



# A new paradox of the digital economy - Structural sources of the limitation of GDP statistics

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## ABSTRACT

The Internet has dramatically changed the way we conduct business and our daily lives by provided us with unprecedented services and conveniences. However, contrary to such accomplishments, productivity in industrialized countries is now experiences an apparent decline. This has raised the question of a possible productivity paradox in the digital economy. The limitation of GDP statistics in measuring the advancement of the digital economy has thus become an important subject.

This paper analyzed the structural sources of this problem.

Utilizing the results of empirical analyses of national, industrial, and individual behavior in the digital economy, solutions to these critical issues were investigated.

Based on the two-faced nature of information and communication technology (ICT) and the fact that people's preferences extend beyond economic value, the concept of uncaptured GDP was postulated and spinoff dynamism to a new co-evolution among advancement of the Internet, increasing dependence on uncaptured GDP, and a shift in people's preferences was reviewed. This provided new insight and suggested a transformative direction to address the limitation of using GDP statistics in the digital economy.

## 1. Introduction

### 1.1. Myth of GDP

The dramatic advancement of the Internet has generated the digital economy, which has changed the way we conduct business and our daily lives [1]. The further progression of digitized innovation over the last two decades, such as cloud services, mobile services, and artificial intelligence, has augmented this change significantly. This has accelerated permeation of the Internet into information and communication technology (ICT) in general as illustrated in Fig. 1 (see the details of this phenomenon in Appendix 1) and has provided us unprecedented services and conveniences [2].

However, contrary to these accomplishments, productivity in industrialized countries has experienced a structural decline [3,57], as demonstrated in Figs. 2 and 3. These suggest that there may be a productivity paradox in the digital economy.

Consequently, the limitations of GDP statistics in measuring the advancement of the digital economy have become an important subject [3,5–7].

OECD has raised the question: “Are GDP and productivity measures up to the challenges of the digital economy?” [8]. The question aims to address seven productivity loop holes that stem 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) mis-measurement of ICT price.

These loop holes can be attributed to the advancement of the digital economy initiated by the Internet and to the role of online intermediaries [9,10].

Furthermore, the social well-being enabled by digitization is feared not to be duly considered in identifying a nation's optimal trajectory. The OECD has explained how the measures of the total value of consumer welfare are at odds with the conceptual basis of measuring GDP and income [8]. This may result in seeking the pseudo optimization in a subsystem. It is definite that the optimal solution in the subsystem does not correspond to the optimal solution in the total system.

Without a reasonable solution to this problem, decision making and

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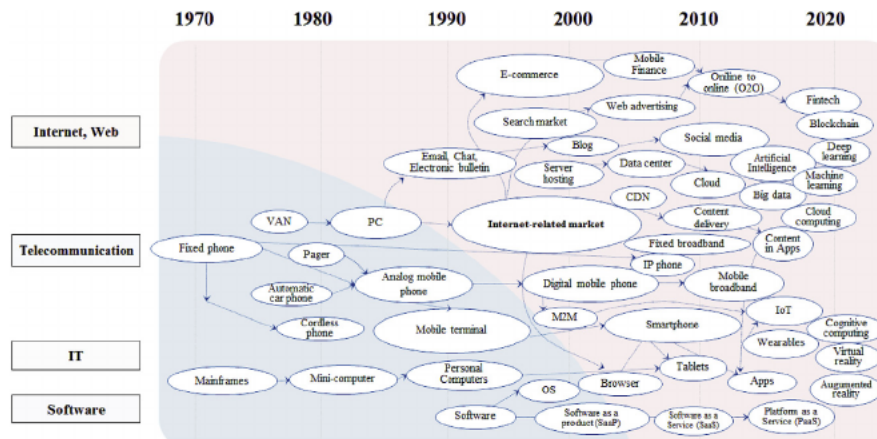


Fig. 1. Illustration of the digital innovation initiated by the advancement of the internet.

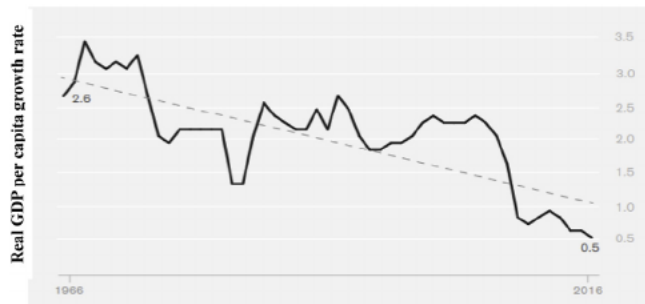


Fig. 2. Trend in Productivity Decline in the US - Real GDP per capita growth rate (1966–2016).  
Source: No Recovery [3].

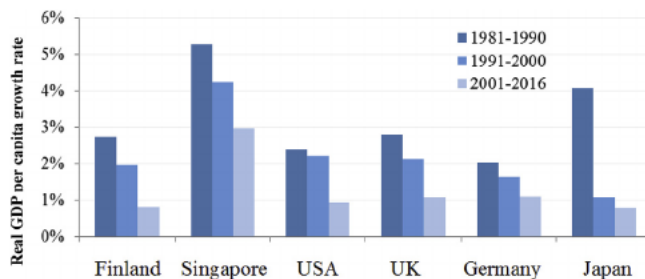


Fig. 3. Trend in Productivity Decline in Six ICT Advanced Countries- Real GDP per capita growth rate (1981–2016).  
Indicate average growth rate in three periods. The country order is world ICT ranking in 2014 (WEF) (see Table 1).  
Source: World Economic Outlook Database [4].

policy implementation can become biased and misleading. Given the long stagnation in GDP growth despite its leading position in the world ICT in Finland<sup>1</sup> as demonstrated in Table 1, such hopeful interpretation could be justified as “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” [11].

By utilizing the advancement of the digital economy, Finland occupies a leading position in the world regarding ICT advancement and human capital development (Finland is ranked second and top in the

Table 1

World ICT leaders by ICT rank (2013–2016).

Source: The Global Information Technology Report (WEF, annual issues).

2013	<sup>1</sup> Finland	<sup>2</sup> Singapore	<sup>7</sup> UK	<sup>9</sup> USA	<sup>13</sup> Germany	<sup>21</sup> Japan
2014	<sup>1</sup> Finland	<sup>2</sup> Singapore	<sup>7</sup> USA	<sup>9</sup> UK	<sup>12</sup> Germany	<sup>16</sup> Japan
2015	<sup>1</sup> Singapore	<sup>2</sup> Finland	<sup>7</sup> USA	<sup>8</sup> UK	<sup>10</sup> Japan	<sup>13</sup> Germany
2016	<sup>1</sup> Singapore	<sup>2</sup> Finland	<sup>5</sup> USA	<sup>8</sup> UK	<sup>10</sup> Japan	<sup>15</sup> Germany

Figures indicate world rank by Networked Readiness Index (NRI).

world in 2016, respectively) and demonstrates high levels of well-being such as trust, gender parity, happiness, and equality. However, its current economic performance, as indicated by GDP data, is the lowest among countries with advanced ICT, as demonstrated in Table 2.

We now confront the third productivity paradox, following the earlier computer-initiated productivity paradox (which manifested in the late 1980s to the 1990s and was postulated by Nobel Laureate [12] but faded with workplace productivity improvement) and the internet-initiated productivity paradox (which manifested in the early 2010s and was postulated by Ref. [13] and supported by Ref. [14]). The third paradox raises a fundamental question regarding the GDP myth in the digital economy.

## 1.2. New challenge

As the GDP is considered the most fundamental yardstick in devising economic policies, a large number of studies have attempted to identify the structural sources of the issues stemming from the GDP as a measurement tool in representing the true picture of a digital economy (e.g., [3,15–19]). However, no study has provided rational answers to this fundamental question [7].

Authors in previous studies stressed the significance of increasing dependence on uncaptured GDP<sup>2</sup> by postulating that the Internet promotes a free culture that provides utility and happiness to people through its consumption but cannot be captured through GDP data, which measure revenue. This added value of providing people with utility and happiness, which extends beyond economic value, is defined as uncaptured GDP [20,21].

The shift in people's preferences from economic value to the supra-functionality beyond economic value (encompassing social, cultural,

<sup>1</sup> Though Finland has ranked first (2013, 2014) or second (2015, 2016) in the world in terms of ICT, the country's average real GDP growth rates have been 0.57% pa. (2006–2013) and 0.34% pa. (2014–2016).

<sup>2</sup> The Internet promotes a free culture that provides utility (satisfaction of consumption) and happiness to people through its consumption but this culture cannot be captured through GDP data which measure revenue. Such utility and happiness constituted uncaptured GDP. This can be defined as added value that provides utility and happiness beyond economic value to people but cannot be measured by traditional GDP accounts (captured GDP) which measure economic value.

**Table 2**  
Institutional state of six ICT advanced countries in the digital economy (2016).

	Finland	Singapore	USA	UK	Germany	Japan	References
Population (million) *2015	5.5	5.5	321.6	65.1	81.9	126.9	The Global Competitiveness Report 2016-2017 World Economic Forum [53–56]
ICT (Rank out of 139)	2 < 1 >	1 < 2 >	5 < 9 >	8 < 7 >	15 < 13 >	10 < 21 >	The Global Information Technology Report 2016 [53–56]
Human capital (Rank out of 130)	1 < 2 >	13 < 3 >	24 < 16 >	19 < 8 >	11 < 6 >	4 < 15 >	The Human Capital Report 2016 [53–56]
Global competitiveness (Rank out of 138)	10 < 3 >	2 < 2 >	3 < 5 >	7 < 10 >	5 < 4 >	8 < 9 >	The Global Competitiveness Report 2016-2017 [53–56]
GDP per capita (1000 US\$) *2015	42.0	52.9	55.8	43.8	41.0	32.5	The Global Competitiveness Report 2016-2017 [53–56]
GDP growth rate (% pa at fixed prices)Average	2006-2013 0.57	5.85	1.26	0.63	1.46	0.56	World Economic Outlook Database (IMF annual issues)
	2014-2016 0.34	2.50	2.20	2.36	1.62	0.85	
Trust (Rank out of 21) *2013	2	7	5	12	16	19	Global Teachers Status Index [48]
Gender parity (Rank out of 144)	2	55	45	20	13	111	Global Gender Gap Report 2013 [53–56]
Happiness *2015-2017 (Rank out of 156) < 2010-2012 >	1 < 7 >	34 < 30 >	18 < 17 >	19 < 22 >	15 < 26 >	54 < 43 >	World Happiness Report 2013, 2018 [46,59]
Inequality(GINI index) *2010 state	19	45	47	39	35	34	Distribution of Household Income Source [43]

Figures in < > indicate the state in 2013. Asterisk indicates the different years than 2016.

and emotional values)<sup>3</sup> induces the further advancement of the Internet, which intensifies the increasing dependence on uncaptured GDP.

Thus, the technological shift from the computer age to the Internet and the abundance of freely available digital products and services in the digital economy have resulted in a new co-evolution among people's shifting preferences, the advancement of the Internet, and the increasing dependence on uncaptured GDP [20–23].

Based on these findings, the authors attempted to compare the spin-off dynamism from traditional computer-initiated ICT innovation in the era of the Product of Things (PoT) with internet-initiated ICT innovations in the Internet of Things (IoT)<sup>4</sup> by using their framework of co-evolutional among the advancement of ICT, a paradigm change, and a shift in people's preferences as illustrated in Fig. 4.

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.

Inspired by this expectation, this study uses the framework of co-evolutionary dynamism and empirical analyses of national, industrial, and individual behaviors in the digital economy to determine solutions to the issues of the measurement of GDP.

First, based on this framework and the results of the above empirical analyses, structural sources of the productivity decline in the digital economy was analyzed (Section 2).

Second, utilizing the findings obtained from this analysis and using intensive reviews of the results of the above empirical analyses, transformation into GDP diminishing structure as a consequence of the above co-evolutionary dynamism was identified as structural sources of the limitation of GDP (Sections 3 and 4).

Third, inspired by the above identification and utilizing the development trajectories of 500 global ICT firms, the transformative challenge against such diminishing structure was investigated (Section 5).

It was identified that the structure of the limitation of GDP measurement in the digital economy could be attributed to the emergence

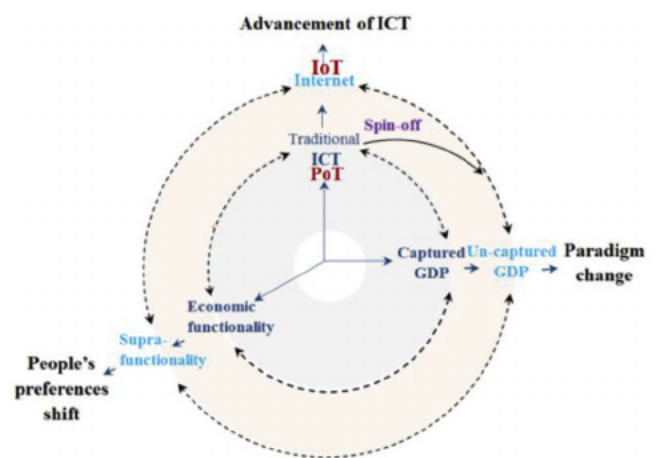


Fig. 4. Spin-off dynamism scheme - Co-evolution among the internet, uncaptured GDP, and supra-functionality.

and increase in activities that cannot be captured by GDP including the emergence of new business and blurring of production boundaries, and also to a transformation into GDP diminishing structure encompassing misleading ICT prices and shift to non-monetary consumption. Against such circumstances, global ICT leading firms have been endeavoring to harness soft innovation resources that activate ICT indigenous self-propagating function leading to inducing supra-functionality beyond economic value.

The structure of this paper is as follows: Section 2 discusses the structural sources of productivity decline in the digital economy. Section 3 analyzes the two-faced nature of ICT. The shift to non-monetary consumption is analyzed in Section 4. Transformative challenges in the digital economy are investigated in Section 5. Section 6 summarizes the noteworthy findings, policy suggestions, and future research.

## 2. Structural sources of the productivity decline in the digital economy

Based on the framework of co-evolution among the advancement of ICT, a paradigm change, and a shift in people's preferences, structural sources of the productivity decline in the digital economy is analyzed in this section.

<sup>3</sup> Supra-functionality beyond economic value illustrates peoples' shifting preferences which encompass social (e.g., creation of and contribution to social communication), cultural (e.g., brand value, cool and cute), aspirational (e.g., aspiration of traditional beauty), tribal (e.g., cognitive sense, fellow feeling), and emotional (e.g., perception value, five senses) values [25]. (See the detail in Fig. 11).

<sup>4</sup> IoT is a system of interrelated computing devices, mechanical and digital machines, objects, animals, or people that are provided with unique identifiers and the ability to transfer data over a network without requiring human-to-human or human-to-computer interaction. PoT transfers products through semi-conductor-to-computer, and computer-to-human interactions.

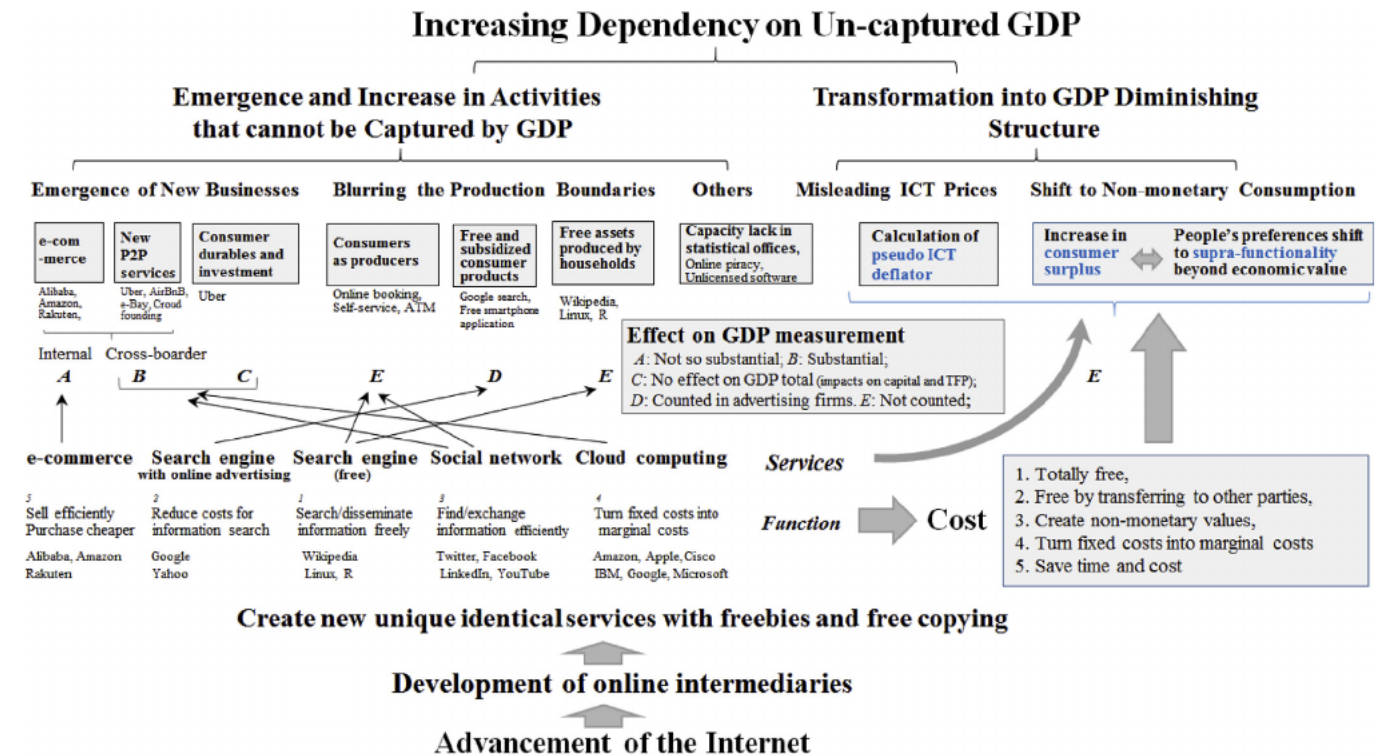


Fig. 5. Scheme of measuring the digital economy.

**Original sources:** The Economic and Social Role of Internet Intermediaries [10], The Impact of Online Intermediaries on the EU Economy [9], Are GDP and Productivity Measures Up to the Challenges of the Digital Economy? (Ahmad et al., OECD, 2016), Operationalization of Un-captured GDP [22].

## 2.1. Measuring the digital economy scheme

Fig. 5 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 that include the provision of freebies, easy replication, and mass standardization through the development of online intermediaries [10].

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, with services of turning fixed costs into marginal costs.

These services are provided for free, are free by transferring to other parties, create non-monetary value, turn fixed costs into marginal costs, and save on time and cost.

## 2.2. Increasing Dependence on beyond GDP measurement

### 2.2.1. 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, which include (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 production boundaries such as consumers as producers (“prosumers”), free and subsidized consumer products, and free assets produced by households; and (iii) increasing the capacity lacking in statistical officers, online piracy, and unlicensed software.

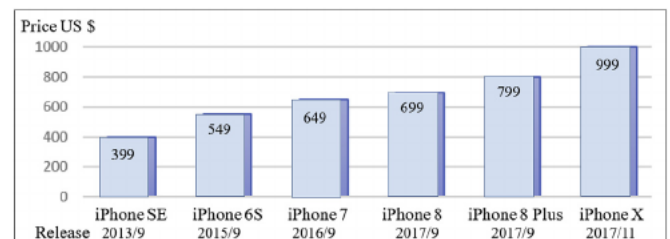


Fig. 6. Trend in iPhone Prices by Function (2013–2017).

Source: Apple press release library.

### 2.2.2. Transformation into a GDP-diminishing structure

The transformation into a GDP-diminishing structure could stem from (i) misleading ICT prices by calculating a pseudo ICT deflator in evaluating the real value of an ICT-driven digital economy and (ii) shifting to non-monetary consumption. This type of consumption results in increased consumer surplus and stems from people's preferences shifting to supra-functionality, which extends beyond economic value by encompassing social, cultural, and emotional values (see footnote 3).

### 2.3. Effect on GDP accounting

As reviewed earlier, because GDP is considered the most fundamental yardstick in devising economic policies, the identification of the loop 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. 5 [8].

Although we expect people to enjoy the well-being that is enabled by the advancement of the digital economy, this well-being is excluded from the GDP accounting and is considered at odds with the conceptual



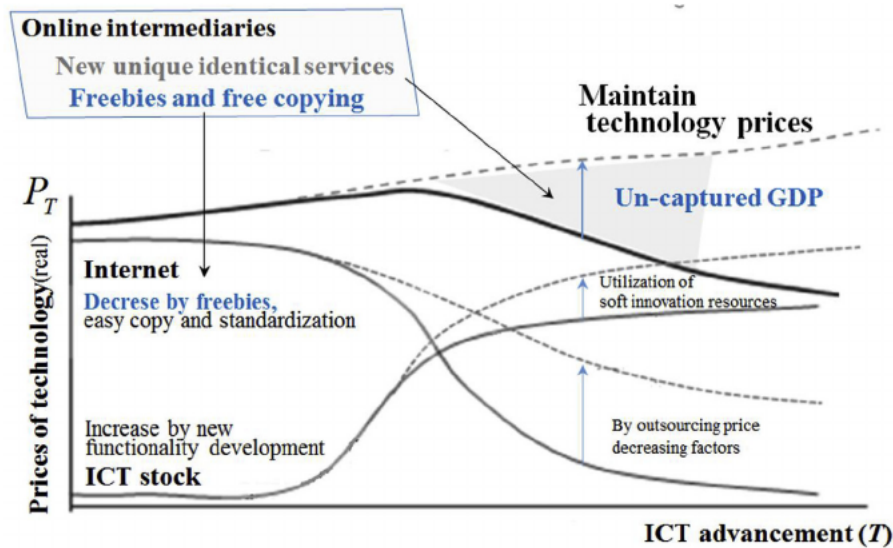


Fig. 7. Dynamism of ICT price decrease as a consequence of its two-faced nature.

Original source: New Paradigm of ICT Productivity – Increasing Role of Uncaptured GDP and Growing Anger of Consumers [20].

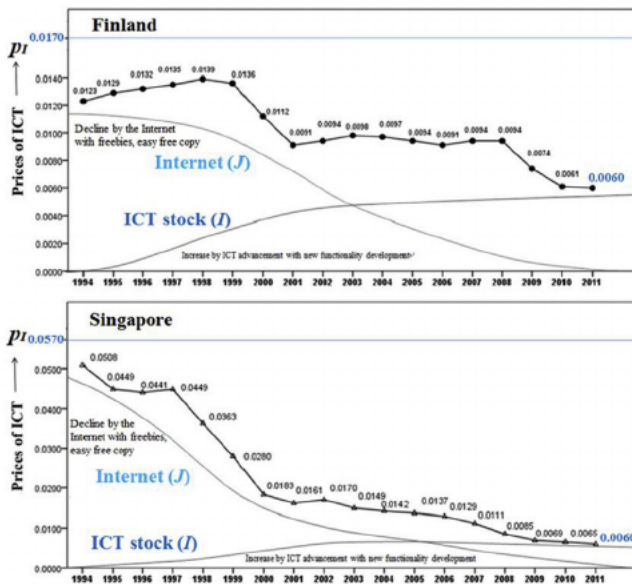


Fig. 8. Trends in ICT prices in world ICT leaders: Finland and Singapore (1994–2011).

Original source: New Paradigm of ICT Productivity – Increasing Role of Uncaptured GDP and Growing Anger of Consumers [20].

basis of measuring the GDP. This treatment causes fear, which leads to the pseudo optimization of a nation's trajectory management.

The above analysis on the structural sources of the productivity decline in the digital economy reveals that the two-faced nature of ICT (which leads to ICT price decline) and the shift to non-monetary consumption are critical sources of the productivity decline in the digital economy.

Therefore, the subsequent sections of this paper focus on the analysis of these two issues by utilizing the results of the preceding empirical analyses of national, industrial, and individual behaviors in the digital economy.

### 3. Two-faced nature of ICT

Inspired by the preceding analysis of the structural sources of the productivity decline in the digital economy, dynamism leading to the

ICT price decrease and its subsequent impacts on GDP measurement are analyzed in this section.

#### 3.1. Calculation of the pseudo ICT deflator

By realizing the two-faced nature of ICT as a consequence of a trap in ICT advancement [21], it was identified that while advancement of ICT generally contributes to enhancing the prices of technology through new functionality development (as demonstrated by the advancement of Apple's iPhones: Fig. 6), the dramatic advancement of the Internet has resulted in the decline of ICT prices because of the characteristics of digital content, including provision of freebies, easy replication, and mass standardization.

The continued drop in ICT prices results in the declining marginal productivity of ICT in leading ICT firms (see Note). With such price decrease and intense competition, ICT firms endeavor to introduce new and unique features in their products and services to fulfill preferences of consumers. However, these efforts are not necessarily captured by the GDP, which measures economic value (uncaptured GDP). Mis-measurement of ICT price can be attributed to this phenomenon.

Fig. 7 illustrates this dynamism. Uncaptured GDP, which is illustrated in the top right of the figure, is produced efforts such as outsourcing price decreasing factors and utilization of soft innovation resources (for more details, see Section 5).

Fig. 8 supports this dynamism by illustrating the trends in ICT price decline and its sources, namely, Internet dependence and the ICT stock<sup>5</sup> increase in world ICT leaders Finland and Singapore<sup>6</sup> in the period of 1994–2011.

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.

Given that firms seek profit maximization in a competitive market, their marginal ICT productivity corresponds to the relative price of ICT,

<sup>5</sup> ICT stock encompasses capital services provided by assets derived from the advancement of ICT, including digital innovations such as computer hardware and equipment, telecommunication equipment, and computer software and services as illustrated in Fig. 1 into which the Internet has been permeating, as illustrated in Fig. A1 in Appendix 1 (for more details on this structure, see Ref. [20]).

<sup>6</sup> Finland and Singapore shared the top and second position in the world ICT rankings as shown in Tables 1 and 2.

$$\begin{aligned}
& \text{Taxable value of digital goods/services equitable to non-digital goods/services} = \frac{\text{Nominal value}}{\text{ICT deflator}} \\
& \text{ICT prices (Deflator)} = \frac{\text{Cost for ICT}}{\text{Utility of ICT}} = \frac{\text{Cost for ICT (nominal)}}{\text{Gross utility (real)}} \\
& \quad \nearrow \text{Pseudo deflator} = \frac{\text{Cost for ICT}}{\text{Captured GDP}} \rightarrow \text{Increase as un-captured GDP increase} \\
& \quad \searrow \text{Actual deflator} = \frac{\text{Cost for ICT}}{\text{Gross utility (Captured GDP + Un-captured GDP)}} \rightarrow \text{Decrease as ICT advances and subsequent un-captured GDP increase}
\end{aligned}$$

Fig. 9. Scheme in calculating the pseudo ICT deflator.

Given the fairness principle for taxation, digital goods/services should be assessed in an equitable way to non-digital goods/services.

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) (see Note). Therefore, the decrease in ICT price results in the stagnation of growth, as postulated by Ref. [13] (see Section 3.2).

Under this dynamism, ICT prices (ICT deflator) calculated without uncaptured GDP lead to a pseudo deflator, which increases as uncaptured GDP increases, thus resulting in the devaluation of the actual (real) value of the digital economy. The actual deflator should be calculated using gross utility, which considers the uncaptured GDP. This deflator decreases as ICT advances and the subsequent uncaptured GDP increases, which leads to the appreciation of the actual (real) value of the digital economy. Fig. 9 explains how this confusion results in the miscalculation of the ICT deflator.

### 3.2. 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 national-level macro analysis that

$$\begin{aligned}
& \text{Contribution by} \\
& \text{traditional factors} \quad \text{technology (TFP)} \quad \text{TFP} \\
& Y = F(X, T) \quad \frac{\Delta Y}{Y} = \underbrace{\Sigma \left( \frac{\partial Y}{\partial X} \cdot \frac{X}{Y} \right) \frac{\Delta X}{X}}_{\text{Elasticity}} + \underbrace{\left( \frac{\partial Y}{\partial T} \cdot \frac{T}{Y} \right) \frac{\Delta T}{T}}_{\text{Elasticity}} \approx \Sigma \left( \frac{\partial Y}{\partial X} \cdot \frac{X}{Y} \right) \frac{\Delta X}{X} + \frac{\partial Y}{\partial T} \cdot \frac{R}{Y} \\
& \text{Since } \frac{\partial Y}{\partial T} = \frac{p_T}{p_Y}, \quad \text{TFP} = \frac{p_T}{p_Y} \cdot \frac{R}{Y} \\
& \frac{p_T}{p_Y} \cdot \frac{R}{Y} \rightarrow p_T \text{ decrease} \rightarrow \frac{\Delta Y}{Y} \text{ decrease}
\end{aligned}$$

Y: GDP, X: traditional production factors (labor and capital), T: technology stock ( $\Delta T \approx R$ ), R: R&D investment,  $p_T, p_Y$ : prices of technology and products

uses aggregated data. To confirm this result using micro data, which represent actual competitive behavior in the digital market.

Fig. 10 illustrates the trends in the decrease of ICT prices due to ICT advancement of 500 global ICT firms in 2005 and 2016 (see Appendix 2 the details of the analytical framework).

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. In addition, given that the Internet has been permeating into ICT in general, the ICT advancement efforts of global ICT firms are represented by their gross R&D investment (incorporating all ICT advancement R&D, including the internet-relevant R&D) (see Fig. 1 and Fig. A1).

Fig. 10 shows the bipolarization between highly R&D-intensive firms and relatively non-intensive firms. 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.<sup>7</sup> The former's behavior demonstrates productivity decline as ICT advances, a consequence of the digital economy.

Fig. 10 demonstrates how the two-faced nature of ICT advances over time and during the development of digitization. The price decrease firms are only 16 out of the 500 global ICT firms in 2005, but they increase to 25 in 2016, as shown in Table 3.

Furthermore, highly R&D-intensive firms are confronting the stagnation of sales, as their sales growth rate decreases over time, while relatively non-intensive firms enjoy sales increases as the sales growth rate increases, as shown in Table 4. Given that stagnation of sales in highly R&D-intensive firms can be attributed to R&D investment centered by the internet-relevant R&D, this contrast corresponds to Cowen's notion of the internet-oriented productivity paradox [13].

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 as analyzed in Section 2.

**Note.** Price, Productivity and Growth

Elasticity is the measurement of how responsive an economic variable (e.g.,  $T$ ) is to a change in another (e.g.,  $Y$ ). The elasticity of  $T$  to  $Y$  ( $T$  elasticity to  $Y$ )  $\varepsilon_{YT}$  implies a 1% increase in  $T$  increases  $\varepsilon_{YT}$  % increase in  $Y$  and represents the efficiency of  $Y$  in the inducement of  $T$ .

Since  $\varepsilon_{YT} = \frac{\partial \ln Y}{\partial \ln T} = \frac{\partial Y}{\partial T} \cdot \frac{T}{Y}$ , Productivity  $\frac{Y}{T} = \frac{1}{\varepsilon_{YT}} \cdot \frac{\partial Y}{\partial T}$ . Therefore, given the certain period with stable elasticity,  $T$  productivity is proportional to marginal productivity of  $T$ .

## 4. Shift from monetary to non-monetary consumption

Similar to Section 3, inspired by the findings identified in Section 2, dynamism leading to shift to non-monetary consumption and its impacts on GDP measurement are analyzed in this section.

<sup>7</sup> The indigenous and unique features of ICT include a logistic growth nature and a two-faced nature.

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

Fig. 10. Bipolarization of ICT price increase and decrease in 500 global ICT firms (2005, 2016).

Original source: The Transformative Direction of Innovation toward an IoT-based Society: Increasing Dependency on Uncaptured GDP in Global ICT Firms [24].

Table 3

R&D-intensive global ICT firms confronting to productivity decline (2005, 2016).

	2005	2016
Productivity declining firms	1 Siemens (Germany)	Samsung Electronics (South Korea)
	2 Microsoft (USA)	Intel (USA)
	3 Panasonic (Japan)	Google (USA)
	4 IBM (USA)	Microsoft (USA)
	5 Nokia (Finland)	Huawei (China)
	6 Sony (Japan)	Apple (USA)
	7 Intel (USA)	Cisco Systems (USA)
	8 Samsung Electronics (South Korea)	Oracle (USA)
	9 Hitachi (Japan)	Qualcomm (USA)
	10 Hewlett-Packard (USA)	Siemens (Germany)
	11 Philips Electronics (Netherlands)	IBM (USA)
	12 Ericsson (Sweden)	Facebook (USA)
	13 Toshiba (Japan)	Ericsson (Sweden)
	14 Cisco Systems (USA)	Sony (Japan)
	15 Canon (Japan)	Panasonic (Japan)
	16 Motorola (USA)	Hewlett-Packard (USA)
	17 LG Electronics (South Korea)	LG Electronics (South Korea)
	18 SAP (Germany)	SAP (Germany)
	19 Hitachi (Japan)	Hitachi (Japan)
	20 Canon (Japan)	Canon (Japan)
	21 Nokia (Finland)	Nokia (Finland)
	22 EMC (USA)	EMC (USA)
	23 Alcatel-Lucent (France)	Alcatel-Lucent (France)
	24 Toshiba (Japan)	Toshiba (Japan)
	25 Amazon (USA)	Amazon (USA)
	<b>Productivity increasing firms</b>	<b>Productivity increasing firms</b>
	484 (out of 500)	475 (out of 500)

#### 4.1. Shift from economic functionality to supra-functionality

Fig. 5 illustrates the significance of the shift from monetary to non-monetary consumptions in the digital economy as one of the source of transforming economy into a GDP-diminishing structure.

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 preference, which extends beyond economic value-driven preference. Here, supra-functionality encompasses social, cultural, aspirational, tribal, and emotional values as illustrated in Fig. 11. These values are not necessarily captured by the GDP [25]. This shift seems to have a significant relevance to consumer surplus, as shown in Fig. 5, and an increasing dependence on uncaptured GDP as illustrated in Fig. 4.

Table 4

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.).

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

Data sources: Same as Fig. 10.

This shift can be clearly observed in Japan, which is extremely sensitive to institutional innovation against external shocks and crises [26,27]. Fig. 12 illustrates this shift as demonstrated by Japan's *Public Opinion Survey Concerning People's Lifestyles*<sup>8</sup> which is conducted annually by Japan's Cabinet Office (see Appendix 3).

As shown in Fig. 12, contrary to the steady decline in people's preference in economic functionality (V), supra-functionality beyond economic value (Q) steadily increases and exceeds V in 1979, which is the year of the second energy crisis. Whereas Q continues to increase steadily, V declines to its lowest level in 1992, which is the year that immediately follows 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 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 by  $D_1 - D_4$  in Fig. 12, respectively.

This shift in people's preference induces the advancement of the Internet, which, in turn, accelerates the shift in people's preferences. Therefore, the advancement of the Internet and the shift to supra-functionality lead to a co-evolutionary dynamism, as illustrated in Fig. 4. Under this co-evolutionary dynamism, conflict occurs between

<sup>8</sup> In this survey, personal preference for future life is chosen from three options: (i) Richness of the heart-spiritual happiness (because 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 [39].

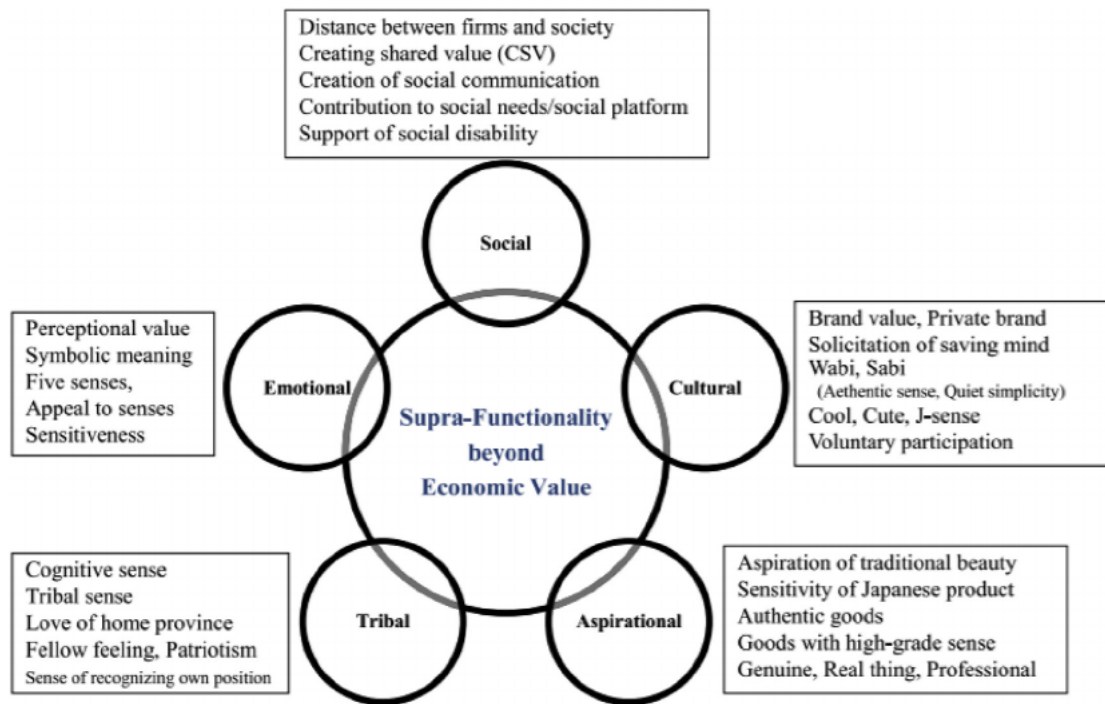


Fig. 11. Basic concept of supra-functionality beyond economic value.

Original source: New Paradigm of ICT Productivity – Increasing Role of Uncaptured GDP and Growing Anger of Consumers [20].

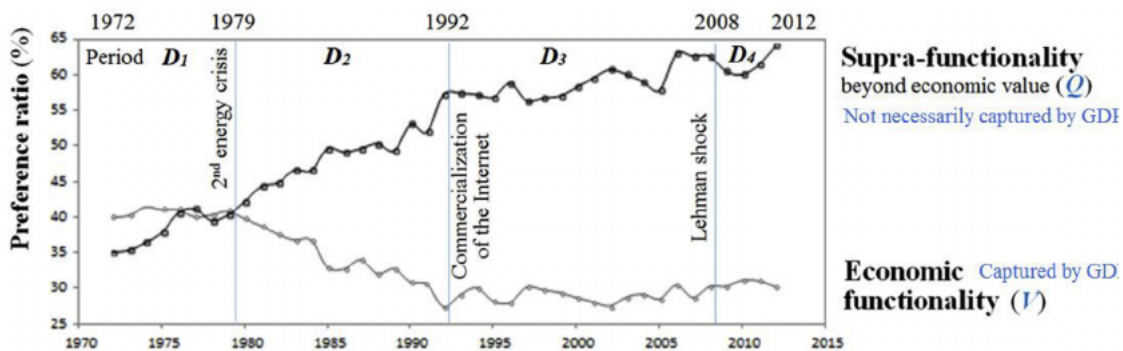


Fig. 12. Trends in the shift of preferences in Japan (1972–2012).

Source: National Survey of Lifestyle Preferences, annual issues [28].

captured GDP and uncaptured GDP during this shift. This conflict leads to growing anger among consumers [20], thus resulting in the decline of consumption. This situation is a source of great stagnation [13] from the demand side.

During the great stagnation due to the 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, as both the marginal propensity of consume and marginal productivity of ICT decline [20].

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

Furthermore, because consumption constitutes a major part of GDP (55–70% of GDP in five countries in Table 2 while 40% in Singapore), the extent to which GDP effectively reflects utility to consumption

would be a key measure for assessing the state of uncaptured GDP dependence.<sup>9</sup>

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

Utility is governed by ICT stock and Internet dependence in the digital economy. Therefore, the elasticity of utility to consumption<sup>10</sup> can be measured by the sum of elasticity of ICT stock to consumption and that of Internet dependence to consumption. Table 5 compares the

<sup>9</sup> A lower level of utility reflection to consumption suggests a higher level of uncaptured GDP dependence.

<sup>10</sup> 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)  $\epsilon_{WX}$  implies a 1% increase in X increases  $\epsilon_{WX}$  % increase in W and represents the efficiency of X in the inducement of W (see Note in Section 3).



**Table 5**

Elasticity of utility to consumption in six countries (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 [20].

	Finland	Singapore	USA	UK	Germany	Japan
Efficiency of $J$ inducement of $I$ 1. $J$ elasticity to $I$ ( $\varepsilon_{ji}$ )	0.75	0.39	0.55	0.39	0.22	0.21
Efficiency of $J$ inducement of $C$ 2. $J$ elasticity to $C$ ( $\varepsilon_{cj}$ )	0.23	0.49	0.37	0.15	0.10	0.10
Efficiency of $I$ inducement of $C$ 3. $I$ elasticity to $C$ ( $\varepsilon_{ci} = \frac{\varepsilon_{ci}}{\varepsilon_{ji}}$ ) [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 $C$ ( $\varepsilon_{cu}$ ) [2+3]	0.53	1.76	1.05	0.55	0.57	0.58

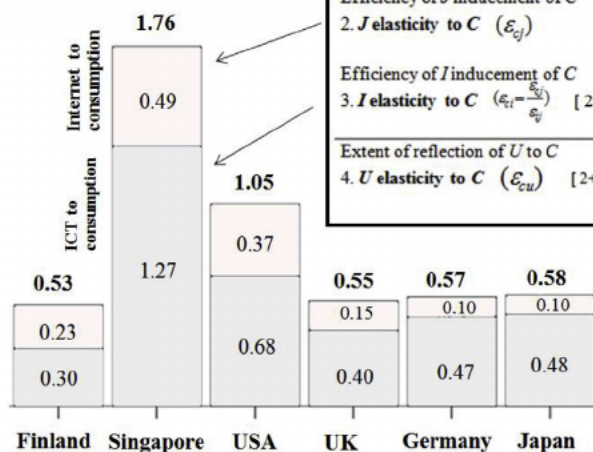
$$\begin{aligned}
 U &= U(V, Q) \quad V = V(I, J), Q = Q(I, J) \\
 U &= U(I, J) = \frac{\partial U}{\partial I} \cdot I + \frac{\partial U}{\partial J} \cdot J = \frac{\partial U}{\partial C} \left( \frac{\partial C}{\partial I} \cdot I + \frac{\partial C}{\partial J} \cdot J \right) \\
 \frac{\partial C}{\partial U} \cdot \frac{U}{C} &= \frac{\partial C}{\partial I} \cdot \frac{I}{C} + \frac{\partial C}{\partial J} \cdot \frac{J}{C} \\
 (\varepsilon_{cu}) \quad (\varepsilon_{ci}) \quad (\varepsilon_{cj})
 \end{aligned}$$

$U$ : Utility,  $C$ : Traditional consumption  
 $V$ : Economic functionality,  $Q$ : Supra-functionality  
 $J$ : Internet dependency,  $I$ : ICT stock

Under the digital economy,

**Elasticity of  $U$  to  $C$** 

= Elasticity of  $I$  to  $C$   
 + Elasticity of  $J$  to  $C$

**Table 5 Elasticity of Utility to Consumption in Six Countries (2013)**

	Finland	Singapore	USA	UK	Germany	Japan
Efficiency of $J$ inducement of $I$ 1. $J$ elasticity to $I$ ( $\varepsilon_{ji}$ )	0.75	0.39	0.55	0.39	0.22	0.21
Efficiency of $J$ inducement of $C$ 2. $J$ elasticity to $C$ ( $\varepsilon_{cj}$ )	0.23	0.49	0.37	0.15	0.10	0.10
Efficiency of $I$ inducement of $C$ 3. $I$ elasticity to $C$ ( $\varepsilon_{ci} = \frac{\varepsilon_{ci}}{\varepsilon_{ji}}$ ) [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 $C$ ( $\varepsilon_{cu}$ ) [2+3]	0.53	1.76	1.05	0.55	0.57	0.58

$$\begin{aligned}
 U &= U(V, Q) \quad V = V(I, J), Q = Q(I, J) \\
 U &= U(I, J) = \frac{\partial U}{\partial I} \cdot I + \frac{\partial U}{\partial J} \cdot J = \frac{\partial U}{\partial C} \left( \frac{\partial C}{\partial I} \cdot I + \frac{\partial C}{\partial J} \cdot J \right) \\
 \frac{\partial C}{\partial U} \cdot \frac{U}{C} &= \frac{\partial C}{\partial I} \cdot \frac{I}{C} + \frac{\partial C}{\partial J} \cdot \frac{J}{C} \\
 (\varepsilon_{cu}) \quad (\varepsilon_{ci}) \quad (\varepsilon_{cj})
 \end{aligned}$$

$U$ : Utility,  $C$ : Traditional consumption  
 $V$ : Economic functionality,  $Q$ : Supra-functionality  
 $J$ : Internet dependency,  $I$ : ICT stock

**Fig. 13.** Elasticity of utility to consumption in six countries (2013).**Original source:**Same as Table 5

elasticity of consumption in six countries in 2013.

Fig. 13 presents the contrast of this elasticity in six countries. Singapore demonstrates conspicuously high elasticity, whereas Finland demonstrates the opposite: it has the lowest level among the six

countries.

With this observation in mind, Fig. 14 illustrates the contrast in the development trajectories between these world ICT leaders. This figure clearly demonstrates the difference between Finland and Singapore

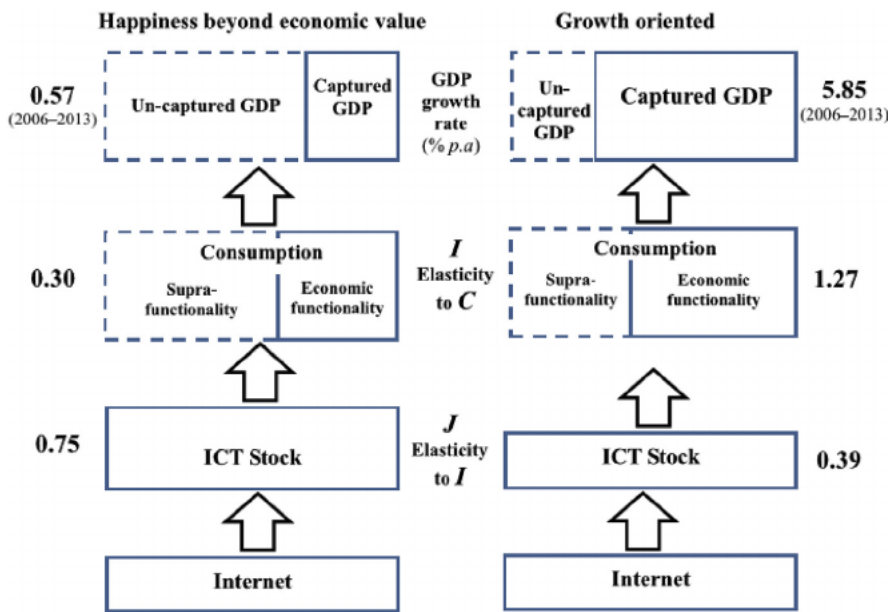


Fig. 14. Contrasting the development trajectories of the world ICT leaders Finland and Singapore (2013). *J*: Internet dependency, *I*: ICT stock, *C*: Consumption. GDP growth rate is an average between 2006 and 2013. **Original source:**Dependence on Uncaptured GDP as a Source of Resilience beyond Economic Value in Countries with Advanced ICT Infrastructure: Similarities and Disparities between Finland and Singapore [20].

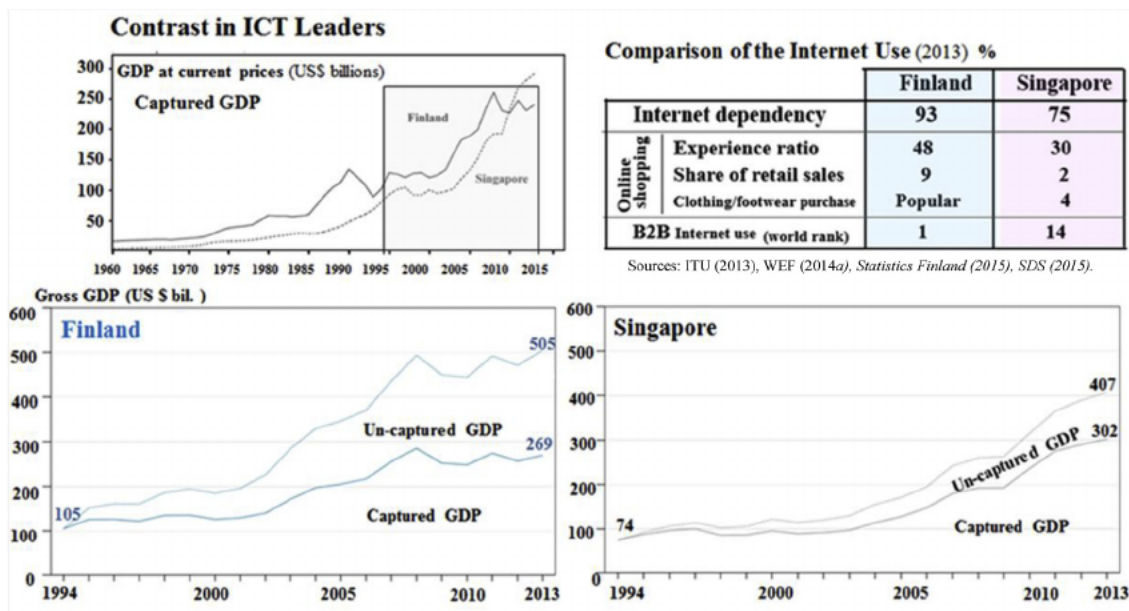


Fig. 15. Comparison of captured and un-captured GDP between Finland and Singapore (1994–2013).

**Original source:**Operationalization of Un-captured GDP: Innovation Stream under New Global Mega-trends [22].

with respect to development trajectory. Finland effectively utilizes the Internet (*J*) in inducing ICT stock (*I*), 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.

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 preference 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 as compared in Table 2).

#### 4.3. 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. 4, stimulation from both Internet advancement and the inducement of the shift of people's preferences drives the uncaptured GDP dependence. The equilibrium of both inertia leads to a rising power emerging uncaptured GDP.

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 preference depends on the elasticity of utility to consumption.

Fig. 15 compares the trends in captured and uncaptured GDP between both countries over the period of 1994–2013. Sources: [29,30]; Statistics Finland (2015), [31].

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 sum of captured and uncaptured GDP) than Singapore does. 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.

## 5. Transformative challenges in the digital economy

Inspired by the findings obtained from Sections 3 and 4 identifying the transformation into GDP diminishing structure, transformative challenge initiated by the forefront of global ICT firms against such structure is investigated in this section. An empirical analysis utilizing the development trajectories of 500 global ICT firms is conducted.

### 5.1. Key features of the digital economy

As analyzed in the preceding sections of the paper, key features of the digital economy can be highlighted as follows:

- (i) Expanding 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 a substantially different business model,
- (v) The boundary between consumer and producer is thin and creates a “prosumer,”
- (vi) Barriers of entry are low which makes companies innovate seamlessly,
- (vii) Companies can fully enjoy network externalities and subsequent self-propagation,
- (viii) Companies are bipolarized between those enjoy network externality and not,
- (ix) Digital companies have a tendency towards gigantic monopoly, and
- (x) Contrary to traditional monopoly, this new monopoly can enhance convenience.

These features remind us of growing significance of the analysis of the transformative innovation stream in the new co-evolution spinning off from traditional co-evolution among PoT, GDP and economic functionality to IoT, uncaptured GDP and supra-functionality beyond economic value, as illustrated in Fig. 4 for overcoming the current crucial problem in the digital economy: the limitation of GDP.

Analyses in the preceding sections identified that structural sources of this crucial problem can be attributed to ICT price decrease and subsequent marginal productivity decline in supply side, and a shift in people's preferences to supra-functionality beyond economic value in demand side.

These features prompt us to envision transformative direction to address this crucial problem in the digital economy which can be expected in the forefront endeavor of highly R&D-intensive global ICT firms for the above new co-evolution.

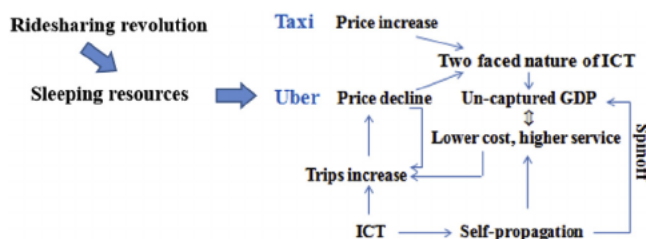


Fig. 16. Activation of self-propagating Function by Means of Effective Utilization of Sleeping Resources – A Case of Ridesharing Revolution by Uber.

### 5.2. Transformative direction of leading global ICT firms

#### 5.2.1. (1) Transformative direction of highly R&D-intensive firms

While advancement of the digital economy has been largely depend on the strong initiative of highly R&D-intensive global ICT firms, they are confronting to the dilemma of R&D investment at the forefront of the digital economy, that is marginal productivity declines as R&D investment increases as revealed in Fig. 10.

Given the shift in people's preferences to supra-functionality beyond economic value in the foregoing co-evolution, possible solution to this unanswered question can be expected by exploring supra-functionality by means of new sophisticated innovation not depending on tough R&D investment.

Since such functionality can be induced by ICT indigenous self-propagating function [32], a key to this solution depends on how to activate this self-propagating function as illustrated in Fig. 16. Fig. 16 illustrates a dynamism activating self-propagating function by means of effective utilization of sleeping resources (not commercially operating cars and drivers) initiated in ridesharing revolution by Uber.

Confronting to productivity decline in the digital economy, highly R&D-intensive global ICT firms have been endeavoring to transform into a new business model that creates supra-functionality by not largely depending on R&D investment.

Key of this business model is how effectively induce functionality that leads to creating supra-functionality by activating potential self-propagating function.

Fig. 17 demonstrates transformative trajectories of highly R&D-intensive 25 global ICT firms in 2016 toward a new business model. These firms have been confronting to productivity decline as illustrated in Fig. 10 and tabulated in Table 3. In order to address such critical circumstances, these firms have been endeavoring to effectively create new functionality that leads to exploring supra-functionality beyond economic value corresponding to a shift in people's preferences as reviewed in Section 4.1.

Aiming at accomplishing such endeavor without depending largely on R&D investment which may accelerate productivity decline, these firms have been making every effort in activating their potential self-propagating function which induces functionality development [32].

Given the logistic growth nature of ICT,<sup>11</sup> development trajectories of global ICT firms can be depicted by R&D-driven logistic growth function (see the details of mathematical explanation in Appendix 2). While development trajectory based on simple logistic growth (SLG) saturates at certain upper limit of development (carrying capacity) which is assumed constant through the development process, in particular innovations, the correlation of the interaction between innovation and institutional systems (encompassing not only business but also socio-cultural environments governing people's preferences) displays a systematic change in the process of growth and leads to the creation of a new carrying capacity in the process of the development [33] introduced an extension of the widely used logistic model of growth by allowing it for a sigmoidally increasing carrying capacity (see the mathematical details in Appendix 2). They stressed that, “evidently, new technologies affect how resources are consumed, and carrying capacity would change.” This explains unique development process of ICT, which develops and diffuses by altering the carrying capacity or creating a new carrying capacity in the process. They then proposed logistic growth within a dynamic carrying capacity (LGDC) to model these behaviors.

This dynamism can be considered corresponding to ICT indigenous self-propagating function incorporation [32]. Therefore, the magnitude

<sup>11</sup> ICT in which network externalities function to alter the correlation between innovations and institutional systems which creates new features of the innovation leading to exponential increase [40] portrayed an array of logistically developing and diffusing social mechanisms stimulated by these interactions.

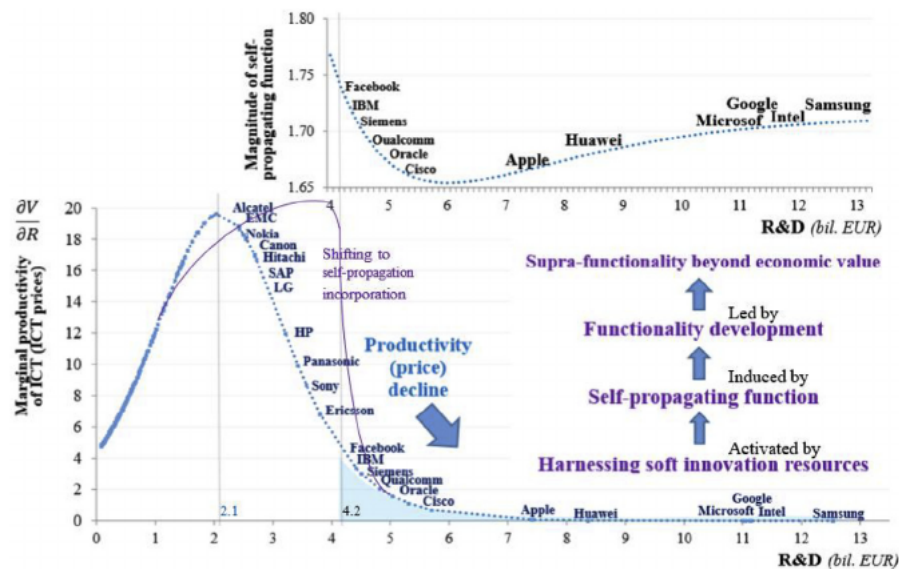


Fig. 17. Transformative direction of highly R&D-intensive global ICT firms (2016).

of the self-propagating function can be estimated by the ratio of dynamic carrying capacity that leads development trajectory after incorporating the self-propagating function and development trajectory estimated by *SLG* that demonstrates development level when no self-propagating function incorporates [34].

Fig. 17 demonstrates trends in marginal productivity of ICT and this magnitude in highly R&D intensive global ICT firms in 2016 (see the details of analysis in Appendix 2).

Looking at Fig. 17 we note that activation of self-propagating function enables to maintain marginal productivity increase with higher level of R&D investment by shifting the inflection point of R&D investment that changes a virtuous cycle between R&D investment and marginal productivity to a vicious cycle (marginal productivity declines as R&D investment increases) as illustrated by purple line in the lower left in Fig. 17. However, notwithstanding such effect, extremely highly R&D-intensive firms (12 firms out of 25 firms) cannot avoid marginal productivity decline stream.

Consequently, they depend on soft innovation resources like sleeping resources in Fig. 16. Since effective utilization of these soft innovation resources activate self-propagating function indigenous to ICT [35]. [23,34,36–38], this utilization induces functionality development leading to developing supra-functionality beyond economic value without depending on R&D investment increase.

These resources can be attained in reaction to the marginal productivity of ICT decline due to the high dependence on ICT, which has a two-faced nature. Thus, survival strategy of extremely highly R&D-intensive global ICT firms depends on the construction of the platform which demonstrates the above dynamism.

### 5.2.2. (2) Transformative direction of ICT-driven business model

Confronting to such dilemma of R&D investment and productivity decline while sustainable R&D investment is essential for new innovation, highly R&D-intensive global ICT firms have been endeavoring to transform into a new business model that creates optimal balance of self-propagating function creation and sustainable R&D investment.

Fig. 17 demonstrates that while top R&D 6 firms as Samsung, Intel, Google, Microsoft, Huawei and Apple have succeeded in constructing a virtuous cycle between sustainable R&D investment and magnitude of self-propagating function increase despite marginal productivity decline, another 6 firms out of extremely high-R&D intensive 12 firms are not necessary successful in constructing such a cycle.

Given such a tough challenge, learning from a successful virtuous

cycle accomplished by top R&D 6 firms may provide insightful suggestion in finding the solution of current crucial problem in the digital economy, the limitation of GDP by solving two structural questions as ICT price decrease and subsequent marginal productivity decline in supply side, and a shift in people's preferences to supra-functionality beyond economic value in demand side.

Effective utilization of soft innovation resources leads a way in satisfying both demands simultaneously. Soft innovation resources activate self-propagating function by awaking its potential incorporating in ICT firms, which induces functionality development and this induced functionality explores supra-functionality beyond economic value. Thus, simultaneous solution to satisfying demands from both supply side and demand side can be provided.

Fig. 18 demonstrates significant direction of ICT-driven disruptive business models which leading global ICT firms have been endeavoring by harnessing the vigor of soft innovation resources.

Soft innovation resources harnessed by these firms can be highlighted as follows majority of them are beyond the GDP counting [20,28].

- Driving force of a shift in people's preferences from economic value to supra-functionality [21,25].
- Sleeping resources, such as the ridesharing revolution [23].
- Trust by overdrawing past information [37].
- Utmost gratification ever experienced [58]
- Memory and dreams [38].
- Untapped resources and vision [34].

### 5.2.3. (3) spin-off dynamism to Increase Dependency on uncaptured GDP

These accomplishments in the forefront of the leading global ICT firms are based on harnessing soft innovation resources identified as a soft value addition corresponding to uncaptured GDP and that are essential for the spin-off from traditional co-evolution among PoT, GDP and economic functionality to new co-evolution among IoT, uncaptured GDP and supra-functionality beyond economic value.

Based on the preceding confidence, Fig. 19 illustrates a platform that demonstrates spin-off dynamism to increase dependence on uncaptured GDP, which leads to a new trajectory to sustainable growth in the digital economy [50].

This shift accelerates a shift from a PoT society to an IoT society by inducing further advancement of the Internet which increases further dependency on uncaptured GDP. At the same time, supra-functionality



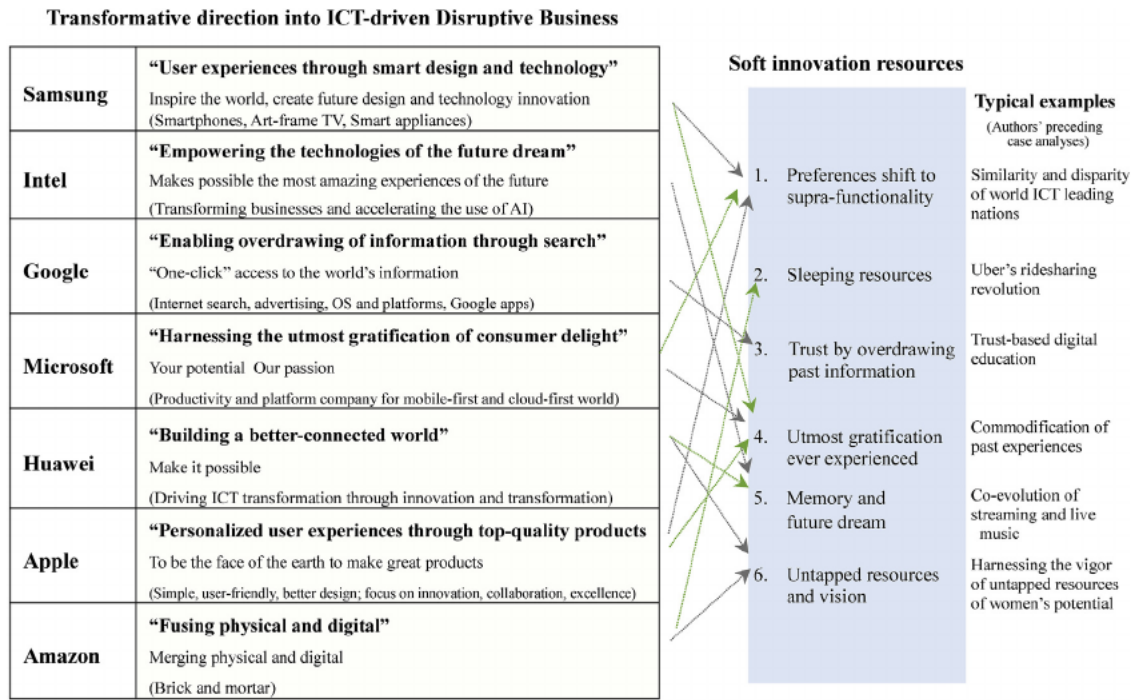


Fig. 18. Significant direction of ICT-driven disruptive business models.

While Amazon was not included in top R&D intensive firms in 2016, given its conspicuous R&D investment growth rate which changed it top R&D firm in 2017, it was included in this comparison.

Source: Authors' elaboration based on Naveed et al. (2018).

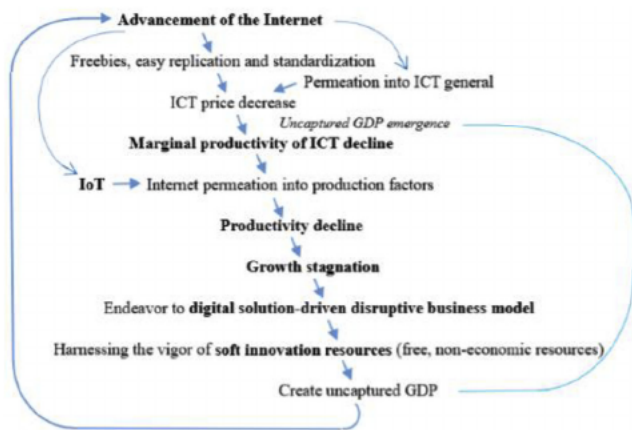


Fig. 19. Scheme of the Platform which Demonstrates Spin-off Dynamism to Increase Dependence on Uncaptured GDP.

beyond economic value also accelerates uncaptured GDP dependence as illustrated in Fig. 20 [51].

Furthermore, effective utilization of soft innovation resources which triggered the above dynamism contributes to removing structural impediments in captured GDP growth such as conflict between public, employers and labour union, and also disparity of gender. Thus, spontaneous creation of uncaptured GDP through effective utilization of soft innovation resources contributes to overcoming economic stagnation by its hybrid functions as illustrated in Fig. 20.

Such endeavour toward transformative direction towards an IoT society leads to a new stream of digital solution-driven disruptive business model that creates uncaptured GDP spontaneously not merely depending on it passively.

Locomotive power of this stream can largely be attributed to effective utilization of soft innovation resources which activates self-propagating function identical to ICT and induces functionality

development leading to supra-functionality beyond economic value corresponding to a shift in people's preferences.

This shift accelerates a shift from a PoT society to an IoT society which increases further dependency on uncaptured GDP. At the same time, supra-functionality beyond economic value also accelerates uncaptured GDP dependence as illustrated in Fig. 20.

Thus, spontaneous creation of uncaptured GDP through effective utilization of soft innovation resources plays a hybrid role in accelerating new co-evolution among IoT, uncaptured GDP and supra-functionality beyond economic value while contributing to overcoming economic stagnation.

These findings provide new insight and constructive suggestions to a transformative direction to address the limitation of GDP in the digital economy.

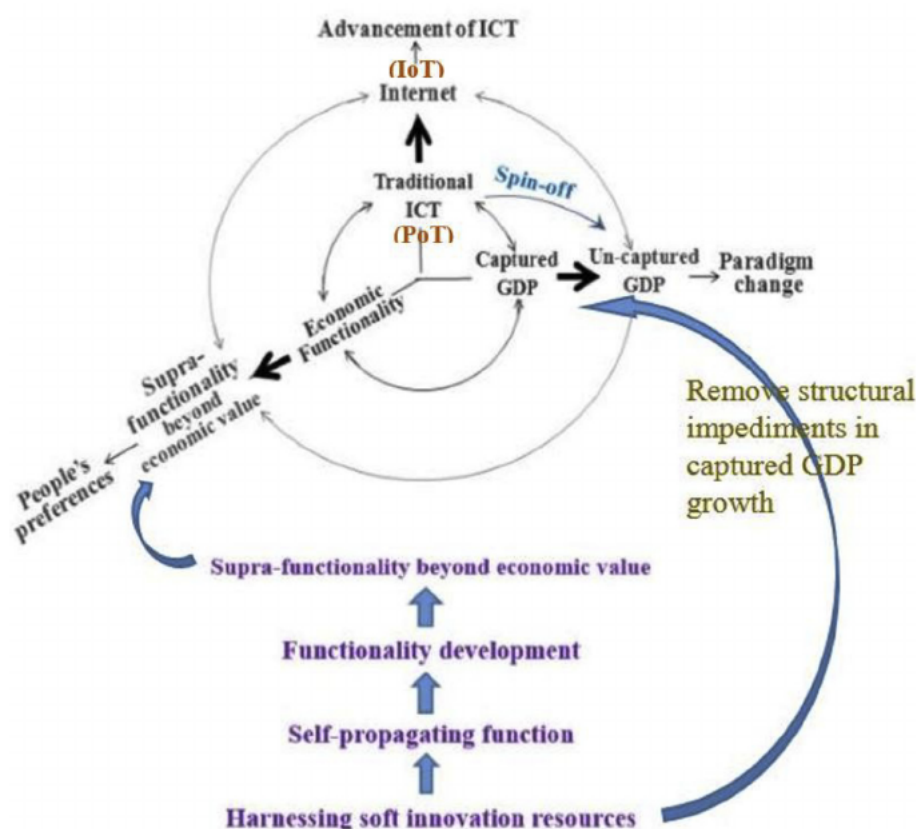
## 6. Conclusion

Considering the increasing significance of measuring GDP in the digital economy because of growing concern regarding the limitation of GDP, a practical new solution was examined. The problem was investigated based on the results of intensive empirical analyses of the national, industrial, and individual behavior in the digital economy.

Given the two-faced nature of ICT and that people's preferences extend beyond economic value, the concept of uncaptured GDP was postulated and spinoff dynamism to a new co-evolution among advancement of the Internet, increasing dependence on uncaptured GDP, and a shift in people's preferences to supra-functionality beyond economic value was reviewed. Structural sources of the limitation of GDP in the digital economy were thus identified and a transformative direction to address the problem was suggested based on investigation of the forefront endeavor of leading global ICT firms.

The following findings outline the structural sources of the problem:

- ICT prices have continued to decline because of a trap in ICT advancement that stems from the two-faced nature of ICT. That is, the



**Fig. 20.** Hybrid role of soft innovation resources removing structural impediments in GDP growth.

advancement of ICT generally contributes to enhanced prices of technology through new functionality development, whereas the dramatic advancement of the Internet decreases prices of technology because of the following characteristics: provision of freebies, easy and free replication, and mass standardization. Therefore, the marginal productivity declines in leading ICT firms.

- To compensate for decreases in prices, new and unique services have been introduced 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 a pseudo deflator) can be attributed to this phenomenon.
- The new services that have been introduced correspond to a shift in people's preferences from economic functionality to supra-functionality beyond economic value, which encompasses social, cultural, and emotional values.
- This shift induces further advancement of the Internet, which intensifies increasing dependence on uncaptured GDP. Therefore, a new co-evolution among Internet advancement, increasing uncaptured GDP, and a shift in people's preferences has emerged.

In addition, the following noteworthy findings provide constructive insight on the above issues:

- 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.
- The survival strategy of global ICT firms depends on the construction of a platform that demonstrates above dynamism.
- The transformative direction of highly R&D-intensive firms may

provide a constructive suggestion for identifying where a company's real economic activity is taking place.

These findings give rise to the following insightful suggestions for optimal countermeasures to these critical issues:

- Spinning off to new co-evolution among advancement of the Internet, increasing dependence on uncaptured GDP, and a shift in people's preferences to supra-functionality beyond economic value should be realized.
- Sustainable growth in 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 should be developed.
- Comprehensive uncaptured GDP measurement should be developed.
- The higher well-being that a nation actually enjoys should be demonstrated rather than merely assessed through captured GDP.

Thus, this analysis provides new insights for measuring the digital economy.

Future works should focus on international and historical reviews of success stories of gross GDP management both at national and industrial levels. The development of public policies based on the gross GDP concept should also be prioritized.

In addition, given the increasing significance of minimizing tax evasion, development of a tax principle for prosumers, taxation of uncaptured GDP, and precise evaluation of digital value to be taxed, tax challenges in the digital economy should also be investigated.

An optimal balance between new revenues for public policy through taxation of uncaptured GDP and reasonable incentive with the aim of

encouraging the harnessing of soft innovation resources should be carefully considered.

## Acknowledgement

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## Appendix A. Supplementary data

Supplementary data related to this article can be found at <http://dx.doi.org/10.1016/j.techsoc.2018.05.004>.

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