue that the effects of IT investments on production are not as apparent as we would expect because statistical methodologies are not sufficiently developed yet to calculate the relationship exactly. Others claim that ICT is simply not yet fully mature to be effectively incorporated into every step of production and its organizations, and thus the effects of ICT are not completely revealed yet. The latter insist that productivity effects from ICT appear with a time lag after the technologies are developed [49].

Since Solow stated the IT paradox, many research studies have investigated whether there is a positive relationship between ICT and productivity. One of them was Schreyer's [50], which reaffirmed that ICT capital was a critical factor for economic growth in all G7 countries, though to a different degree in each country. Hilbert [49] also validated the high growth from IT and tried to measure it in different ways.

On the other hand, David [51] and Crafts [52] proposed a time lag to explain the IT productivity paradox. Both of them pointed out that it took more than a century for the invention of the steam engine in England, during the Industrial Revolution in the eighteenth century, or the invention of electricity in the nineteenth century to demonstrate practical influences on economic growth. Therefore, both of them were sceptical about Solow's productivity paradox as it judged the relationship between ICT developments and economic growth only on the basis of current observed data. David [51] warned that productivity might be underestimated as it was very hard to measure all the relevant outputs that a technology produced when productivity was evaluated. In the case of electricity, although the filament was invented in 1879, it was not until the early 1920s that electricity affected productivity improvement, because the relationship could be visible only after electrical equipment spread among at least a half of factories, stores, and homes.

Figure 15 shows that a single technological paradigm forms the S-curve by going through the three steps of slow growth, rapid growth, and leaving off, while the overall sequence of cascaded technological paradigms sticks to an exponential growth trend [53]. Kurzweil's [53] S-curve explains the contradiction that the productivity does not increase, and even appears to decrease, as a technology progresses in the early years of the technological revolution. This is not an uncommon phenomenon during the period of a paradigm shift.

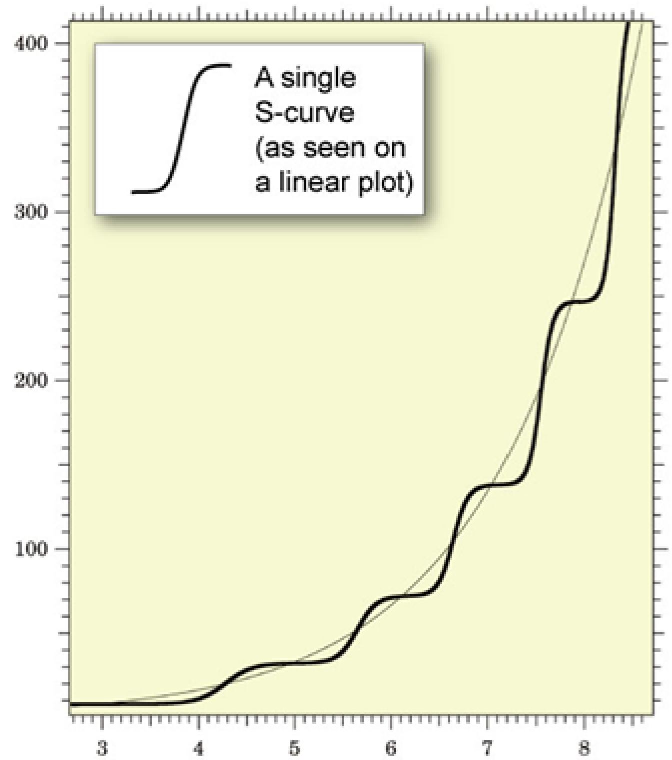


Figure 15. An ongoing exponential sequence made up of a cascade of S-curves (linear plot). (Source: Kurzweil, 2005, p. 43 [53])

Meanwhile, Hilbert [49] presented the theory of creative destruction of innovation, which proposes that one technological innovation pulled the next, the former becoming the foundation for the latter in the process. According to this mushroom effect of innovation, the next technological innovation has already begun when the former reaches its peak, but has a latent period to capture the market in an industry or a society. From this point of view, the effect of a new technology on industries in general, or on productivity improvement in particular, may well appear to be relatively lower than that of the existing technology in its incipient stage (Figure 16).

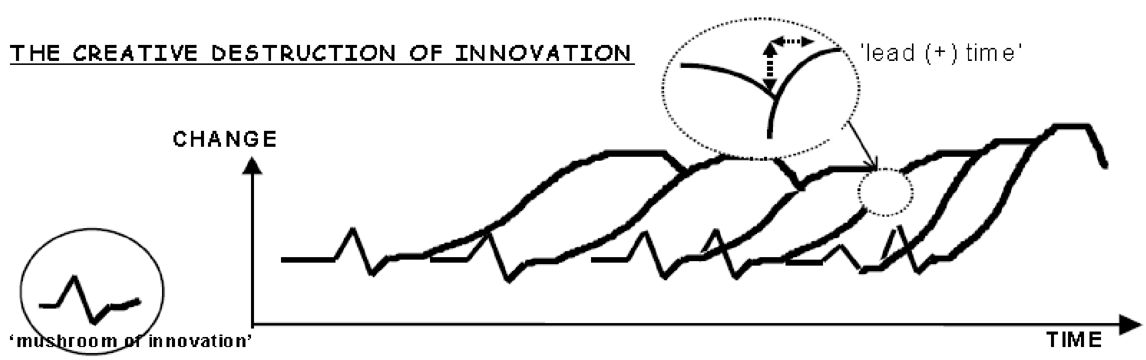


Figure 16. The creative destruction of innovation. (Source: Hilbert, 2001, p. 53 [49])

It is possible that the growth of the digital economy, at the start, is slower than that of the existing industrial societies. However, it just looks slower because this new economy is in its initial phase. Brynjolfsson and Hitt [7] said that the long-term benefit from IT investments was profit, not only directly from IT but also indirectly, from changes of technological systems and organization. They forecasted that even if computerization could not improve the current productivity, it would finally bring in productivity growth as ICT grows progressively faster. David and Olsen [54] mentioned that the speed of technology adoption was slower than the social optimum needed for the transfer of technology in an industry. Gordon [55] published a paper in 2002 proposing that technological acceleration through ICT in the 1990s could create an IT boom based on the social infrastructure that the US already had, but could not tell if it affected the productivity growth of other industries and the whole society. However, in another paper of his, published in 2003 [56], he agreed that the sudden productivity increase in the early 2000s was due to the continuous increase of ICT investments. As with these studies, during the relatively short period of time called the 'transition period', the positive relationship between ICT development and economic growth might not be fully recognized. Putting all the above ideas together, the stagnation of the digital economy at its immature stage is also a part of its faster-accelerating characteristics, which is the main topic of this paper, because an accelerating curve exhibits the characteristic of the very slow rate of increase in the initial phase. This situation is almost identical to the history of the industrial society. A controversy about the Industrial Revolution existed in the initial stage of the industrial society as well. Scepticism about the Industrial Revolution was on the rise among people who experienced low growth in the initial stages of the industrial society, but later it turned out that this was due to a misunderstanding about the characteristic of accelerating economic growth of the industrial society. Thus, this paper predicts a faster-accelerating economic growth through ICT as an inevitable outcome, notwithstanding the IT productivity paradox of the current digital economy. Furthermore, the state-of-the-art science and technologies such BT and NT, which are advancing phenomenally, are expected to be drivers of an explosive growth to power the economy towards the faster-accelerating knowledge-based society.

6. Discussion and Conclusions

The knowledge-based society is expected to bring about significant changes in the production process, which means that intellectual production factors such as knowledge and information will substitute for a large portion of traditional material production factors such as labour, capital, resources, and energy. In the future, new knowledge-based goods and services made of these new production factors will provide the driving force for economic growth and national development. The ICT Revolution that has given rise to the digital economy is the very first key to open the knowledge-based society.

Regardless of whether the digital economy represents a continuation of the previous industrial economy or the emergence of a new type of economy, it is clear is that a transition to the digital economy brings about faster changes and development than were ever witnessed in the previous industrial societies. This paper concludes, from an investigation into the definition, characteristics, and mechanism of the faster-accelerating digital economy, that the digital economy is a new economic growth structure, which is qualitatively different from the former industrial society, despite the similarity in the growth pattern. In addition, it is confirmed that the innovative development of ICT is the force behind the faster acceleration of the digital economy.

The major contribution of this paper is to classify the reasons of the digital economy's faster-accelerating economic growth into three groups and to investigate how these features make the ERS of an economy more efficient. The digital economy has already been studied by many scholars, who have advanced various theories, including the increasing returns of software industries, path dependency, network externality, and the tipping effect in technology standardization. However, although these theories could explain why a certain industry accomplished a sudden growth in the digital economy, they were insufficient to describe the changes of an economy as a whole or explain how different from former societies is the one arising from the digital economy in exhibiting its growth pattern. This paper segmented the ERS of the digital economy by dividing the ICT development effects in the economy into the efficient uses of traditional industries through convergence, the creation of new industries by ICT and the IRS production function driving new demand, and the total social changes expediting the economic circulation. In particular, we theoretically verified that the faster-accelerating economic growth, distinct from the industrial society, occurred because the IRS short-term production function along with the rapid technological progress of the digital economy could accelerate the growth curve of the digital economy faster than the previous industrial societies in the long term.

The second contribution of this paper is to demonstrate real-world examples that the digital economy indeed surpassed the traditional industrial societies in the rate of economic growth and to reaffirm the potential for the advancement of the knowledge-based society of the future. The examples provided in this paper, the US, Ireland and Finland, experienced faster economic growth than before by the advancement of ICT industries and the technological innovation. The effect of the efficient uses of traditional industries by ICT, combined with the effect of the creation of new industries by ICT, led to the improvement of labour productivity. Besides, the effect of the creation of new industries by ICT influenced the growth of GDP as well as the change in labour productivity. These examples showed that the countries far surpassed other countries in terms of GDP and the gap became progressively larger because they entered the digital economy earlier than others. Although all three countries seemed to face stagnation in their economies by the late 2000s, this was due to other problems not directly related to the characteristics of the ICT-based digital economy. It is easily expected that, when the knowledge-based society becomes fully mature in the future, the digital economy based on ICT will be the society in which economic growth will accelerate faster than in any society that existed previously.

Third, this paper pointed out that the ICT productivity paradox was based only on short-term and temporary situations at the incipient stage of the digital economy. The ICT productivity paradox arose from a contradiction when the effect of ICT investments for economic growth fell short of expectations. It is possible that the growth rate of the digital economy, in spite of its faster-accelerating property, may be slower, for a while, than that of the existing industrial society that has reached full maturity, because the digital economy has just started. This situation is similar to the development process of the industrial society. The economic growth of the industrial society started slowly in the beginning despite the inventions of steam engine and electricity. However, after the dissemination and utilization of the technologies began in earnest, no other old production style could catch up with the mass production of the industrial society. Therefore, the digital economy based on ICT might also exhibit low growth during the transition period, which caused scepticism about the Industrial Revolution in England. However, it will ultimately reveal its original characteristic of faster acceleration.

Finally, the paper provides insights into the economic growth of the knowledge-based society. If it was the Industrial Revolution that overcame the Malthusian trap of the agricultural society, it will be the knowledge-based revolution initiated by ICT that will resolve the fundamental challenges and hardship that modern industrial societies are now facing. Global issues such as the exhaustion of energy resources, global warming, and the destruction of the ecological environment are problems caused by industrial societies, which industrial technologies could not resolve. They are basically considered as the unavoidable cost paid to accomplish the remarkable benefits that caused the population to increase about 6.8 times and the income level to rise about 9.1 times compared to the days of the Industrial Revolution in the late eighteenth century. In order to resolve the cost issues without abandoning these achievements, we have to pursue future state-of-the-art new technologies like ICT, BT, and NT, which generate new value, rather than adopt solutions based on the social sciences, like the law and the regulations. Moreover, it is true that there is no better solution than to rely on state-of-the-art new technologies for the desperate issues humankind confronts in these days, and for the improvement of the quality of life while absorbing the rapid increase of the developing countries' populations. No one yet knows how BT and NT, which we will develop some day in the not too distant future, will contribute to the welfare of humankind through economic growth and development. In this regard, this paper, which investigated the fruits of the digital economy that humankind has already tasted to some extent, though it has just arrived, is expected to provide clues for the discovery of the wonderful realities of the future knowledge-based society that will have reached full maturity.

Notes

1 The expansive reproduction system (ERS) is a unique growth structure of an industrial society that expands its economy through capital accumulation and technological innovation (Kim, Kim and Lee, 2010).

2. OECD-Europe covers, in addition to EU 15, the Czech Republic, Hungary, Iceland, Norway, Poland, the Slovak Republic, Switzerland, and Turkey. We assume there is no significant difference between EU15 and OECD-Europe, with regard to their representativeness.

3 The US economy experienced a temporary recession in 2001. The adjustment process after the rapid economic growth, the decrease in bond price and increase in interest rate,

the increase in energy price, the collapse of the high-technology sector, and the impact of Y2K and 9/11 are cited as the reasons (White House, 2002).

4. The Bureau of Economic Analysis (BEA) grouped computer and electronic products, publishing industries (includes software), information and data processing services, and computer systems design and related services under the ICT-producing industry and estimates its GDP independently.

5. Foreign direct investment (FDI) played an important role in the development of Ireland. However, before it could improve the productivity and efficiency of the domestic firms of Ireland, the inflow of FDI decreased, and finally the gross inflow of FDI turned to gross outflow in 2004. This lowered the potential growth rate of Ireland and expanded the GDP gap, which in turn intensified the economic bubble. In late 2007 when the bubble crashed, the banking industries suffered from a lack of funds as housing prices plummeted and bad loans increased. Finally, the aftermath of the global financial crisis in 2008 pushed Ireland into a period of economic recession.

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