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Measuring GDP in the digital economy: Increasing dependence on uncaptured GDP

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ABSTRACT

As revealed by Tapscott in his best-seller *The Digital Economy* published in 1994, the Internet has dramatically changed the way of conducting business and our daily lives. Further advancement of digital innovation, including cloud, mobile services, and artificial intelligence, has augmented this change significantly and provided us with extraordinary services and welfare never anticipated before. However, contrary to such an accomplishment, productivity in industrialized countries now confronts an apparent decline raising the question of a possible productivity paradox in the digital economy. The limitations of gross domestic product (GDP) statistics in measuring the advancement of the digital economy have become an important subject.

While this mismatch is an old problem rooted in the dynamics of product innovations, since mismatch brought about by information and communication technology (ICT) is very strong, finding a solution to this critical issue has become highly crucial in the digital economy.

Based on an intensive review of preceding studies and empirical analyses of national, industrial and individual behaviors in the digital economy, this paper attempted to draw a perspective on this critical issue.

By means of an analysis of co-evolution among a shift in people's preferences from economic functionality to supra-functionality beyond economic value, the advancement of ICT and paradigm change to uncaptured GDP, a solution to this critical issue was investigated. New insights for measuring the digital economy were explored which provide insight into integration of national accounts with product-oriented micro-analysis efforts.

1. Introduction

The dramatic advancement of the Internet has led us to the digital economy,[1] which has changed the way of conducting business and our daily lives (Tapscott, 1994). The further progression of digitized innovation, including cloud, mobile services, and artificial intelligence, has augmented this change significantly and provided us extraordinary services and welfare never anticipated before. However, contrary to such an accomplishment, productivity in industrialized countries has confronted a structural decline (OECD, 2016; US Council on Competitiveness, 2016), as demonstrated in Fig. 1, and raised the question of a productivity paradox in the digital economy.[2] The limitations of the gross domestic product (GDP) statistics in measuring the advancement of the digital economy have become an important subject (Brynjolfsson and McAfee, 2014; Economist, 2016; IMF, 2017b).

The Organization for Economic Cooperation and Development (OECD) has raised the question "Are GDP and productivity measures up to the challenges of the digital economy?" (Ahmad and Schreyer, 2016). It points out the following seven productivity loop holes derived from the advancement of the digital economy: (i) new forms of intermediation of peer-to-peer services, (ii) blurring production boundaries that lead consumers to become producers, (iii) consumer durables and investment, (iv) free and subsidized consumer products, (v) free assets produced by households, (vi) vague transactions through e-commerce, and (vii) mismeasurement of ICT price.

The above points can be attributed to the advancement of the digital economy initiated by the Internet and to the role of online intermediaries (Copenhagen Economics, 2013, 2015; OECD, 2010).

As the GDP is considered the most fundamental yardstick in devising economic policies, a large number of research have attempted to

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[1] As shown by Tapscott (1994) in his bestseller *The Digital Economy*, the Internet has dramatically changed the way of business and daily living. The digital economy is also known as the Internet economy, the new economy, or the web economy.

[2] The causal relationship of why digitalisation leads to productivity decline is demonstrated in Section 4.3.

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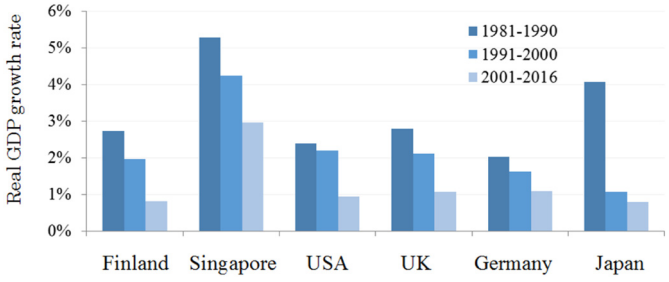

Fig. 1. Trend in productivity decline in six countries: Real GDP per capita growth rate (1981–2016).
Indicate average growth rate in three periods. Country order is world ICT ranking in 2014 (WEF: See Table 3).
Source: World Economic Outlook Database (IMF, 2017a).

understand the issues in GDP as a measurement tool in representing the true picture of a digital economy (e.g., Feldstein, 2017; Syverson, 2017; Groshen et al., 2017; US Council on Competitiveness, 2016; Byrne and Corrado, 2016). However, none has provided rational answers to this fundamental question (IMF, 2017b).

Without a reasonable answer to the above question, decision making and policy implementation can become biased and misleading. Furthermore, the social well-being enabled by digitization is feared to not be duly considered in identifying a nation's optimal trajectory.

We now confront the third productivity paradox, following the earlier computer-initiated productivity paradox (in the late 1980s to the 1990s) and the Internet-initiated productivity paradox (in the early 2010s). The third paradox raises a fundamental question on the GDP myth.

This mismatch is an old problem rooted in the dynamics of product innovations, and it has been affecting our statistical understanding of change and growth for decades.

Nobel Laureate in Economics Richard Stone dealt with the challenge of measuring changes in quality in his impactful book “Quality and Price Indexes in National Accounts” (Stone, 1956). He suggested that quality differences can be measured if information can be obtained based on a set of specifications that can explain price differences among different grades of a product in the base period. Since then, intensive efforts for measuring the prices of quality change in new products have been undertaken. Hedonic prices approach introduced by Griliches (1961) played a central role and successive efforts toward an appropriate analysis of the changes in product quality have been continued (Wasshausen and Moulron, 2006).

Contrary to such successive efforts in product quality, sufficient attempts have not necessarily been undertaken in the national statistical accounts to integrate their sources with these efforts.

Given that the shift in hedonic prices brought about by information and communication technology (ICT) is stronger than the shift that had been taking place in the previous decades, this integration becomes a crucial subject in the digital economy.

By realizing the two faced nature of ICT, the authors postulated it as a trap in ICT advancement (Watanabe et al., 2015b). The advancement of ICT generally contributes to enhancing the prices of technology through new functionality development, as typically demonstrated by iPhoneX, which was released in November 2017.[3] However, contrary to traditional ICT, the dramatic advancement of the Internet has resulted in decline of ICT prices because of the digital contents' characteristics of provision of freebies, easy copying (replication), and mass standardization.

The continued drop in ICT prices results in the declining marginal productivity of ICT in leading ICT firms.

In addition to such supply-side feature in the digital economy, demand-side feature as the shift in people's preferences from economic to beyond economic value (encompassing social, cultural, and emotional values) is significant (McDonagh, 2008; Watanabe et al., 2015a).

With such notable features in the digital economy, the authors stressed the significance of increasing dependence on uncaptured GDP by postulating that the Internet promotes a free culture, the consumption of which provides utility and happiness to people, but that it cannot be captured through GDP data, which measure revenue. This added value that provides people with utility and happiness beyond economic value is defined as uncaptured GDP. This shift in people's preferences induces the further advancement of ICT initiated by the Internet, which intensifies the increasing dependence on uncaptured GDP. Therefore, a new co-evolution among Internet advancement, increasing uncaptured GDP dependence, and people's preferences shift has emerged (Watanabe et al., 2015a, 2015b, 2016a, 2016b, 2017b, 2017c; Naveed et al., 2017).

A possible solution to the critical issue in the digital economy, the limitations of GDP measurement can be obtained by analyzing the dynamism of this co-evolution which may also provide insight into the integration of national accounts with product-oriented hedonic prices efforts.

With this expectation, based on the intensive review of preceding studies and empirical analyses of national, industrial and individual behaviors in the digital economy, this paper attempted to draw a perspective on this critical issue.

By realizing noteworthy co-evolution among a shift in people's preferences from economic functionality to supra-functionality beyond economic value, the advancement of ICT and subsequent quality change in digital products, and paradigm change to uncaptured GDP, a solution to this critical issue was investigated. Thus, new insights for measuring the digital economy were explored which provide insight into integration of national accounts with the above product-oriented micro-analysis efforts.

Section 2 reviews the productivity paradox in the digital economy. Section 3 discusses the structural sources of productivity decline in the digital economy. Section 4 analyzes supply-side features; the two-faced nature of ICT. Demand-side features; the shift to non-monetary consumption is analyzed in Section 5. The measurement of uncaptured GDP is demonstrated in Section 6 by synchronizing both features. Section 7 summarizes the noteworthy findings, policy suggestions, and future research.

2. Review of productivity paradox in the digital economy

2.1. Increasing significance of the mismatch in the digital economy

2.1.1. Mismatch between the quality of products and statistical sources

The mismatch concerns all our macro economic records since their introduction by Nobel Laureate in Economics Richard Stone just after WWII.[4] While Stone made a significant contribution to the development and diffusion of national accounting system as its founder, he always stressed this concern (Baranzini and Marangoni, 2015). In his impactful book “Quality and Price Indexes in National Accounts” (Stone, 1956)[5] he dealt with the challenge of measuring changes in quality. He suggested that quality differences can be measured if information can be obtained based on a set of specifications that can explain price

[3] Price of Apple's smartphone has demonstrated increase as functionality advances as follows: iPhone SE (US$ 399), iPhone 6S (US$ 549), iPhone7 (US$ 649), iPhone8 (US$ 699), iPhone8 plus (US$ 799), and iPhoneX (US$ 999).

[4] Snow produced the national accounts figures covering the years 1938–1944 in 1945 which laid a solid foundation for national income accounting in the UK and led to the current System of National Accounts.

[5] This book is published by OEEC (current OECD) pitching for public officers to the development of an international standard for national accounts (Pesaran and Harcourt, 2000; Baranzini and Marangoni, 2015).

differences among different grades of a product in the base period. This was appreciated by "great thoughtfulness, ingenuity, and clarity of exposition and merits the attention of every user of index numbers" (Chipman, 1959).

However, this is a difficult question, and it "might have been more suitable put in a technical supplement" (Moss, 1958); therefore, a "more theoretical and less empirical method of estimating implicit prices seems to be called for" (Chipman, 1959).

In his Nobel Memorial Lectures in 1984, Stone pointed out the difficulty in estimating the prices of new types of goods for national accounting (Stone, 1984).

Market prices do not necessarily reflect longitudinal changes in the quality of products, particularly new products, resulting in misleading statistical sources. While new products provide better quality services to their users, they are rarely reflected in the change in their market price. This is an old problem rooted in the dynamics of product innovations, and it has been affecting our statistical understanding of change and growth for decades.

2.1.2. Exacerbation in the digital economy

However, the digital economy has provided much stronger change than that which had been taking place in the previous decades due to the following unique features (Watanabe et al., 2018b):

(i) Expanding ICT and the digital economy at a tremendous pace;
(ii) Value can be provided free of charge;
(iii) ICT prices decrease and productivity declines;
(iv) Digital goods are mobile and intangible, thus leading to substantially different business models;
(v) The boundary between consumer and producer is thinning, and consumers are becoming "prosumers;"
(vi) Barriers of entry are low, making companies to innovate seamlessly;
(vii) Companies can enjoy fully network externalities and the subsequent self-propagation phenomenon embedded in ICT products and services[6];
(viii) Companies are bipolarized between those enjoying network externality and those not;
(ix) Digital companies have a tendency toward a gigantic monopoly; and
(x) Contrary to a traditional monopoly, this new monopoly can enhance convenience.

Consequently, the digital economy has exacerbated the above mismatch problem (Ahmad and Schreyer, 2016).

The available statistics inevitably lag behind the reality they are meant to describe. When there is a structural change in the economy, such as digital transformation, the gap between statistics and reality may be so great that the lock-in to the existing statistical framework due to the constellation of interests involved could break (Coyle, 2016).

Although there have been critics of the centrality of GDP growth in economic policy throughout the postwar lifetime of modern national accounting, their critiques seem to have been gaining fresh traction (Coyle, 2016). Recently, questions about the effect of digital technologies on the understanding and measurement of the economy have also come to prominence (Bean, 2016; Coyle, 2016).

2.1.3. Hedonic pricing approach

Accurate price indices are crucial for preparing true estimates of GDP and corresponding productivity measures. The price index must capture price changes for 'relevant' market basket goods, while at the same time controlling for changes in the characteristics and/or quality of these goods (Wasshausen and Moulron, 2006).

Traditional price indices are well suited for capturing price change for goods that exhibit little or no quality change over time; however, for products whose characteristics and/or quality are changing rapidly (e.g., ICT goods) or are heterogeneous by nature (e.g., custom software), hedonic methods may be more suitable and practical (Wasshausen and Moulron, 2006).

Hedonic prices were introduced by Griliches (1961). While some preceding attempts to apply hedonic techniques to price statistics exist (e.g., Court, 1939; Stone, 1954, 1956; Waugh, 1928), Griliches took an unconventional method - then on the periphery of price statistics - and demonstrated to the economics and statistics community its use in addressing critical quality adjustment problems that previously had been considered intractable (Wasshausen and Moulron, 2006).

Following Griliches, hedonic methods quickly grew to be a new branch of economic research (e.g., Berndt, 1983; Griliches, 1971, 1990; Triplett, 1975, 1987, 1990).

Hedonic prices try to measure the deflated monetary price of a good by considering changes in quality. As identified by Stone in the 1950s, the assessment of changes in the quality of goods is problematic and quite subjective. This is the ultimate cause of the limited influence of the methodology.

The shift in hedonic prices brought about by ICT is stronger than the shift that had been taking place in previous decades (Wasshausen and Moulron, 2006; BLS, 2011; Byrne and Corrado, 2015; Corrado and Ukhaneva, 2016; Cavallo and Rigobon, 2016; Wasshausen, 2017); thus, the digital economy has exacerbated this problem (Ahmad and Schreyer, 2016).

2.1.4. Integration of national statistical accounts with accurate price index efforts

Although digitalisation has increased the size of this problem, it may also be part of the solution. There is a considerable scope to complement traditional methods of price measurement with new data sources and data-gathering techniques, including scanner data and web-scraping, which provide the capacity to collect large samples of prices at a high frequency (Ahmad and Schreyer, 2016).

Griffith and Nesheim (2013) demonstrated the significance of the scanner data approach in assessing consumers' willingness to pay for the organic characteristics of food products. These pioneer challenges explore a complex hedonic pricing methods approach by using the advancement of digital innovation. The evidence suggests that the more timely collection of data and information using digitalised sources can provide robust and more efficient alternatives (Ahmad and Schreyer, 2016).

Contrary to such successive efforts toward an appropriate analysis of the changes in product quality, sufficient attempts have not necessarily been undertaken in the national statistical accounts to integrate their sources with these efforts.[7]

Given that the shift in hedonic prices brought about by ICT is stronger than the shift that had been taking place in the previous decades, as reviewed earlier, this integration becomes a crucial subject in the digital economy. In addition, provided that the significant shift in people's preferences from economic functionality to supra-functionality beyond economic value encompassing socio, cultural and emotional values (McDonagh, 2008), the measurement of changes in the quality of goods and services corresponding to people's satisfaction will certainly become complicated. Thus, the above integration becomes highly

[6] ICT in which explicit network externalities function to alter the correlation between innovations and institutional systems. This altered correlation creates new features of the innovation leading to an exponential increase (Watanabe et al., 2004). Schelling (1998) portrayed an array of logistically developing and diffusing social mechanisms stimulated by these interactions.

[7] Hedonic price indices used to deflate a number of GDP final demand components in recent years remain 20% of the nominal GDP (Wasshausen and Moulron, 2006).

crucial in measuring GDP in the digital economy.

Provided that there exists noteworthy co-evolution among a shift in people's preferences from economic functionality to supra-functionality beyond economic value, the advancement of ICT and subsequent quality change in digital products, and paradigm change to uncaptured GDP as reviewed earlier (see details of this co-evolution in Section 2.4.2), may provide insight into integration of national accounts with the above product-oriented micro-analysis efforts.

2.2. From the "computer-initiated" to "internet-initiated" productivity paradox

2.2.1. Computer-initiated productivity paradox

Following the "Productivity Paradox" postulated by Nobel Laureate Solow (Solow, 1987), a significant number of studies has discussed the social and economic effects of ICT advancement. The reaction to the productivity paradox by Brynjolfsson (1993) and several other analyses attempted to understand the relationship between ICT and its productivity (Brynjolfsson and Hitt, 1996; Kraemer and Dedrick, 1994; Lichtenberg, 1995).

Brynjolfsson and Hitt (1996) disproved the productivity paradox and attributed it to the problems in productivity measurement and a long lag between technology investments and productivity gains. Later, Brynjolfsson et al. found a significant positive relationship between ICT investments and productivity (Brynjolfsson and Hitt, 1998; Brynjolfsson and Yang, 1999). In the late 1990s, some signs emerged that productivity in the workplace had improved, especially in the United States, thus encouraging the popular consideration that there was no paradox (Triplett, 1999).

2.2.2. Internet-initiated productivity paradox

A new paradox appeared late in the first decade of this century, and it was largely attributed to the third industrial revolution initiated by the dramatic advancement of the Internet (Rifkin, 2011). In two decades, the Internet became the day-to-day reality of billions of people from only a network of researchers (McKinsey, 2011). Undoubtedly, the Internet has transformed how people live, work, and socialize and how countries develop and grow. Consequently, the computer-initiated ICT world has become more interactive, integrated, and seamless, and this interconnectedness is creating many new opportunities.

However, Cowen (2011) argued that, "Contrary to the dramatic advancement of the Internet and subsequent ICT advancement, we were living through the consequence of a dramatic decrease in the rate of innovation." He claimed that the consequence of reduced innovation was fewer new industries and lesser creative destruction, thus fewer new jobs. He stressed that, historically the technological progress brought a large and predictable stream of growth across most of the economy. However, these assumptions turned out to be wrong or misleading in terms of the Internet. He then suggested it as the possible consequence of the two-faced nature of ICT.

Brynjolfsson, who first reacted to Solow's production paradox in 1993, raised the following: question, "Could technology be destroying jobs?" (Brynjolfsson and McAfee, 2011). By setting the music industry as an example, he contended: "Because you and I stopped buying CDs, the music industry has shrunk according to revenues and GDP. But we're not listening to less music. There's more music consumed than before." He further mentioned that rather than growth, the yardstick could be the one that was deficient and thus postulated the limitations of GDP statistics in reflecting the true picture of digital consumption (Brynjolfsson and McAfee, 2014).

Lowrey (2011) maintained that the Internet promotes a free culture, the consumption of which provides utility and happiness to people, but that it could not be captured through the GDP data, which measure revenue.

2.3. Limitations of the GDP in measuring the digital economy

2.3.1. Emergence of a free culture

Several analyses and debates were initiated to understand the sources of the so-called free culture promoted by the Internet.

2.3.1.1. Unique functions derived from online intermediaries. Online intermediaries play a core role in how the Internet functions, and the Internet relies on the efficient operation of the online intermediaries, which provide platforms to facilitate the exchange of goods, services, or information online. The Copenhagen Economics (2013) examined the effect of online intermediaries[8] on the GDP of EU 27 countries in 2012. Its report estimated the (i) direct GDP contribution through consumption (EUR 220 billion, 1.7% of the GDP), (ii) indirect GDP contribution through productivity increase (EUR 210 billion, 1.65% of the GDP), and (iii) beyond the GDP measurement contribution (EUR 640 billion, 5.0% of the GDP) derived from B2B platforms by e-commerce, online advertising, and consumer benefits of free services such as Google search, among others. The report also pointed out that these estimates were understated because they did not include the direct contribution of investments (which are hard to measure), and the sociocultural value created by social network development.

2.3.1.2. Consumer surplus. In the digital economy, the economic gain by increasing consumer surplus is another source of uncaptured GDP. Brynjolfsson et al. (revised 2017) analyzed online booksellers and found that the increased product variety available through electronic markets could be the significantly larger source of consumer surplus comparing efficiency gains through increased competition and low average prices. Their analysis indicated that the increased product variety of online bookstores enhanced consumer welfare by US$731 million to US$1.03 billion in the year 2000. This value is 7–10 times larger than the consumer welfare gain from increased competition and lower prices in this market.

Brynjolfsson et al. (revised 2017) also pointed out the possibility of large welfare gains in other Stock Keeping Unit (SKU)-intensive consumer goods, such as music, movies, consumer electronics, and computers. The white paper of Japan's Ministry of Internal Affairs and Communication (2016) demonstrated similar results by analyzing consumer surplus in music and audio-visual services. Analyzing the economics of the Internet of Things (IoT), McKinsey (2015) estimated that consumer surplus derived from the IoT could be more than 10% of the global economy by 2025.

2.3.1.3. New goods and services derived from disruptive innovations. Clearly, new goods are at the heart of economic progress, but this realization is only the beginning of an understanding of the economics of new goods (Brynjolfsson et al., revised 2017).

The US Council on Competitiveness (2016) pointed out that the apparent slowdown in productivity in industrialized countries could simply be due to the lack of capacity in statistical offices to properly measure the massive quality gains and hard-to-measure benefits of relatively new goods and services (e.g., Google, Facebook, and Twitter), which are radical breaks with previous products or, in some cases, are provided for free to users. According to this report, some evidence suggests that statistical agencies can now better understand the economics of new goods and services, however, adjustment issues related to previous gains still remain a problem in accurately measuring productivity growth.

The current estimates for the non-market benefits of free goods and services, such as Google, Wikipedia, and Facebook, do not make up for the shortfall in productivity growth (The US Council on

[8] Online intermediaries provide platforms for the exchange of goods, services, or information over the Internet.

Competitiveness, 2016). Moreover, these estimates may understate the non-market benefits, but knowing so would be difficult.

The Economist (2016) also raised similar concerns by claiming that "GDP is a bad gauge of material well-being and it is a time for fresh approach."

2.3.1.4. Online piracy. In addition to the foregoing beyond-measurement difficulties inherent in disruptive innovations caused by the dramatic advancement of the Internet, the corresponding increase in online piracy is also another difficult issue beyond GDP measurement.

2.3.2. Emergence of uncaptured GDP

Analyzing the economic effect of the advancement of technology in the digital economy, Watanabe et al. (2015a) discussed the two-faced nature of ICT and the emergence of uncaptured GDP, which is fatal to the advancement of the Internet (Watanabe et al., 2015a, 2015b, 2016a, 2016b). They pointed out that, although the advancement of ICT generally contributes to enhance prices of technology through new functionality development, the dramatic advancement of the Internet contributes to decrease prices of technology because of the unique inherent characteristics of freebies, easy copying, and mass standardization. With this understanding, they supported Lowrey's (2011) supposition that the Internet promotes a free culture, the consumption of which provides utility and happiness to people, but that it cannot accurately be captured through the current GDP statistics, which measure revenue. They defined these added values that provide people with utility and happiness beyond economic value under a free culture as an uncaptured GDP.

2.4. New business strategies spinning off from a Product of Things (PoT) society to an IoT society

2.4.1. New stream toward an IoT society

The IoT[9] has the potential to change the base of competition and drive new business models (McKinsey Global Institute, 2015), thus propelling the next phase of the digitization of our society (European Union (EU), 2017).

Aside from discussing the opportunities, some studies indicated the possibility of another productivity paradox. According to McKinsey (2015), the economic effect of IoT would reach US$ 3.9–11.1 trillion per year, which is roughly equivalent to 11% of the global GDP, by 2025. However, McKinsey (2015) also saw the possibility of another productivity paradox in the context of IoT because of a possible lag between technology investments and productivity gains to be reflected at the macroeconomic level.

With the rapid advancement of the Internet and the IoT, our world is transforming into an IoT-based society (Bharadwaj et al., 2013; Internet Society, 2016). The IoT has changed the traditional meaning of the word "product" introduced in the PoT era. In the IoT era, a product can be a technology, device, service (powered by software), flow of data, software application, or any combination of the above.

The transformation of the traditional Internet, in which data are "created by people," into the IoT, in which data are "created by things" (Madakam et al., 2015), generates data at a much larger scale. To capitalize on the highly promising business opportunities of the IoT, global ICT firms need to restructure their business models and embrace sophisticated digital solutions (Bharadwaj et al., 2013).

The importance of business models and digital business strategies (DBS) cannot be over-emphasized because of the challenges and huge interest in the IoT. Bharadwaj et al. (2013) and Kahre et al. (2017) stressed the significance of DBS and discussed the fundamental role of digital technologies in transforming business strategies, business processes, firm capabilities, and the nature of products and services.

They also highlighted the significance of DBS as (i) the significant role of ICT pervading digital resources in other functional areas, such as operations, purchasing, supply chain, and marketing; (ii) going beyond systems and technologies; and (iii) explicitly linking DBS to create differential business value, thereby elevating the performance implications of the ICT strategy beyond efficiency and productivity.

Bharadwaj et al. (2013) also pointed out that the role of ICT strategy should be reconsidered from that of a functional-level strategy subordinating the business strategy in the DBS, which fuses the ICT strategy and the business strategy.

2.4.2. Spin-off dynamism toward a new co-evolution

The authors previously analyzed the business strategies of 500 global ICT firms in 2007 and 2010 (before and after the Lehman shock in 2008) and identified the following strategies for resilient market value creation in the digital economy (Watanabe et al., 2014):

- Dependence on high research and development (R&D) profitability while restraining its elasticity
- Effective utilization of external resources in innovation
- Hybrid management of technology between indigenous R&D and assimilation of spillover technology.

In their succeeding studies, the authors attempted to compare the spin-off dynamism from traditional computer-initiated ICT innovation in the era of the PoT with Internet-initiated ICT innovations by using their developed co-evolutional framework among the advancement of ICT, a paradigm change, and a shift in people's preferences, as illustrated in Fig. 2.

The authors found that, people's preferences have shifted from economic functionality to supra-functionality, consistent with the shift from computer-initiated innovation to the new stream of Internet-initiated innovations. The economic effect of innovation has shifted from captured GDP (monetized consumption) to increasingly uncaptured GDP (non-monetized consumption) because of digital nature, free availability of the products, and new business models (Watanabe et al., 2015a, 2015b, 2016a, 2016b, 2017a).

This concept of spin-off dynamism toward a new co-evolution may shed light on the current critical issues related to the measurement of GDP in the digital economy.

3. Structural sources of the productivity decline in the digital economy

3.1. Measuring the digital economy scheme

Fig. 3 presents the scheme of measuring the digital economy focusing on the dramatic advancement of the Internet. The advancement of the Internet creates new and unique identical services with the characteristics of provision of freebies, easy copying for free, and mass standardization through the development of online intermediaries (OECD, 2010).

New and unique identical services include (i) e-commerce as initiated by Alibaba, Amazon, and Rakuten, which sells efficiently and offers inexpensive services; (ii) search engine with online advertising such as Google and Yahoo, with reduced costs for information search services; (iii) free search engines such as Wikipedia, Linux, and R, with free information search and dissemination; (iv) social networks such as Twitter, Facebook, LinkedIn, and YouTube, with services of finding and exchanging information efficiently; and (v) cloud computing platforms such as Amazon, Apple, Cisco, IBM, Google, and Microsoft provide services that are turning fixed costs into marginal costs.

[9] Internet Society (2015) defines IoT as scenarios in which network connectivity and computing capability extend to objects, sensors, and everyday items not normally considered by computers, allowing these devices to generate exchanges and consume data with minimal human intervention.

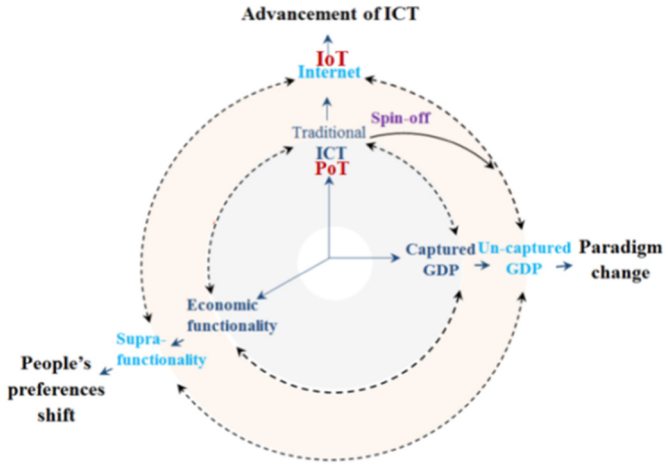

Fig. 2. Spin-off dynamism scheme - Co-evolution among the Internet, un-captured GDP, and supra-functionality.

production boundaries such as consumers as producers, free and subsidized consumer products, and free assets produced by householders; and (iii) increasing the capacity lacking in statistical officers, online piracy, and unlicensed software.

3.2.2. *Transformation into a GDP diminishing structure*

The transformation into a GDP diminishing structure cannot be overlooked. It can be derived from (i) misleading ICT prices by calculating a pseudo ICT deflator in evaluating the real value of ICT-driven digital economy, and (ii) shifting to non-monetary consumption. This type of consumption results in increased consumer surplus, as reviewed in Section 2, and stems from people's preferences shifting to supra-functionality, which is beyond economic value that encompasses social, cultural, and emotional values.

3.3. *Effect on GDP accountings*

As reviewed earlier, as the GDP is considered the most fundamental yardstick in devising economic policy, the identification of the loop-

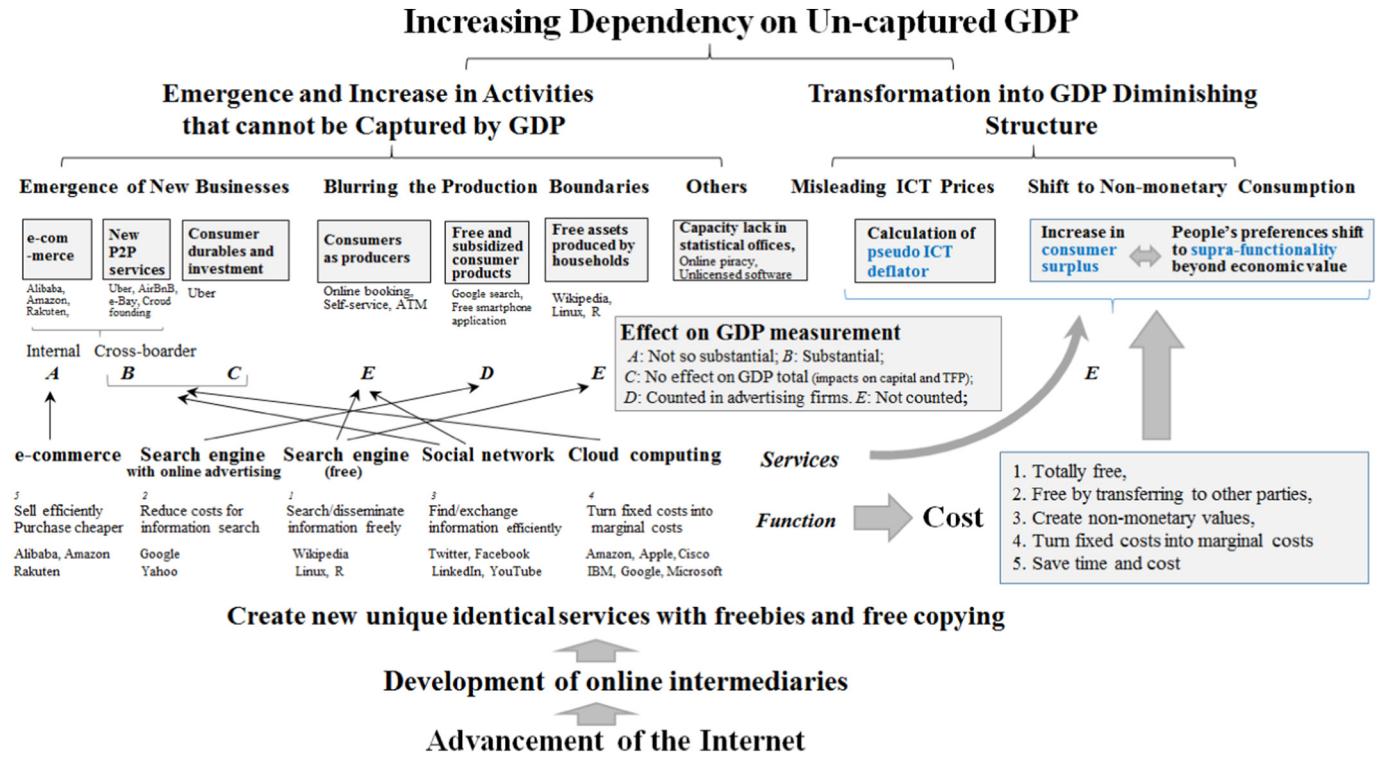

Fig. 3. Measuring the digital economy scheme.
Original sources: The Economic and Social Role of Internet Intermediaries (OECD, 2010), The Impact of Online Intermediaries on the EU Economy (Copenhagen Economics, 2013), Are GDP and productivity measures up to the challenges of the digital economy? (Ahmad and Schreyer, 2016; OECD, 2016), Operationalization of un-captured GDP (Watanabe et al., 2016a).

These services are provided totally free, free by transferring to other parties, creating non-monetary value, turning fixed costs into marginal costs, and saving on time and cost.

3.2. *Increasing dependency on beyond GDP measurement*

3.2.1. *Emergence of and increase in activities that cannot be captured by GDP*

This service creation leads to the emergence and increase in activities that cannot be captured by GDP. These activities are as follows: (i) emergence of new businesses such as e-commerce-based transactions, new P2P services (e.g., Uber, AirBnB, e-Bay, and crowd founding), and consumer durables and investment (e.g., Uber); (ii) blurring the

holes of GDP measurement and the extent of the resultant bias has become a crucial subject under the digital economy. The OECD has been taking a leading role in this identification. It has classified the above effects into A) not so substantial, B) substantial, C) no effect on the GDP total, D) counted in certain parties, and E) not counted by the GDP frame as illustrated in Fig. 3 (Ahmad and Schreyer, 2016).

Although we expect people to enjoy the well-being that is enabled by the digital economy, it is excluded from the GDP accountings and is considered at odds with the conceptual basis of measuring the GDP. This treatment causes fear, which leads to the pseudo optimization of a nation's trajectory management.

The above overview on the structural sources of the productivity decline in the digital economy reveals that the two-faced nature of ICT

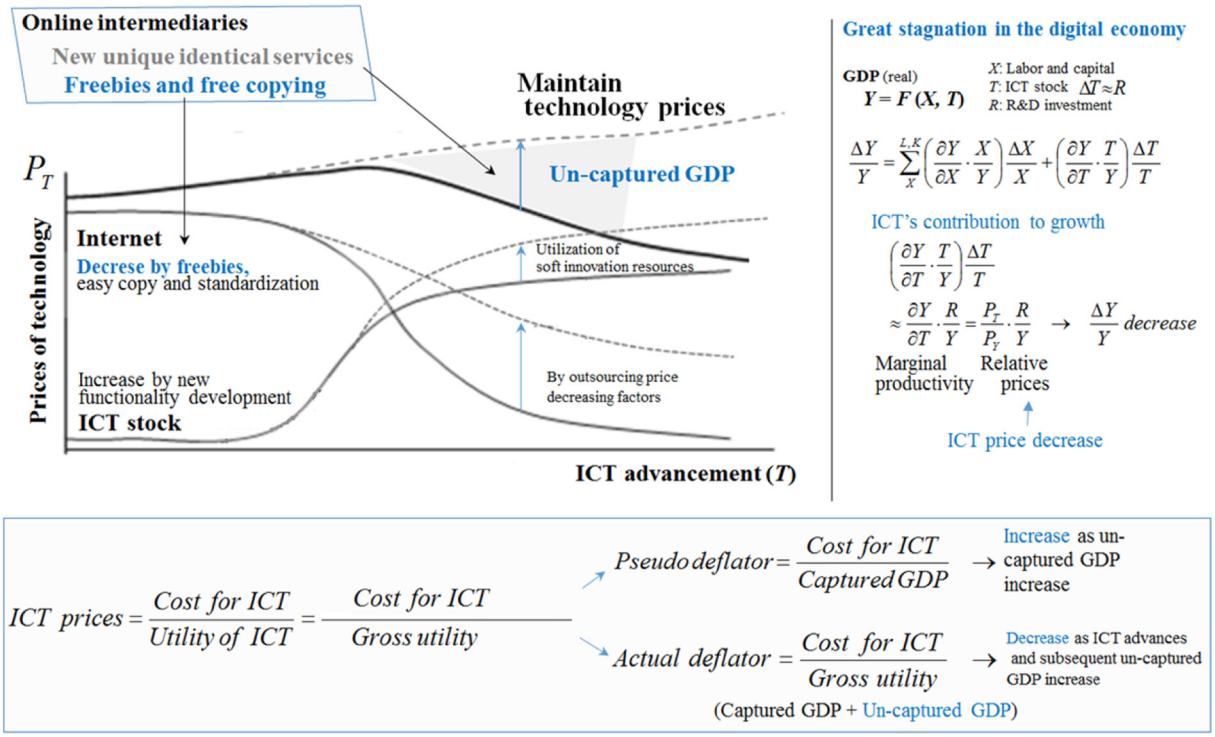

Fig. 4. Calculating the pseudo ICT deflator scheme.
Original source: New paradigm of ICT productivity – increasing role of uncaptured GDP and growing anger of consumers (Watanabe et al., 2015a).

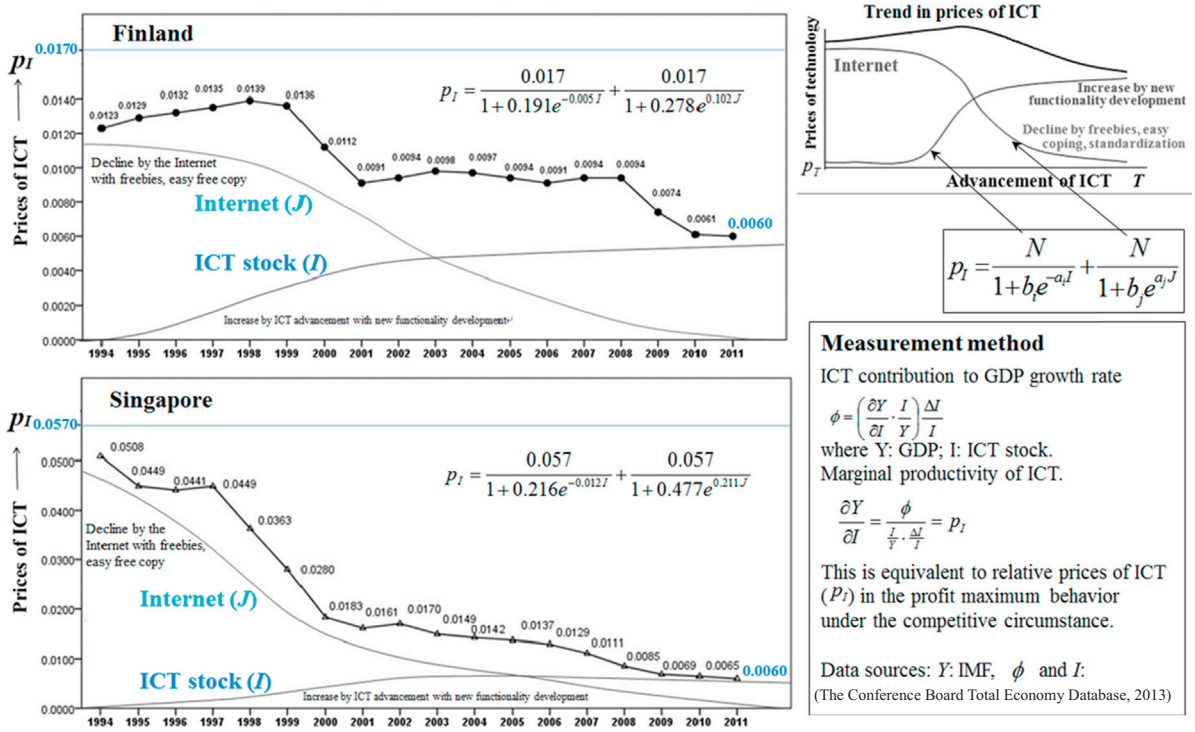

Fig. 5. Trends in ICT prices in world ICT leaders: Finland and Singapore (1994–2011).
Data sources: *I*: ICT stock (The Conference Board Total Economy Database, 2013), *J*: Internet dependency – percentage of individuals using the Internet (ITU, 2014).Original source: New paradigm of ICT productivity – increasing role of uncaptured GDP and growing anger of consumers (Watanabe et al., 2015a).

(which leads to ICT price decline) from the supply-side and the shift to non-monetary consumption from the demand-side are critical sources of the productivity decline in the digital economy. The succeeding sections focus on the analysis of these issues.

4. Two-faced nature of ICT

4.1. Calculation of the pseudo ICT deflator

The dynamism inspired by the preceding review on the structural

sources of the productivity decline in the digital economy triggered by the ICT price decrease is analyzed.

As reviewed in Section 2, the Internet promotes a free culture, the consumption of which provides utility and happiness to people but cannot be captured through the GDP data, which measure revenue. These identical services are called uncaptured GDP. They are provided to compensate for the ICT price decrease because of its two-faced nature, as reviewed previously. Fig. 4 illustrates this dynamism.

The right-hand side of Fig. 4 presents the consequence of a great stagnation in the digital economy (Cowen, 2011). Given that firms seek profit maximization in a competitive market, their marginal ICT productivity corresponds to the relative price of ICT, and the contribution of ICT to the growth rate can be attributed to the product of this productivity and R&D intensity (R&D expenditure per sales). Therefore, ICT price decrease results in the stagnation of growth.

Under this dynamism, ICT prices (ICT deflator) calculated without uncaptured GDP lead to a pseudo deflator, which increases as uncaptured GDP increases. The actual deflator should be calculated by using gross utility, which considers the uncaptured GDP. This deflation decreases as ICT advances, and the subsequent uncaptured GDP increases. The bottom portion of Fig. 4 explains this confusion that results in the miscalculation of the ICT deflator.

4.2. Two faces of ICT in world ICT leaders

To further demonstrate the above supposition of the two-faced nature of ICT, Fig. 5 illustrates the trends in ICT price decline and its sources, namely, the Internet dependency and the ICT stock increase in world ICT leaders Finland and Singapore[10] in the period of 1994–2011 (see the details on the analytical framework and the empirical result in Appendix 1).

Both ICT leaders demonstrated clear evidence of the two-faced nature of ICT. That is, the advancement of ICT (represented by ICT stock increase) leads to increased prices of ICT, whereas the advancement of the Internet leads to decreased prices of ICT.

4.3. Two faces of ICT in 500 global ICT firms: Bipolarization

The preceding analysis demonstrates clear evidence of the two-faced nature of ICT, but it depends on the national-level macro analysis using aggregated data. To confirm this result using micro data, which represent actual competitive behavior in the digital market, Fig. 6 illustrates the trends in ICT prices decrease by ICT advancement among 500 global ICT firms between 2005 and 2016[11] (see the details of analytical framework and the empirical result in Appendix 2).

Provided that global ICT firms seek the profit maximum strategy in the competitive global market, their ICT prices are represented by the marginal productivity of ICT, and their ICT advancement efforts are represented by their gross ICT stock (incorporating all ICT advancement facilities including the Internet relevant facilities) proportional to their broad perspective R&D investment (see Figs. A2 and A3 in Appendix 2).

Fig. 6 shows the bipolarization between highly R&D-intensive firms and relatively non-intensive firms (see Fig. A5 in Appendix 2). The former experiences a price decrease as a consequence of ICT advancement through R&D investment increase, and the latter maintains a virtuous cycle as prices increase with the increase in R&D investment.

This bipolarization can be attributed to the logistic growth nature of this ICT-driven trajectory (Watanabe et al., 2004). The former's behavior demonstrates productivity decline as ICT advances, a consequence of the digital economy.

[10] Finland and Singapore shared world top and second position by world ICT ranking (WEF, 2014a) (see Table 3).

[11] Over 50,000 primary data (500 firms by 7 items by 11 years + 14,438 scientific paper data) were used.

Fig. 6 demonstrates that two-faced nature of ICT advances as years pass and digitization proceeds. The price decrease firms are only 16 out of the 500 global ICT firms in 2005, but they increase to 25 in 2016. Furthermore, highly R&D-intensive firms are confronting stagnation of sales while relatively non intensive firms enjoy sales increase as indicated in Table 1.

All these results support the supposition of the two-faced nature of ICT, which is one of the critical structural sources of productivity decline in the digital economy.

Confronting to such circumstances in the digital economy highly R&D intensive global ICT firms have been endeavoring to activate their latent self-propagating function based on their explicit network externalities function which alters the correlation between innovations and institutional systems and creates new features of innovation leading to an exponential increase. Activated self-propagating function induces new functionality development leading to supra-functionality beyond economic value which corresponds to a shift in people's preferences in the digital economy. Transformative strategy that matches productivity decline derived from the supply side in the digital economy with the structural change in the demand side is thus crucial for the survival strategy in the digital economy (Naveed et al., 2018; Watanabe et al., 2018a, 2018b).

Next section analyzes a shift in people's preferences in the digital economy.

5. Shift from monetary to non-monetary consumption

5.1. Shift from economic functionality to supra-functionality

Fig. 3 illustrates the significance of the shift to non-monetary consumptions as the economy transforms into a GDP diminishing structure in the digital economy.

As a consequence of historical change in the experience of nations and in accordance with the general shift from a commodity-oriented society to a service-and information-oriented society, consumer preference is generally assumed to steadily shift from an economic functionality-driven preference (captured by the GDP) to supra-functionality beyond economic value-driven preference. Here, supra-functionality beyond economic value encompasses social, cultural, aspirational, tribal and emotional values as illustrated in Fig. 7, and these values are not necessarily captured by the GDP (McDonagh, 2008). This shift seems to have a significant relevance to consumer surplus, as reviewed in Fig. 3, and an increasing dependence on uncaptured GDP.

This shift can be clearly observed in Japan, which is extremely sensitive to institutional innovation against external shocks and crises (Hofstede, 1991; Watanabe, 2009). Fig. 8 illustrates this shift as demonstrated by Japan's *Public Opinion Survey Concerning People's Lifestyles*[12] conducted annually by Japan's Cabinet Office.

As shown in Fig. 8, contrary to the steady decline in people's preferences in economic functionality (V), supra-functionality beyond economic value (Q) steadily increases and exceeds V in 1979, the year of the second energy crisis. Whereas Q continues to increase steadily, V declines to its lowest level in 1992, the year immediately after the commercialization of the Internet in 1991. It has remained at the same level since then. A decline in Q due to the Lehman shock in 2008 is followed by a sharp recovery. Consequently, a shifting trend from V to

[12] In this survey, personal preference for future life is chosen from three options: (i) Richness of the heart-spiritual happiness (*since a reasonable level of material affluence has been achieved, future emphasis should be put on spiritual happiness and a comfortable life*), (ii) wealth of things – material affluence (*emphasis should still be put on material affluence for future life*), or (iii) cannot identify explicitly. While the second option corresponds to a preference for economic functionality, the first option corresponds to that of supra-functionality beyond economic value (Watanabe et al., 2011, 2012).

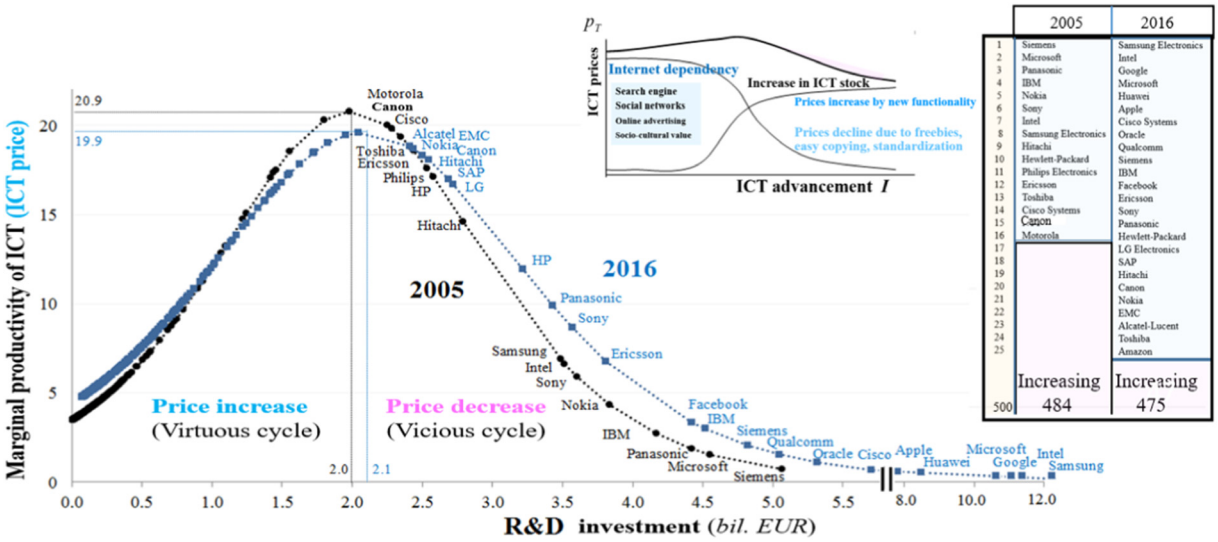

Fig. 6. Bipolarization of ICT price increase and decrease in 500 global ICT firms (2005, 2016).
Sources: Economics of Industrial Research and Innovation, annual issues (European Union (EU), 2017), and each firm's annual reports.

Table 1
Contrast of sales growth rate between highly R&D-intensive and non R&D-intensive global ICT firms (2005–2016) - Average of sales growth rate (% p.a.).
Data sources: Same as Fig. 6.

Highly R&D-intensive firms

	Samsung	Google	Microsoft	Apple	Amazon
2005–2008	14.5	72.6	13.3	38.5	25.5
2009–2012	14.2	27.5	8.8	53.5	38.7
2013–2016	9.7	24.0	8.7	27.5	28.0

Relatively non R&D-intensive firms

	Electronic Arts	Taiwan Semiconductor	Accenture	Kyocera	Free Scale
2005–2008	1.9	9.7	0.8	0.1	−1.5
2009–2012	7.4	15.9	5.8	12.4	0.8
2013–2016	8.0	21.6	14.6	18.6	4.0

Q can be classified into four phases: *Phase 1* (1972–1979), *Phase 2* (1980–1992), *Phase 3* (1993–2008), and *Phase 4* (2009–2012) as indicated D_1–D_4 in Fig. 8, respectively.

This shift in people's preference induces the advancement of the Internet, which in turn accelerates people's preferences shift. Therefore, the advancement of the Internet and the shift to supra-functionality lead to a co-evolutionary dynamism, as illustrated in Fig. 2. Under this co-evolutionary dynamism, conflict occurs between captured GDP and uncaptured GDP during this shift. This conflict leads to a growing anger among consumers (Watanabe et al., 2015a), thus resulting in the decline of consumption. This situation can be considered a source of great stagnation (Cowen, 2011) from the demand side.

During the great stagnation due to this conflict in ICT advancement, which has a two-faced nature of ICT on the supply side, the only possible option for sustainable growth comes from enhancing utility (satisfaction of consumption) through the Internet inducement of ICT stock, namely, marginal propensity of consume and marginal productivity of ICT decline (see the mathematical demonstration and the empirical result in Appendix 3).

Consequently, the effective enhancement of utility as a function of the Internet and ICT stock can be the key for sustainable growth under the current great stagnation in the digital economy.

Furthermore, since consumption shares major part of GDP, how effectively reflects this utility to consumption would be a key measure to assess the state of uncaptured GDP dependence.[13]

5.2. Shift in consumer preferences - measurement of elasticity of utility to consumption

Utility is governed by ICT stock and Internet dependence in the digital economy. The elasticity of utility to consumption[14] can be measured by the sum of elasticity of ICT stock to consumption and that of Internet dependency to consumption. Table 2[15] compares the elasticity of consumption in six countries in 2013.

Fig. 9 presents the contrast between the world ICT leaders Finland and Singapore in this elasticity. Singapore demonstrates conspicuously high elasticity, whereas Finland demonstrates the opposite: it has the lowest level among the six countries compared.

With this observation in mind, Fig. 10 illustrates the contrast in the development trajectories between these world ICT leaders. This figure clearly demonstrates the difference between Finland and Singapore with respect to development trajectory. Finland effectively utilizes the Internet in inducing ICT stock, as demonstrated by its highest Internet elasticity to ICT stock. Its induced ICT stock contributes significantly to satisfying consumer preference for supra-functionality beyond economic value rather than economic functionality only. Consequently, increased ICT does not reflect increased consumption, which is measured by the GDP value, thus resulting in a low GDP growth rate. Although its ICT significantly contributes to supra-functionality beyond economic value, it cannot necessarily be captured by GDP.

[13] Lower level of utility reflection to consumption suggests higher level of uncaptured GDP dependence.

[14] Elasticity is the measurement of how responsive an economic variable (X) is to a change in another (W). The elasticity of X to W (X elasticity to W) ε_{WX} implies a 1 % increase in X increases ε_{WX} % increase in W, and represents the efficiency of X inducement of W.

[15] This elasticity is computed by using a consumption function governed by I and J as follows: $C = C(I,J)$ = Taylor expansion to the secondary term. $\ln C = a + b\ln I + c\ln J + d\ln I\cdot\ln J$,
$\varepsilon_{cj} = \frac{\partial \ln C}{\partial \ln J} = c + d\ln I + (b + d\ln J)\cdot\frac{\partial \ln C}{\partial \ln J} = c + d\ln I + (b + d\ln J)\cdot\varepsilon_{ji}$ where a–d: coefficients (see the original source of Fig. 9).

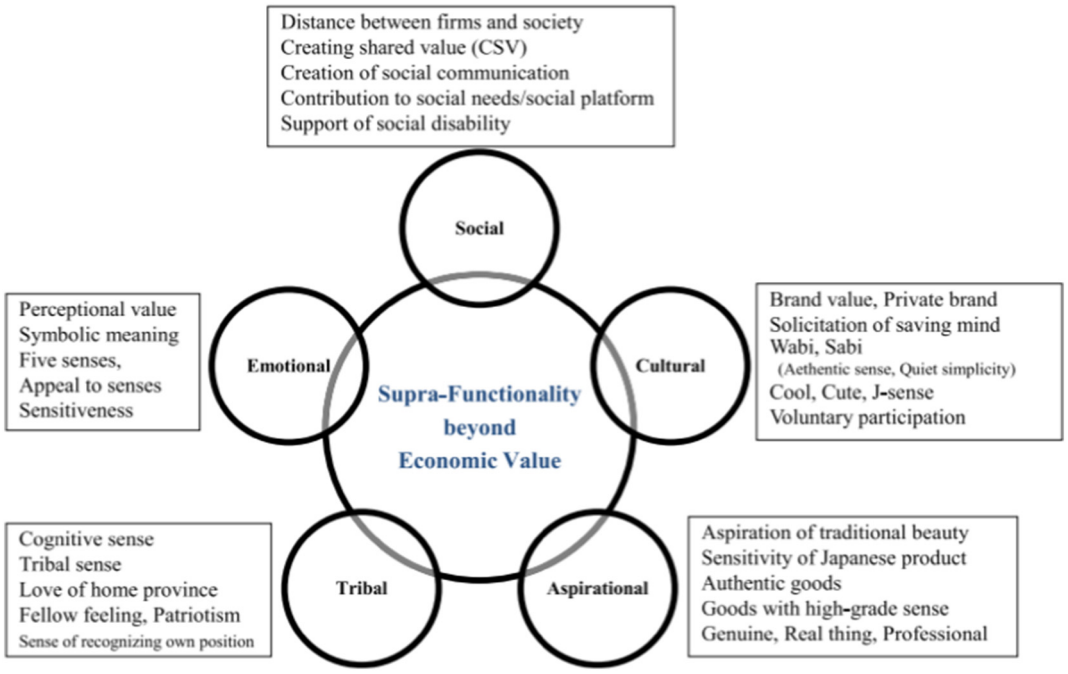

Fig. 7. Basic concept of supra-functionality beyond economic value.
Original source: New paradigm of ICT productivity – increasing role of uncaptured GDP and growing anger of consumers (Watanabe et al., 2015a).

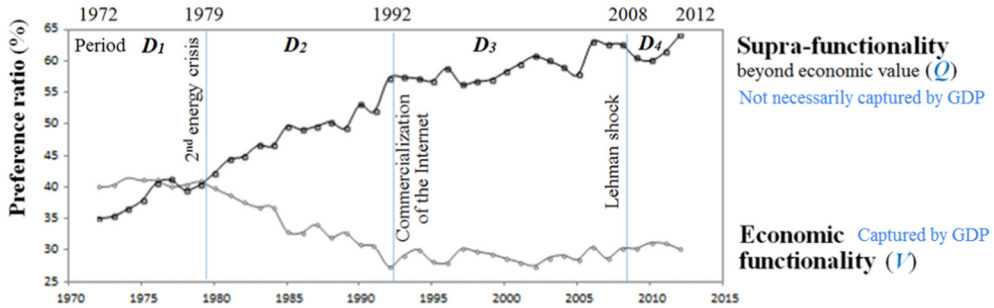

Fig. 8. Trends in the shift of preferences in Japan (1972–2012).
Source: National Survey of Lifestyle Preferences, annual issues (Japan Cabinet Office, 2012).

Table 2
Elasticity of utility to consumption in six countries (2013).

	Finland	Singapore	USA	UK	Germany	Japan
Efficiency of *J* inducement of *I* 1. *J* elasticity of *I* (ε_{ij})	0.75	0.39	0.55	0.39	0.22	0.21
Efficiency of *J* inducement of *C* 2. *J* elasticity of *C* (ε_{cj})	0.23	0.49	0.37	0.15	0.10	0.10
Efficiency of *I* inducement of *C* 3. *I* elasticity of *C* ($\varepsilon_{ci} = \frac{\varepsilon_{cj}}{\varepsilon_{ij}}$) [2/1]	0.30	1.27	0.68	0.40	0.47	0.48
Extent of reflection of *U* to *C* 4. *U* elasticity to *C* (ε_{cu}) [2+3]	0.53	1.76	1.05	0.55	0.57	0.58

$U = U(V, Q)\ V = (I, J), Q = (I, J)$

$$U = U(I,J) = \frac{\partial U}{\partial I}\cdot I + \frac{\partial U}{\partial J}\cdot J = \frac{\partial U}{\partial I}\left(\frac{\partial C}{\partial I}\cdot I + \frac{\partial C}{\partial J}\cdot J\right)$$

$$\frac{\partial C}{\partial U}\cdot\frac{U}{C} = \frac{\partial C}{\partial I}\cdot\frac{I}{C} + \frac{\partial C}{\partial J}\cdot\frac{J}{C}$$

$(\varepsilon_{cu})\quad(\varepsilon_{ci})\quad(\varepsilon_{cj})$

U: utility, *C*: traditional consumption
V: economic functionality, *Q*: supra-functionality
J: Internet dependency, *I*: ICT Stock

Singapore's behavior is contrary to that of Finland. Although Singapore's ICT inducement by the Internet is smaller than that of Finland, it contributes largely to consumer preferences for economic functionality, which is captured by the GDP value, thus leading to a high GDP growth rate (5.85% in Singapore vs 0.57% in Finland on average for 2006–2013).

6. Measuring uncaptured GDP

6.1. Measurement of uncaptured GDP

In the spin-off dynamism that leads to the co-evolution among the Internet, uncaptured GDP, and supra-functionality beyond economic value, as illustrated in Fig. 2, stimulation by ICT advancement and

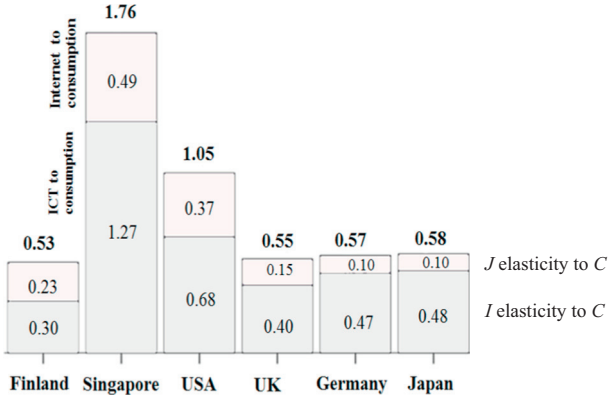

Fig. 9. Elasticity of utility to consumption in six countries (2013).
Original source: Dependency on uncaptured GDP as a source of resilience beyond economic value in countries with advanced ICT infrastructure: similarities and disparities between Finland and Singapore (Watanabe et al., 2015a).

sum of captured and uncaptured GDP) than Singapore. This result agrees with the previous estimate comparing the elasticity of utility to consumption and suggests that Finland has shifted largely to uncaptured GDP dependence, whereas Singapore has maintained its traditional GDP dependence.

6.2. Difference in the shift to the new co-evolution

People's preferences have been shifting to supra-functionality beyond economic value, which cannot be measured by the GDP. A great difference exists between Finland and Singapore, the world's ICT leader countries: Finland experiences happiness and well-being amidst the great stagnation, whereas Singapore undergoes economic growth amidst its choking society (Table 3). This difference can be explained by the contrasting uncaptured GDP trends between the two countries.

Given the above estimation of uncaptured GDP, the correlation between the Internet advancement and uncaptured GDP ratio in Finland and Singapore over the period of 1996–2013 was analyzed to

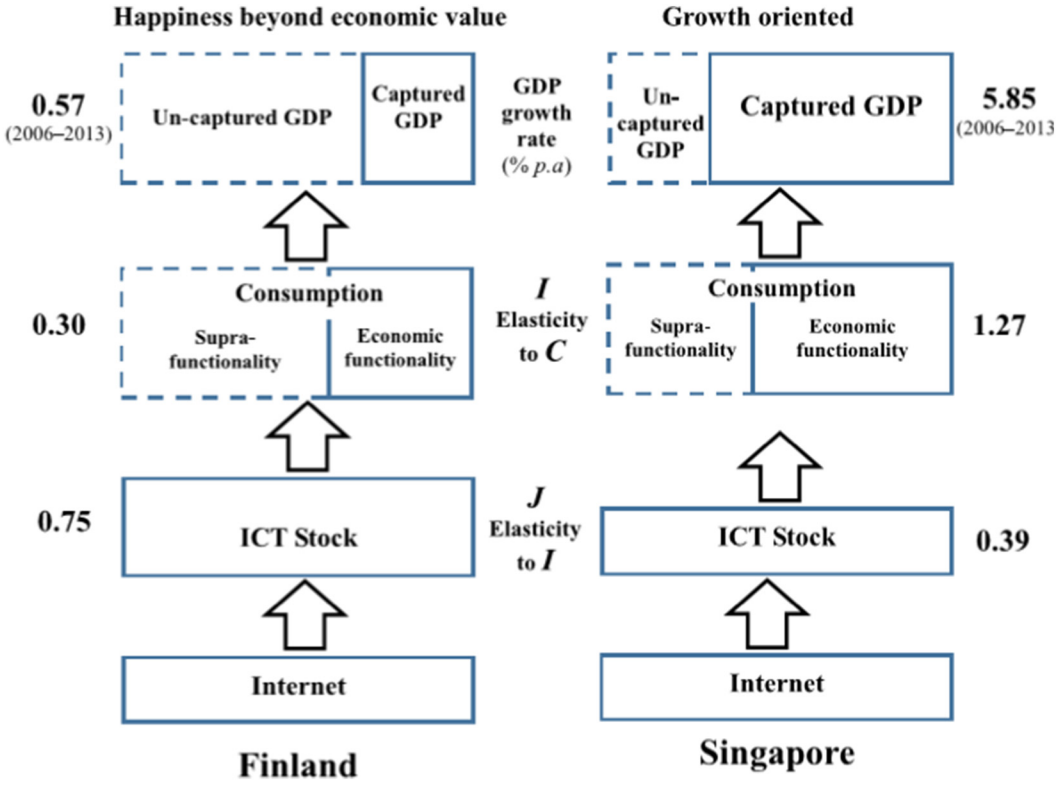

Fig. 10. Contrasting development trajectory of the world ICT leaders Finland and Singapore (2013).
J: Internet dependence, *I*: ICT stock, *C*: consumption. GDP growth rate is an average between 2006 and 2013.
Original source: Dependence on uncaptured GDP as a source of resilience beyond economic value in countries with advanced ICT infrastructure: similarities and disparities between Finland and Singapore (Watanabe et al., 2015a).

inducement by a shift in people's preferences drives the uncaptured GDP dependence. The equilibrium of both inertia leads to a rising power emerging uncaptured GDP (see Fig. A8 in Appendix 4).

With this understanding, the uncaptured GDP of the world ICT leaders Finland and Singapore is measured. Here, the inducement of the shift of people's preferences depends on the elasticity of utility to consumption (see the details of the analytical framework and the empirical result in Appendix 4).

Fig. 11 compares the trends in captured and uncaptured GDP between both countries over the period of 1994–2013.

As shown in the figure, although Finland's captured GDP is lower than that of Singapore after 2010, Finland has a higher gross GDP (the

identify the possible shift from the traditional co-evolution to the new co-evolution. Fig. 12 demonstrates the difference in the correlation between the two ICT leaders (see the details of the analysis in Appendix 4).

As shown in the figure, Finland's tendency toward the co-evolution of ICT advancement through Internet productivity increases, and its increase in uncaptured GDP dependence occurs in 2002, which is immediately after the bursting of the net bubble in 2000 and subsequent to the emergence of the substantial digital economy. Since then, Finland has shown higher elasticity of ICT advancement to uncaptured GDP ratio, thereby suggesting its active co-evolution.

Singapore's experience is contrary to such a noticeable co-evolution

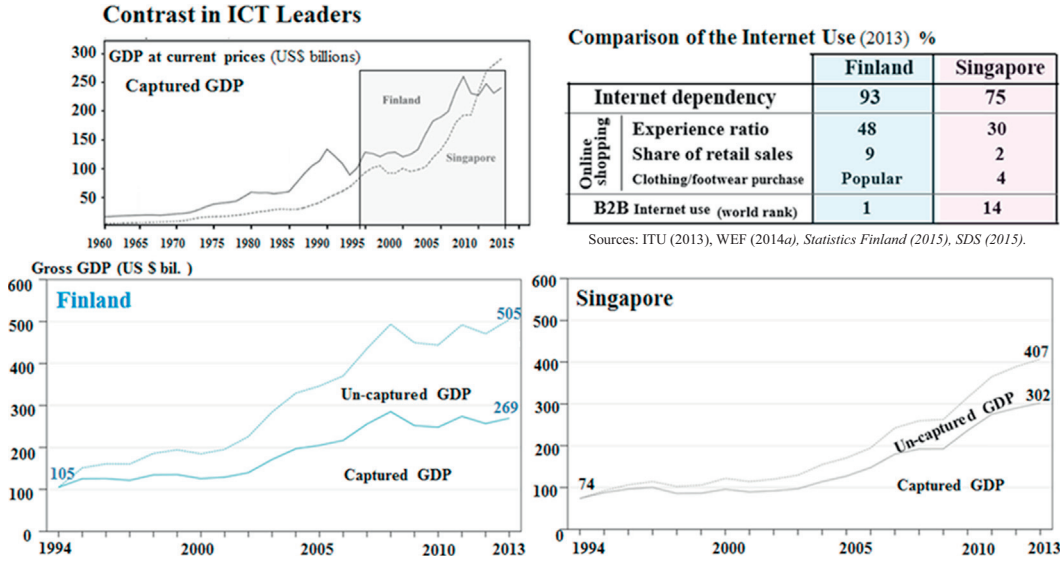

Fig. 11. Comparison of captured and un-captured GDP between Finland and Singapore (1994–2013).
Original source: Operationalization of un-captured GDP: innovation stream under new global mega-trends (International Telecommunication Union (ITU), 2013; Singapore Department of Statistics (SDS), 2015; Statistics Finland, 2015; Watanabe et al., 2016a).

Table 3
Difference in institutional systems between Finland and Singapore (2013).

	Finland	Singapore	References
Population (million)	5.5	5.4	The Global Competitiveness Report 2014 (WEF, 2014a, 2014b)
ICT (rank out of 148)	1	2	The Global Information and Technology Report 2014 (WEF, 2014a, 2014b)
Global competitiveness (rank out of 148)	3	2	The Global Competitiveness Report 2014 (WEF, 2014a, 2014b)
GDP per capita (US$1000)	47.1	54.8	The Global Competitiveness Report 2014 (WEF, 2014a, 2014b)
GDP growth rate (2006–2013) (% p.a. at fixed price)	0.57	5.85	World Economic Outlook Database (IMF, 2014)
Happiness (rank out of 156)	7	30	World Happiness Report 2013 (The Earth Institute, Colombia University, 2013)
Inequality (GINI index) *2010	19	45	Distribution of Household Income by Source (ILO, 2012)
Gender parity (rank out of 136)	2	58	The Global Gender Gap Report 2013 (WEF, 2013)

in Finland. Singapore increases its traditional captured GDP even if it reacted earlier than Finland to its Internet productivity immediately after the bursting of the net bubble in 2000. Therefore, this nation still clings to the traditional co-evolutionary cycle depending on the traditional captured GDP.

As reviewed earlier, significant co-evolution occurs among the advancement of the Internet, uncaptured GDP dependence, and co-evolution of people's preferences shift with the advancement of the Internet. The contrasting co-evolution of the advancement of the Internet and uncaptured GDP dependence between the two countries suggests that Finland has shifted from the "*traditional co-evolution of computer-initiated ICT, captured GDP, and economic functionality*" to the "*new co-evolution of the advancement of the Internet, uncaptured GDP, and supra-functionality beyond economic value*," whereas Singapore has maintained the former type of co-evolution.

This finding supports the following view: "The well-being of the Finnish people has developed in a more positive direction than one might conclude on the basis of the economic development of recent years indicated by GDP data" (Ylhainen, 2017).

These results reminds us of the limitations of the GDP for measuring the digital economy and the significance of uncaptured GDP to represent the real state of the digital economy.

7. Conclusion

In light of the increasing significance of measuring the GDP in the digital economy because of the increasing concern of the limitations of the GDP, a new practical solution was examined. A solution to this critical issue was investigated on the basis of intensive empirical analyses on the national, industrial, and individual behaviors in the digital economy.

Given the two-faced nature of ICT and people's preferences shift to beyond economic value, uncaptured GDP concept was postulated and its measurement was attempted. The significance of uncaptured GDP dependence was demonstrated by identifying the transformative direction of leading global ICT firms.

The following findings are noteworthy:

- ICT prices have continued to decline because of a trap in ICT advancement derived from the two-faced nature of ICT. That is, the advancement of ICT generally contributes to enhanced prices of technology through the new functionality development, whereas the dramatic advancement of the Internet decreases the prices of technology because of its following characteristics: provision of freebies, easy copying for free, and mass standardization. Therefore, the marginal productivity declines in leading ICT firms.
- To compensate for this price decrease, new unique identical services have been provided that are not necessarily captured by the GDP, which measures economic value, thus leading to increased dependence on uncaptured GDP.
- Mismeasurement of ICT price (dependence on the pseudo deflator) can be attributed to this phenomenon.
- These services correspond to people's preferences shift from economic functionality to supra-functionality beyond economic value that encompasses social, cultural, and emotional values.
- This shift induces the further advancement of the Internet, which

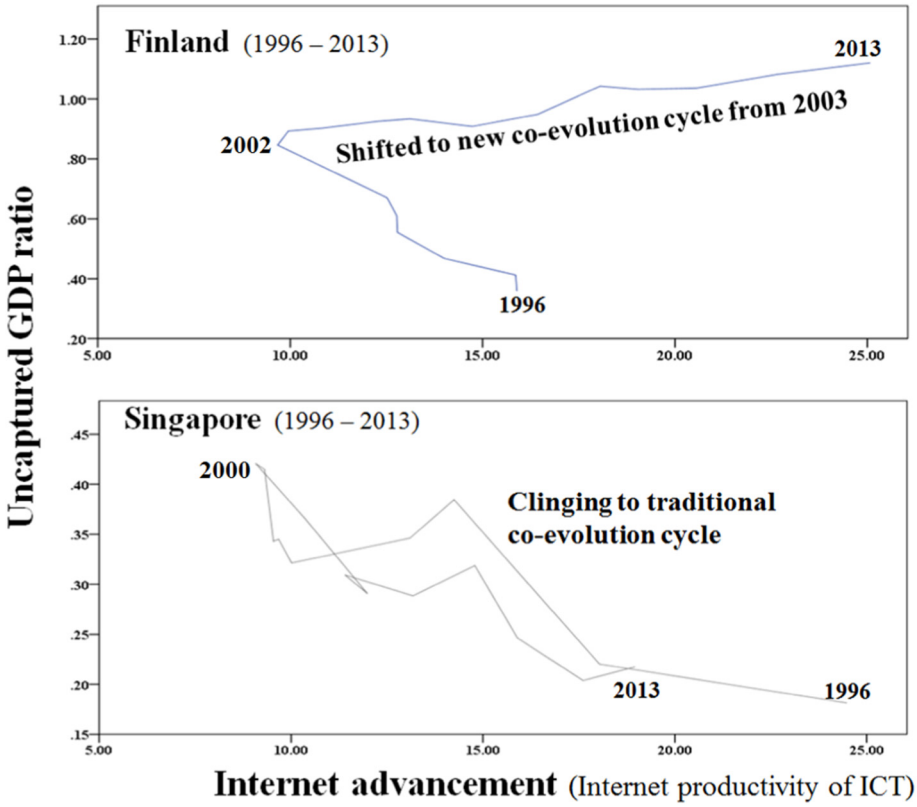

Fig. 12. Correlation between internet advancement and un-captured GDP shift in Finland and Singapore.
Original source: Operationalization of un-captured GDP: innovation stream under new global mega-trends (Watanabe et al., 2016a).

intensifies the increasing dependence on uncaptured GDP. Therefore, a new co-evolution among Internet advancement, increasing uncaptured GDP, and people's preferences shift has emerged.
- This co-evolution may provide insight into the integration of national accounts with product-oriented micro-analysis efforts.
- Under such circumstances in the digital economy, leading global ICT firms have been endeavoring to create supra-functionality by harnessing soft innovation resources.
- This trajectory is a way to achieve sustainable growth by means of the gross GDP, including uncaptured GDP.
- Survival strategy of global ICT firms depends on the construction of the platform which demonstrates above dynamism.

These findings give rise to the following insightful suggestions for optimal trajectory management in the digital economy:

- Spinning off to a new co-evolution among advancement of the Internet, increasing dependence on uncaptured GDP, and people's preferences shift to supra-functionality beyond economic value should be realized.
- Further effort to transferring insight of this dynamism to the integration of national accounts with product-oriented micro analysis efforts should be conducted.
- Sustainable growth by gross GDP, including uncaptured GDP, should be targeted.
- Management system harnessing soft innovation resources should be further explored.
- Optimal national accounting based on gross GDP and the corresponding taxation system should be developed.
- A comprehensive uncaptured GDP measurement should be developed.
- The higher well-being that the nation actually enjoys should be demonstrated rather than merely assessed through captured GDP.

Therefore, this analysis drew a perspective on a current critical issue and explores new insights for measuring the digital economy. However, the analysis is still a macro-level analysis which needs further development for exploring and integrating micro investigations.

Future works should focus on in-depth micro-level international and historical reviews of success stories of gross GDP management at both the national and industrial levels.

The development of public policies based on the gross GDP concept with the views to seek optimal trajectories in the total system taking both captured and uncaptured GDP should be prioritized. In this context, transformative direction of leading global ICT firms should be carefully analyzed and possible suggestions expected to be obtained at the forefront endeavors of such firms should be extracted.

In addition, in light of the significant role that hedonic prices approach will take in the digital economy, particularly by a complex hedonic pricing methods approach by using the advancement of digital innovation, integration of national accounts with these advancement efforts should be undertaken. Insights obtained from co-evolutionary dynamism should be further developed for the support of this integration.

Acknowledgement

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.techfore.2018.07.053.

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