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The Transformative Direction of Innovation Toward an IoT-based Society - Increasing Dependency on Uncaptured GDP in Global ICT Firms

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Abstract

Driven by the possibilities of the Internet of Things (IoT), global information and communication technology (ICT) firms have taken significant steps forward in recent years.

The Internet provides extraordinary services to people while promoting a free culture. However, such services cannot be captured through gross domestic product (GDP) data that measure revenue. Consequently, advancement of the Internet leads to increasing dependency on uncaptured GDP (added value providing people utility and happiness beyond economic value) and ICT price decreases.

Against such circumstances, global ICT firms are quickly embracing digital solutions for new competitiveness that urge them to restructure their business model toward digital business strategies. Aiming at demonstrating this hypothetical view, this paper attempts to explore new approach for analyzing such dynamism and examines some optimal solutions that are co-evolving with it.

An empirical analysis of digital business solutions in 500 global ICT firms over the period 2005–2016 was conducted with special attention to their specific features.

It was identified that research and development–intensive firms have fallen into a trap in ICT advancement, resulting in a decline in their marginal productivity of ICT that could be due to increasing dependency on uncaptured GDP. As a result, these firms are endeavoring to harness soft innovation resources and activate a self-propagating function that induces functionality development sublimating sophisticated digital business strategies, such as:

- Shifting from software to network (e.g., Apple and Google),
- Merging network and real (e.g., Amazon's merging of e-commerce and brick-and-mortal retail),
- Shifting from commodity to culture (e.g., Facebook and Samsung).

All can be considered as soft value addition in response to uncaptured GDP.

This analysis explores new insights for ICT firms in their transformative strategies toward an IoT-based society.

Keywords: IoT, global ICT firms, uncaptured GDP, digital business solutions, transformative strategy

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1 Introduction

1.1 IoT and the New Productivity Paradox

Driven by the Internet of Things (IoT)[1], the physical world is becoming an ecosystem composed of physical objects embedded with sensors and actuators connected to applications and services through a wide range of networks. The IoT has the potential to drive the next steps toward the digitization of our society and economy (EU, 2017). It promises several benefits to its customers, varying from faster and more accurate sensing of our environment to more cost-effective tracking of industrial processes. The wide adoption of the IoT is expected to generate significant revenues to the providers of its applications and services (Mazhelis et al., 2012).

The IoT will change the bases of competition and drive new business models for users and suppliers. Firms that use the IoT in novel ways to develop new business models or discover new ways to monetize the IoT data are likely to enjoy more sustainable benefits (McKinsey Global Institute, 2015). McKinsey (2015) report also discussed that the challenges in capturing the full potential of the IoT require innovation in technologies, business models, investment capabilities, and talent, together with policy actions to encourage interoperability, security, and protection of privacy and property rights. It was also noted the possibility of a new "productivity paradox" in the context of the IoT—a possible lag between technology investments and productivity gains at macroeconomic level.

1.2 From "Computer Paradox" to "Productivity Paradox" in the IoT

1.2.1 Computer-Initiated Productivity Paradox

There have been long-lasting debates on the information and communication technology (ICT)–driven "productivity paradox."

Significant numbers of analyses demonstrated the impact of ICT advancement on the socio-economy triggered by Nobel Laureate Solow's "Productivity Paradox" (Solow, 1987) and reaction to it by Brynjolfsson (1993). This reaction was followed by more sophisticated models to tease out the relationship between ICT and productivity (Kraemer and Dedrick, 1994; Lichtenberg, 1995; Brynjolfsson and Hitt, 1996).

By the late 1990s, there were some signs that productivity in the workplace had been improved by the introduction of ICT, especially in the US. Brynjolfsson et al. found a significant positive relationship between ICT investments and productivity (Brynjolfsson and Hitt, 1998; Brynjolfsson and Yang, 1999) encouraging popular consideration that there was no paradox (Triplett, 1999).

1.2.2 Internet-Initiated New Productivity Paradox

Late in the first decade of this century, a new paradox appeared to have emerged. This can largely be attributed to the third industrial revolution initiated by the dramatic

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

advancement of the Internet (Rifkin, 2011). The Internet has transformed how people live, work, socialize, and meet, and how countries develop and grow. It has changed from a network for researchers to a day-to-day reality for billions of people in two decades (McKinsey, 2011). Consequently, the computer-initiated ICT world has changed significantly. The entire system has become interactive, integrated, and seamless. This interconnectedness is creating new opportunities for cross-industry relationships.

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 argued that the consequence of slowing innovation was fewer new industries and less creative destruction, hence fewer new jobs. He stressed that, while the technological progress brought a big and predictable stream of growth across most of the economy, those assumptions were turning out to be wrong or misleading when it came to the Internet. He then suggested the possibility of the consequence of the two-faced nature of ICT.

From the dramatic advancement of the Internet and subsequent third industrial revolution inevitably emerged a new paradox of the advancement of ICT. Brynjolfsson, who first reacted to Solow’s production paradox in 1993, raised the question, “Could technology be destroying jobs?” (Brynjolfsson and McAfee, 2011). He argued by giving an example of the music industry: "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 maybe it’s not the growth that is deficient but the yardstick that is deficient and postulated the limit of GDP (Brynjolfsson et al., 2014).

Inspired by these arguments, Lowrey (2011) postulated that the Internet promotes more free culture, the consumption of which provides utility and happiness to people but cannot be captured through the GDP data that measure revenue.

1.3 Uncaptured GDP and Its Source

1.3.1 Sources of Free Culture

Considering the evolutional services that the Internet provides under free culture, several analyses and debates were initiated on the sources of its free culture.

1.3.1.1 Unique function stemmed from online intermediaries

Copenhagen Economics (2013) studied the impact of online intermediaries[2] (that play a core role in the Internet function) on GDP of EU27 countries in 2012 by identifying: (i) direct contribution through consumption increase, (ii) indirect contribution through productivity increase, and (iii) beyond measurement. The report estimated that, contrary to direct and indirect GDP contributions of EUR 220 billion (1.7% of GDP) and EUR 210 billion (1.65% of GDP), respectively, EUR 640 billion (5.0% of GDP) derived from B2B platforms by e-commerce, online advertising, and consumer benefits of free

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

services like Google search was beyond measurement by the GDP statistics. The report also pointed out that these estimates were understated, as they didn't include the direct contribution by investments, which are hard to measure, and the sociocultural value created by social network development.

1.3.1.2 Consumer surplus

The research by Brynjolfsson et al. (Revised 2017) analyzing online booksellers found that significant consumer surplus gains were created by the increased product variety available through electronic markets and that efficiency gains resulted from increased competition leading to lower average prices. Their analysis indicates that the increased product variety of online bookstores enhanced consumer welfare by US$731 million to US$1.03 billion in the year 2000, which is seven to 10 times larger than the consumer welfare gain from increased competition and lower prices in this market.

Brynjolfsson et al. (Revised 2017) also mentioned the possibility of large welfare gains in other SKU-intensive consumer goods, such as music, movies, consumer electronics, and computers. Similar results were demonstrated by the white paper of Japan's ICT, analyzing consumer surplus in music and audio-visual services (Japan's Ministry of Internal Affairs and Communication, 2016).

Analyzing the big economic opportunities and challenges in capturing the maximum value of IoT, McKinsey (2015) estimated that consumer surplus derived from the IoT could be more than 10 percent of the global economy by 2025.

1.3.1.3 New goods and services derived from disruptive innovations

The US Council on Competitiveness (2016) pointed out that the apparent slowdown in productivity in the industrialized countries could be simply 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, Twitter) that are radical breaks with previous products or, in some cases, are provided for free to the users.

The report also discussed that, despite tremendous previous problems in accurately measuring the benefits of new goods and services, there is some evidence that statistical agencies are now better at capturing this value. But adjustment issues related to previous gains still remain to accurately measure productivity growth.

It also pointed out that current estimates for the non-market benefits of free goods and services like Google, Wikipedia, and Facebook do not make up for the shortfall in productivity growth. It may turn out that those estimates understate the non-market benefits, but it would be very hard to know.

Similar points were also made by The Economist (2016) claiming that "GDP is a bad gauge of material well-being and it is a time for fresh approach."

1.3.1.4 Online piracy

In addition to the foregoing beyond-measurement difficulties inherent to disruptive innovations caused by the dramatic advancement of the Internet, it was generally pointed out that a corresponding increase in online piracy is another difficult issue beyond GDP measurement.

1.3.2 Uncaptured GDP

Following these analyses and debates, Watanabe et al. (2015a) discussed the two-faced nature of ICT and the emergence of uncaptured GDP as fatal to the advancement of the Internet (Watanabe et al., 2015a, 2015b, 2016a, 2016b). They pointed out that, while advancement of ICT generally contributes to enhanced prices of technology by new functionality development, the dramatic advancement of the Internet contributes to decreased prices of technology due to its unique, inherent characteristics of freebies, easy copying, and mass standardization. With this understanding, they supported Lowrey's (2011) postulate that the Internet promotes free culture, the consumption of which provides utility and happiness to people but cannot be captured through GDP data that measure revenue. The authors defined these added values that provide people utility and happiness beyond economic value under free culture as an uncaptured GDP.

1.4 Consequence of IoT

The Internet continues to grow rapidly and changes every aspect of our lives by introducing new ways of communication, learning, socialization, and doing business, further transforming our world into an IoT-based society (Bharadwaj et al., 2013; Internet Society, 2016). The IoT has also changed the traditional meaning of the word "product" introduced in the era of "Product of Things (PoT)." In the era of the IoT, the product can be a technology, device, service powered by software, a flow of data, a software application for monitoring, automation, and analysis, or any combination of the above.

The transformation of the traditional Internet, where data are "created by people," to the IoT, where data are "created by things" (Madakam et al., 2015) will generate data at a much larger scale that requires more advanced technological capabilities, as most of the data collected today are not fully exploited. To be competitive and to capitalize on the highly promising business opportunities of the IoT, global ICT firms need to embrace sophisticated digital solutions and restructure their business models (Bharadwaj et al., 2013).

Due to the challenges and huge interest in the IoT, the importance of business models and digital business strategies cannot be over-emphasized. Bharadwaj et al. (2013) and Kahre et al. (2017) stressed the significance of digital business strategies (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 digital business strategy 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 digital business strategy to creating differential business value, thereby elevating the performance implications of ICT strategy beyond efficiency and productivity.

Bharadwaj et al. (2013) also pointed out that it is clearly time to rethink the role of ICT strategy from that of a functional-level strategy subordinating business strategy to the digital business strategy that fuses ICT strategy and business strategy.

1.5 New Business Strategies Spinning Off From a PoT Society to an IoT Society

The authors, in their previous research, 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 strategy for resilient market value creation in the digital economy[3] (Watanabe et al., 2014).

- Dependency on high 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 sequel studies, the authors tried to compare the spinning-off dynamisms from traditional computer-initiated ICT innovation in the era of the PoT to Internet-initiated ICT innovations by using their developed co-evolutional framework between the advancement of ICT, a paradigm change, and a shift in people's preferences **(Fig. 1)**.

The authors have found that, corresponding to a shift from computer-initiated innovation toward the new stream of Internet-initiated innovations, social preferences have shifted from economic functionality to supra-functionality. The economic impact of innovation has shifted from captured GDP (monetized revenues) to increasingly uncaptured GDP (un-monetized revenues) due to the digital nature, free availability of the products, and new business models (Watanabe et al., 2015*a*, *b*, 2016*a*, *b*; 2017*a*).

In their further studies (Watanabe et al., 2016b, 2017a; Naveed et al., 2017) the authors recognized the consolidated challenges in social demand and the importance of trust between stakeholders in introducing successful disruptive innovations. Copenhagen Economics (2015) in its sequel report also pointed out the significant contribution of online intermediaries in building trust.

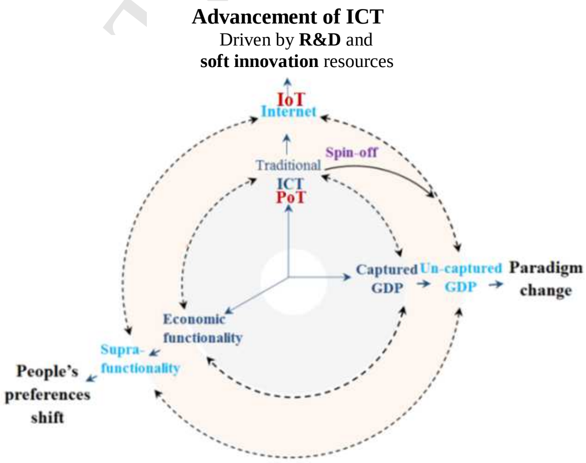

Fig. 1. Scheme of Spin-Off Dynamism.

[3] As shown by Tapscott in his best-seller "The Digital Economy" (1995), the Internet has changed the way of business and daily life dramatically. The digital economy is also known as the Internet economy, the new economy, or the web economy.

The authors suggested that the digital business strategy corresponding to the new stream of innovations should be supported by a trust-based, ICT-driven disruptive business model (IDBM) with consolidated challenge to social demand (CCSD) incorporating the inherent self-propagating function.
The significance of the above suggestions should be recognized in the foregoing transformation of traditional ICT-driven functionality development strategy toward digital business strategy (Ahmad et al., 2016).

1.6 Dynamism Transforming into Digital Business Strategy

None of the previous research has elucidated the dynamism of this transformation leading global ICT firms to create digital business strategy corresponding to an IoT-based society.

This paper attempts to explore new approach to demonstrate the above hypothetical views by explaining the transformation dynamism, in shifting from the PoT toward the IoT and give constructive insights to global ICT firms for their digital business strategies.

Based on the findings obtained from the following preceding analyses illustrating the spin-off from traditional to new co-evolution, an empirical analysis was conducted by evaluating the new survival strategy of top 500 global ICT firms over the period of 2005–2016, with a focus toward the following new business models and also paying special attention to their specific features similar to:

- Similarity and disparity of world ICT leaders (Watanabe et al., 2015*b*, 2016*a*),
- Uber's ridesharing revolution (Watanabe et al., 2016*b*, 2017*a*),
- Trust-based digital education (Watanabe et al., 2017*b*),
- Commodification of past experiences (Watanabe et al., 2012),
- Co-evolution of streaming and live music (Naveed et al., 2017), and
- Harnessing the vigor of untapped resources by activating women's potential (Watanabe et al., 2017*c*).

It was identified that high R&D-intensive firms have fallen into a trap in ICT advancement resulting in declining their marginal productivity of ICT that, which can be considered a consequence of two-faced nature of GDP. Consequently, these firms are endeavoring to increase self-propagating functionality development by sublimating sophisticated digital business strategies, which can be considered a soft value addition to deal with the issue of uncaptured GDP. **Fig. 2** illustrates dynamism spinning-off to increasing dependency on uncaptured GDP.

This analysis thus explores a new insight for ICT firms for their transformative strategy toward an IoT-based society.

Section 2 of this paper reviews the shift of global ICT firms toward the IoT. Section 3 analyzes increasing dependency on uncaptured GDP in the global ICT firms. The sources inducing high self-propagating function are analyzed in Section 4. Section 5 briefly summarizes noteworthy findings, policy suggestions, and future research.

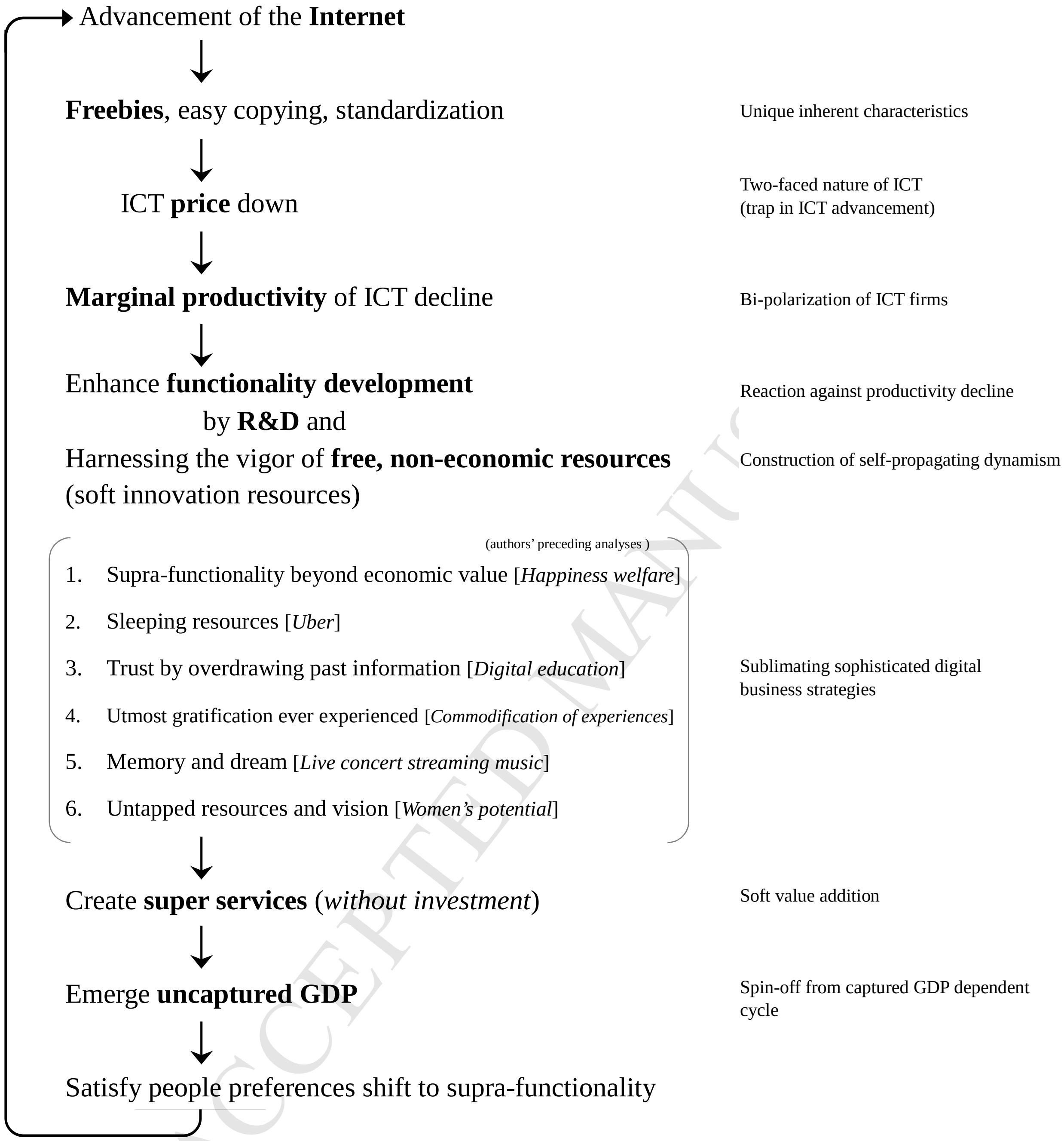

Fig. 2. Dynamism Spinning-Off to Increasing Dependency on Uncaptured GDP.

2 Shift of Global Firms Toward IoT

2.1 Influence of R&D-Driven Growth in Global ICT Firms

Given that sales *(S)* of global ICT firms are governed by ICT stock, their sales can be depicted as follows (see Appendix A):

$$\ln S = a + b \ln R \qquad (1)$$

where *R:* R&D investments; and *a*, *b*: coefficients.

The top 500 global ICT firms were divided into three groups by using cluster analysis[4] based on their R&D and sales levels in year 2016 as illustrated in **Fig. 3.**

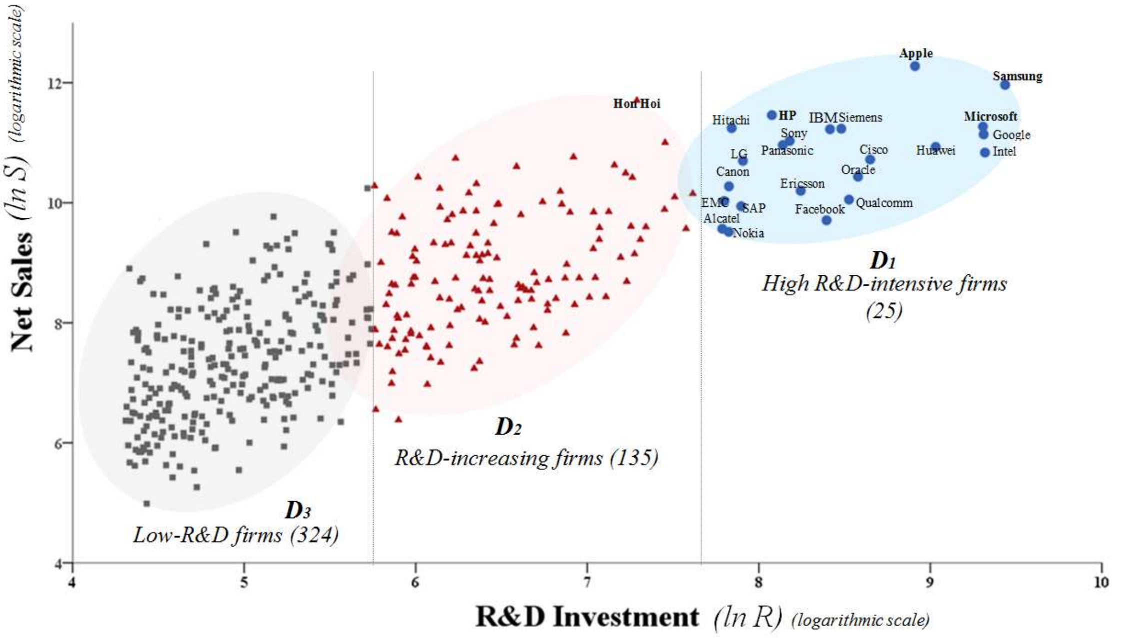

Fig. 3. Correlation Between R&D Investment and Sales in 500 Global ICT Firms (2016).
Note: The figures in parentheses indicate number of ICT firms. 16 outliners scattered in D_2 and D_3 were not presented.

Based on the above findings, and utilizing equation (1), correlation between *(S)* and *(R)* in the top 500 global ICT firms by R&D level in 2016 was analyzed.

$$lnS = \underset{(4.43)}{2.319} + \underset{(15.18)}{0.997}D_1 \ln R + \underset{(12.40)}{1.013}\, D_2 \ln R + \underset{(9.65)}{1.023}D_3 \ln R + \underset{(13.22)}{2.903}\, D \qquad adj.\ R^2\ 0.632$$

***S*:** Net sales, ***R*:** R&D investment, D_1, D_2, D_3, and *D* are dummy variables.
$\boldsymbol{D_1}$**:** High R&D-intensive firms, $\boldsymbol{D_2}$**:** R&D-increasing firms, $\boldsymbol{D_3}$**:** Low-R&D firms, ***D*:** Outliers.
The figures in parentheses indicate t-statistics: All are significant at the 1% level.

The result of the correlation analysis is statistically significant. This demonstrates that sales of the global ICT firms are governed by their ICT stock as cumulative stock of R&D investment constructs ICT stock[5].

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[4] K-means clustering analysis was used.

[5] This result leads to $\frac{\partial \ln S}{\partial \ln R} = \frac{\partial S}{\partial R} \cdot \frac{R}{S} = b$ *therefore,* $\frac{\partial S}{\partial R} = b \cdot \frac{S}{R}$ (*b*: elasticity). This suggests that marginal productivity of *R* is proportional to *R* productivity in *R*-driven growth trajectory, typical for the digital innovation.

2.2 Business Structure Comparison of Top 70 Global ICT Firms

With the foregoing understanding, **Table 1** lists the top 70 R&D-intensive global ICT firms in 2016 and compares their business performance by R&D *(R)*, sales *(S)*, operating income *(OI)*, R&D intensity *(R/S)*, profitability *(OI/S)*, and R&D profitability *(OI/R)*.

Table 1 Digital Business Structure in Global ICT Firms in 2016 (Top 70 R&D-intensive ICT firms by R&D level)

R&D level	Firm	R&D *(R)*	Net sales *(S)*	Operating income *(OI)*	R/S	OI/S	OI/R
		EUR mil	EUR mil	EUR mil	%	%	%
1	**Samsung**	12528	157190	20692	8.0	13.2	165.2
2	**Intel**	11140	50845	13016	21.9	25.6	116.8
3	**Google**	11054	68879	17783	16.0	25.8	160.9
4	**Microsoft**	11011	78369	18683	14.1	23.8	169.7
5	**Huawei**	8358	55893	6479	15.0	11.6	77.5
6	**Apple**	7410	214674	65427	3.5	30.5	883.0
7	**Cisco**	5701	45235	11875	12.6	26.3	208.3
8	**Oracle**	5316	34029	12036	15.6	35.4	226.4
9	**Qualcomm**	5043	23221	5451	21.7	23.5	108.1
10	**Siemens**	4820	75636	5809	6.4	7.7	120.5
11	**IBM**	4515	75081	14586	6.0	19.4	323.1
12	**Facebook**	4424	16467	5718	26.9	34.7	129.3
13	**Ericsson**	3806	26870	2356	14.2	8.8	61.9
14	**Sony**	3569	61787	2243	5.8	3.6	62.8
15	**Panasonic**	3429	57559	2797	6.0	4.9	81.6
16	**HP**	3217	94934	7353	3.4	7.7	228.6
17	**LG**	2718	44269	934	6.1	2.1	34.4
18	**SAP**	2689	20793	4252	12.9	20.4	158.1
19	**Hitachi**	2544	76461	4597	3.3	0.1	180.7
20	**Canon**	2504	28968	2708	8.6	9.3	108.1
21	**Nokia**	2502	13574	1842	18.4	13.6	73.6
22	**EMC**	2437	22691	3023	10.7	13.3	124.0
23	**Alcatel**	2409	14280	890	16.9	6.2	36.9
24	**Medtronic**	2043	26484	4860	7.7	18.4	237.9
25	**ZTE**	1954	14176	955	13.8	6.7	48.9
26	**Taiwan SEM**	1827	23508	9104	7.8	38.7	498.4
27	**SK Hynix**	1543	14726	4180	10.5	28.4	270.9
28	**West Digital**	1494	11935	754	12.5	6.3	50.5
29	**Hon Hai**	1463	124916	5219	1.2	4.2	356.7
30	**Baidu**	1444	9393	1651	15.4	17.6	114.3
31	**Mitsubishi**	1426	33497	2296	4.3	6.9	161.0
32	**Micron Tec**	1415	14873	2756	9.5	18.5	194.9
33	**MediaTek**	1380	5943	727	23.2	12.2	52.6
34	**Fujitsu**	1371	36126	1113	3.8	3.1	81.1
35	**Applied Mat**	1332	8872	1387	15.0	15.6	104.1
36	**Lenovo**	1285	41253	-20	3.1	-0.05	-1.6
37	**Fujifilm**	1243	18993	1457	6.5	7.7	117.3
38	**NVidia**	1223	4602	806	26.6	17.5	66.0
39	**Tencent**	1177	14555	5717	8.1	39.3	485.5
40	**Texas Inst**	1176	11941	3946	9.8	33.0	335.6
41	**STM**	1149	6335	121	18.1	1.9	10.6
42	**Danaher**	1138	18888	3298	6.0	17.5	289.8
43	**Seagate**	1136	10251	409	11.1	4.0	36.0
44	**Yahoo!**	1110	4564	-4266	24.3	-93.5	-384.2
45	**ASML**	1046	6287	1861	16.6	29.6	177.8
46	**Elec Arts**	1019	4038	825	25.2	20.4	81.0
47	**Sharp**	992	18764	-1423	5.3	-7.6	-143.5
48	**eBay**	973	7892	2018	12.3	25.6	207.5
49	**Marvell**	968	2504	-750	38.7	-30.0	-77.5
50	**Broadcom**	964	6268	1534	15.4	24.5	159.2
51	**NEC**	945	21505	743	4.4	3.5	78.6
52	**Schneider**	937	26640	2220	3.5	8.3	236.9
53	**Juniper**	913	4462	837	20.5	18.8	91.6
54	**Salesforce**	875	6124	102	14.3	1.7	11.7
55	**Cerner**	870	4065	717	21.4	17.7	82.4
56	**Adv. Micro**	870	3666	-308	23.7	-8.4	-35.4
57	**Sumitomo**	845	22358	999	3.8	4.5	118.2
58	**Twitter**	826	2037	-413	40.6	-20.3	-50.0
59	**Freescale**	817	4108	694	19.9	0.2	84.9
60	**Infineon**	817	5795	557	14.1	9.6	68.2
61	**Boston Sci**	805	6868	944	11.7	13.7	117.4
62	**LinkedIn**	802	2747	-139	29.2	-5.0	-17.3
63	**Adobe**	792	4405	831	18.0	18.9	104.9
64	**NetApp**	791	5094	426	15.5	8.4	53.9
65	**Ricoh**	778	15357	960	5.1	0.1	123.4
66	**SanDisk**	768	5112	698	15.0	13.7	90.9
67	**LAM**	753	5406	987	13.9	18.3	131.0
68	**Midea**	745	18063	1845	4.1	10.2	247.7
69	**Renesas**	742	5285	788	14.0	14.9	106.2
70	**NXP**	734	5604	691	13.1	12.3	94.1

Note: Amazon is not presented because it did not meet the criteria of top 70 R&D-intensive firms in 2016, as its position was 95th. The same applies to GE, Toshiba and Alibaba.

Fig. 4 compares the performance of the top 70 R&D-intensive global ICT firms in 2005 and 2016.

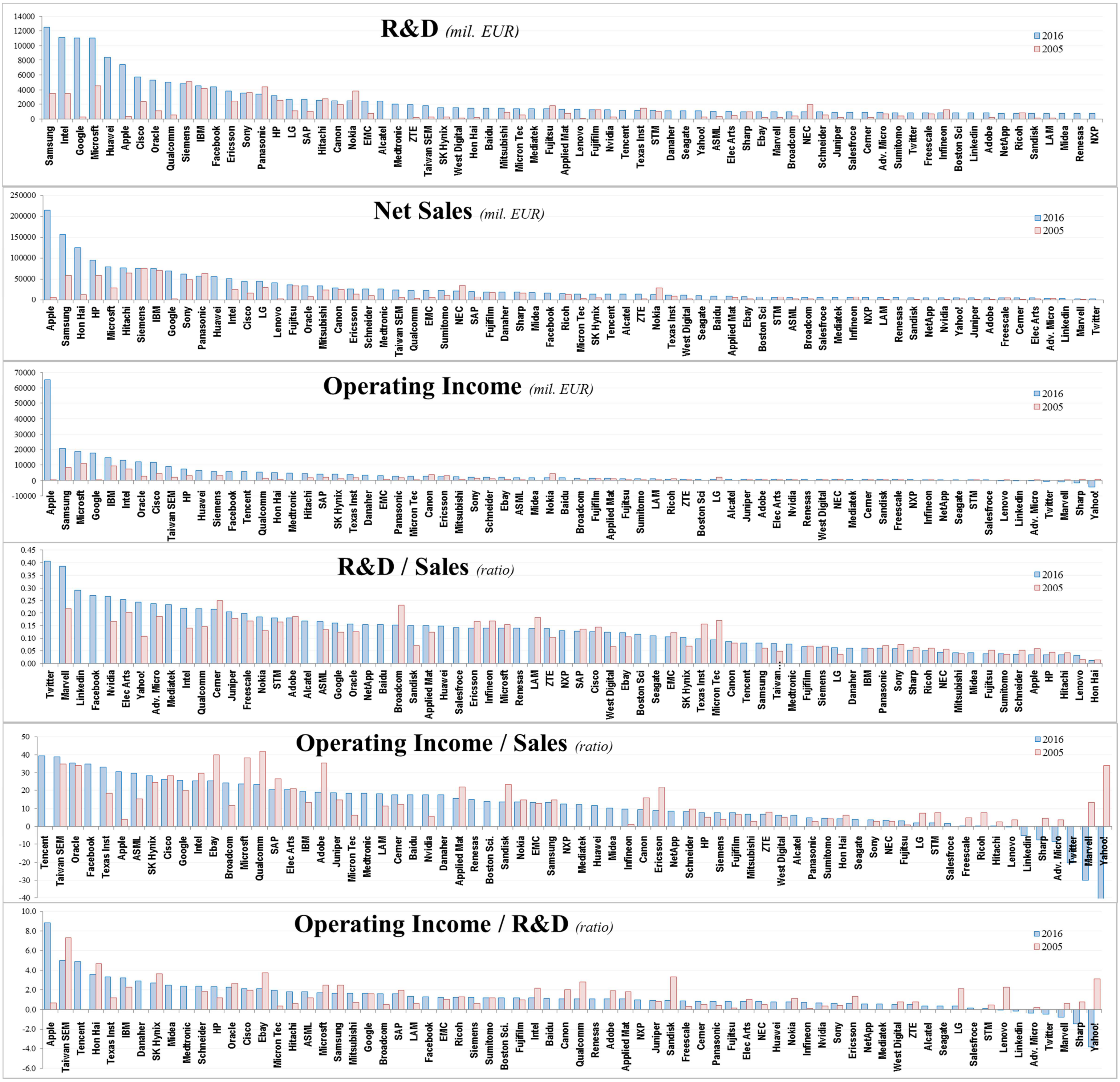


Fig. 4. Digital Business Structure in Global ICT Firms (Top 70 R&D intensive ICT firms in 2016).

2.3 Activation of Global ICT Firms

Over the last decade, dramatic advancement of the Internet worldwide paved the way to the acceleration of the IoT. This advancement was conspicuous after 2010, as initiated by global ICT firms as demonstrated in **Fig. 3** and **Table 2.**

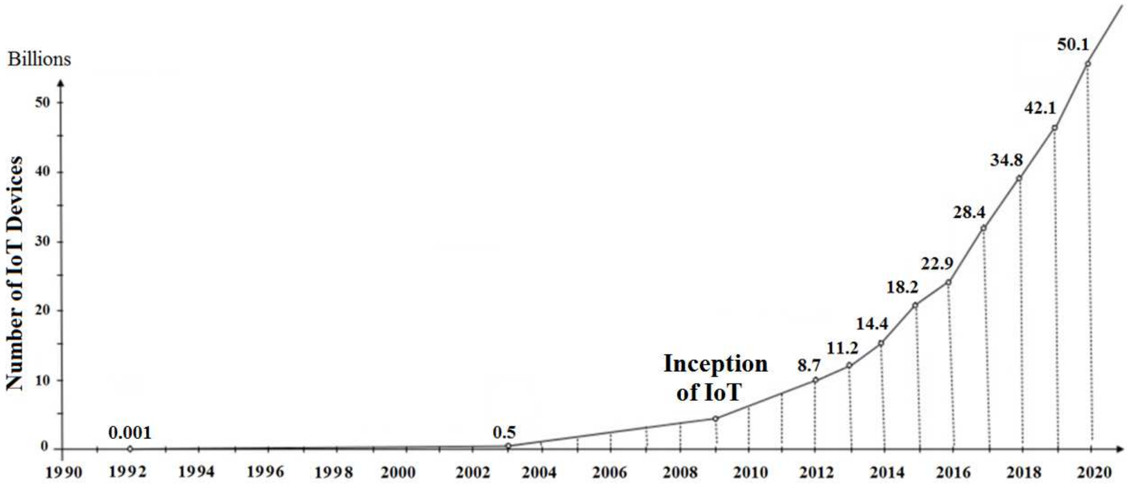


Fig. 5*a*. Trend in Growth of the IoT Worldwide (1990-2020).
Source: The Connectivist (2014).

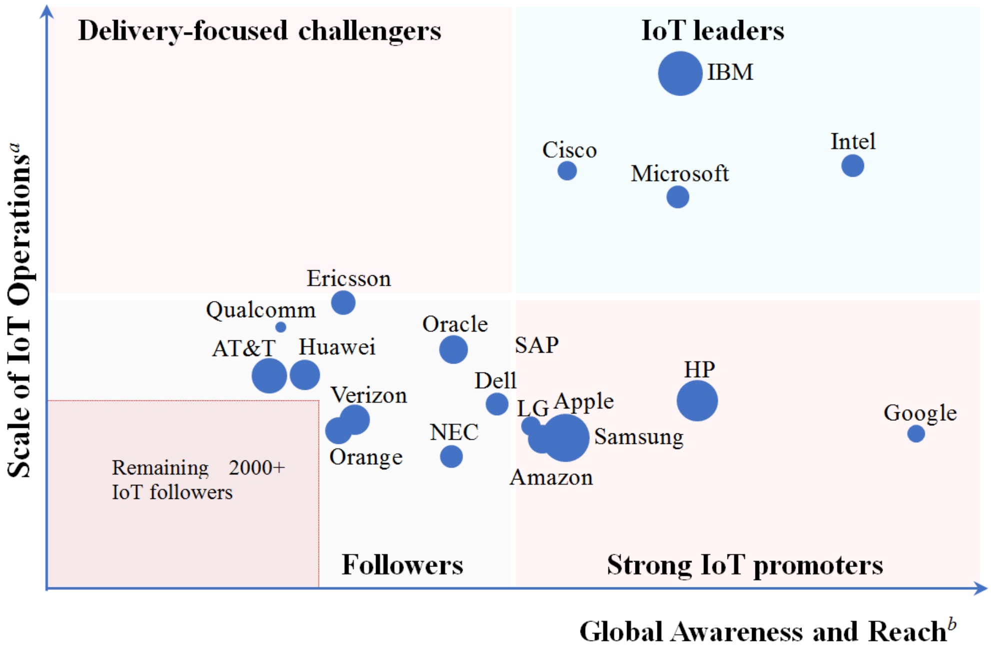


Fig. 5*b*. Leading Firms of the IoT (2015).

● Size of Firm (by number of all employees worldwide).
[a] Measured by estimated number of employees performing IoT-related operations.
[b] Measured by number of news appearances and related search engine inquiries.
Source: IoT Analytics (2015).

Fig. 5. Advancement of IoT Initiated by Global ICT Firms (2015).

Table 2 IoT Endeavor of Top 25 Global ICT Firms

1	**Samsung**	ARTIK platform, smart home, and digital health devices
2	**Intel**	IoT hardware, new-generation low-power chips for connected IoT devices, Intel IoT platform for connecting the data from your things to the cloud, Intel Galileo developer kit
3	**Google**	Self-driving cars, home automation, IoT beacons, work on IoT standards, IoT cloud
4	**Microsoft**	Windows 10 IoT Core operating system, Microsoft IoT Central, Azure IoT suite
5	**Huawei**	Huawei IoT management platform and smart solutions (e.g., Smart water, smart parking, smart logistics, smart energy, internet of vehicles)
6	**Apple**	HomeKit smart home and HealthKit health tracking platforms
7	**Cisco**	Cloud-based IoT software platform, connectivity hardware, IoT-related services and consulting
8	**Oracle**	IoT cloud service platform
9	**Qualcomm**	IoT development platform, chips, security services, acquisition of connected assets from NXP
10	**Siemens**	IoT industrial platforms, IoT security services, connected industrial machines
11	**IBM**	IBM Watson IoT, cloud services
12	**Facebook**	Learning about different cultures, beliefs, histories and technologies
13	**Ericsson**	IoT accelerator
14	**Sony**	Acquisition of Altair Semiconductor for M2M and IoT, Sony Smart Home Automation, mixed-reality hardware, image sensing chips
15	**Panasonic**	Supportive technologies for IoT/robotics, smart electronics using IoT
16	**HP**	Edge computing technology, acquisition of Aruba Networks, HP's Helion cloud platform (an open-source dev-ready cloud platform aimed at connecting devices)
17	**LG**	LG CNS IoT platform, Smart Green Platform
18	**SAP**	SAP HANA Cloud Platform for the IoT
19	**Hitachi**	Lumada intelligent IoT platform
20	**Canon**	Fusing optical technologies with digital health-care
21	**Nokia**	Open innovation challenge to leverage IoT technologies enabling a smart, safe and sustainable world
22	**EMC**	New services framework including management of devices, connectivity, data and storage
23	**Alcatel-Lucent**	Network application challenge with new access switch added analytics and SDN (software defined networking) capabilities
24	**Toshiba**	Imbedding of sensors in data-collection devices, the real time processing of big data
25	**Amazon**	Amazon Web Services (AWS) IoT cloud, Amazon Echo home automation device, Amazon dash buttons

R&D investment level in 2016 order.

While firms 1–23 correspond to Table 1, 24 and 25 are not included in Table 1 (see footnote of **Table 1**).

2.4 Noteworthy Shift of Global Firms from 2010 to 2016

Foregoing strong initiatives toward the IoT led by global ICT firms, particularly after 2010, resulted in a structural change of market value in leading firms. **Table 3** traces the trend in the ranking of market value of the leading firms in 2005, 2010, and 2016.

Table 3 Trend in Market Capitalization of Global ICT Firms

Table 3*a* Ranking of Global ICT Firms within Top 100 Firms

	2005	2010	2016
1	General Electric (2)	Microsoft (3)	Apple (1)
2	Microsoft (3)	**Apple** (10)	Google (2)
3	IBM (13)	General Electric (16)	Microsoft (3)
4	Intel (15)	Google (17)	**Amazon** (4)
5	Cisco (25)	IBM (21)	**Facebook** (6)
6	Dell (34)	Cisco (30)	**Tencent Holdings** (10)
7	Samsung (47)	**Oracle** (36)	**Alibaba** (12)
8	Nokia (50)	HP (38)	General Electric (13)
9	Siemens (55)	Intel (42)	Samsung (14)
10	HP (72)	Samsung (50)	Oracle (34)
11	eBay (82)	Siemens (63)	Intel (40)
12	Google (93)	**Qualcomm** (87)	Cisco (41)
13		**Canon** (98)	IBM (44)
14		Amazon (101)*	**SAP** (56)
15			Siemens (64)
16			**Broadcom** (93)

* While Amazon was ranked 101 in 2010, it is listed for reference, as it conspicuously jumped to rank 4 in 2016.
Firms marked in bold are newly ranked-in firms.

Table 3*b* Ranking of Global ICT Firms within Top 15 Firms

	2005	2010	2016
1	General Electric (2)	Microsoft (3)	Apple (1)
2	Microsoft (3)	Apple (10)	Google (2)
3	IBM (13)		Microsoft (3)
4	Intel (15)		Amazon (4)
5			Facebook (6)
6			Tencent Holdings (10)
7			Alibaba (12)
8			General Electric (13)
9			Samsung (14)

Figures in parentheses indicate market capitalization rank computed based on Forbes Global 2000 statistics.
Telecom firms are not included.
Source: Forbes Global 2000.

The above review highlights the following noteworthy shift of global firms from 2010 to 2016 toward the IoT. First, leading global firms in the market, with respect to their market capitalization, have been shifted from those in the finance and energy sectors to ICT firms. Table 2b demonstrates that ICT firms comprise nine of the top 15 firms with respect to market value in 2016. The top three firms were all ICT firms.

Second, within ICT firms, the following shifts in their business focus have been evidently observed:

- From mechatronics to software (e.g., General Electric, IBM, and Siemens have decreased their status)
- From software to network (e.g., Apple and Google have exceeded their status, while Microsoft has decreased its status)
- From Network to a merging of network and physical (e.g., Amazon has dramatically raised its status by merging e-commerce and brick-and-mortal retail)
- From commodity to culture (e.g., noting increase in status of Facebook and Samsung)

These noteworthy shifts can be considered a consequence of endeavoring to increase a self-propagating functionality development by sublimating sophisticated digital business strategies against a trap in ICT advancement resulting in declining marginal productivity of high R&D-intensive ICT firms. This accomplishment can be considered a soft value addition to deal with the issue of increasing dependency on uncaptured GDP.

The next section demonstrates this hypothetical view.

3. Increasing Dependency on Uncaptured GDP in Global ICT Firms

3.1 Development Trajectory of Global ICT Firms

(1) Analytical Framework

As reviewed in the preceding section, sales (*S*) of the global ICT firms are governed by their ICT stock (*T*). With this situation, their development trajectory can be depicted as follows (Watanabe et al., 2015*a*):

$$S = F(X, T) = F(X(T)) \approx F(T) \quad (2)$$

where *X*: production factors other than *T*.

In long run, *T* can be treated proportional to R&D investment (*R*) and time trend (*t*)[6] (Watanabe, 2009).

Given the logistic growth nature of ICT, increasing trajectory of *S* in global ICT firms can be depicted by the following *R*-driven logistic growth function:

$$\frac{dS}{dR} = aS\left(1-\frac{S}{N}\right) \quad (3)$$

where *a*: velocity of diffusion, and *N*: carrying capacity (upper limit of diffusion).

Given the global ICT firms, equation (3) can be approximated as follows (Watanabe et al., 2009):

$$\frac{dS}{dR} = aS\left(1-\frac{S}{N}\right) \approx \frac{\partial S}{\partial R} \quad (4)$$

Equation (3) is developed to the following simple logistic growth (*SLG*) function which incorporates special advantage in assessing the state and prospect of productivity and development trajectory objectively:

$$S = \frac{N}{1+be^{-aR}} \quad (5)$$

where *b*: coefficient indicating the initial state of the diffusion.

Given that $be^{-aR} \equiv \frac{1}{x}$, marginal productivity of ICT can be depicted as follows:

$$\frac{\partial S}{\partial R} = aS\left(1-\frac{S}{N}\right) = aN \cdot \frac{1}{1+\frac{1}{x}}\left(1-\frac{1}{1+\frac{1}{x}}\right) = \frac{aN \cdot x}{(1+x)^2} \quad (6)$$

(2) Empirical Analysis

Based on this analytical framework, development trajectory of global ICT firms over the period 2005 and 2016 was analyzed.

---

[6] ICT stock at time t can be measured by the following equation:
$T_t = R_{t-m} + (1-\rho)T_{t-1}$ *and* $T_0 = R_{1-m}/(\rho+g)$, Then, $T_t = R_{t+1-m}/(\rho+g)$
When t >> m − 1, $T_t \approx R_t/(\rho+g)$. R_t is generally proportional to time trend *t* in ICT firms.
m: time-lag between R&D and commercialization,
ρ: rate of obsolescence of ICT, and g: growth rate of R&D at the initial period.

1) Specific features of global ICT firms

In conducting the analysis, following specific features of development trajectory identical to global ICT firms were carefully considered.

While digital innovation accelerates logistic growth of global ICT firms induced by logistic growth nature of ICT, this innovation emerges “mutation” firms with outlying behavior. They are generally newly founded young firms but expand at tremendous pace as demonstrated in **Table 4** and **Fig. 6**.

Table 4 Outlining Features of Top 5 Global ICT Firms

		R&D		Sales		Operating income	
Year of foundation	1	Samsung	1969	Apple	1976	Apple	1976
	2	Intel	1968	Samsung	1969	Samsung	1969
	3	Google	1998	Hon Hai	1974	Microsoft	1975
	4	Microsoft	1975	HP	1939	Google	1998
	5	Huawei	1987	Microsoft	1975	IBM	1911
Ratio of Top 1 and 10		2.6		3.5		8.9	

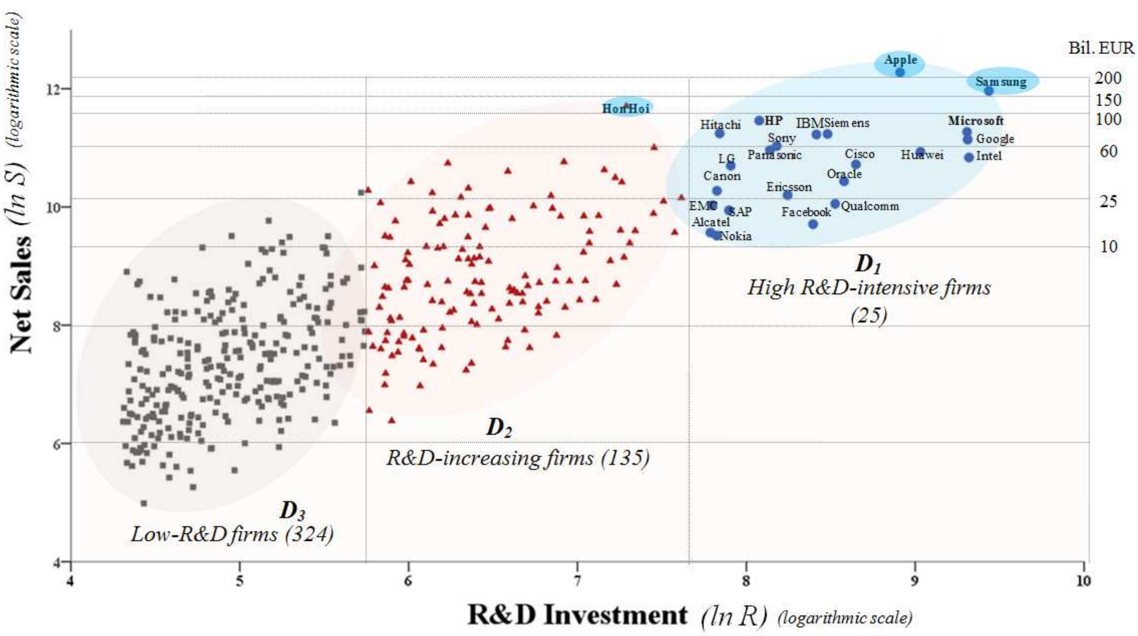


Fig. 6. Correlational Development between R&D and Sales in 500 Global ICT Firms (2016).

16 outliers scattered in D_2 and D_3 were not presented.

In order to explore a new insight for ICT firms for their transformative strategy toward an IoT-based society, objective state and prospect of productivity and development trajectory of global ICT firms general (not certain particular noting firms) should be analyzed not biased by particular gigantic "mutation" firms. However, since *SLG* function depends on fixed carrying capacity common to all firms analyzed resulting in biased estimate by highest development state in gigantic firms.

Fig. 6 allows us to imagine *SLG* estimation of *R*-driven development trajectory of 500 global ICT firms is biased by several gigantic firms with extraordinary high level of sales such as Apple, Samsung and Hon Hai while majority of 500 global ICT firms belong to the sales level below Euro 60 billion.

Aiming at avoiding such bias by certain gigantic firms, comparative assessment of the bias of gigantic firms in distorting *R*-driven development of the majority of 500 global ICT firms was conducted by treating gigantic firms that may distort such behavior as dummy variable in the *SLG* function. This comparative assessment identifies such gigantic ICT firms which have high variance from the general behavior of global ICT firms, and measures the magnitude of that variance, without which the highest representation of *R*-driven development trajectory can be analyzed by using *SLG* function (see the details of this treatment in **Appendix B**).

Table 5 summarizes the result of the comparative assessment.

Table 5 Comparison of Bias of Gigantic Firms in Distorting *R*-driven *SLG* in Majority of 500 Global ICT Firms (2016)

$$S = \frac{N}{1 + b\mathrm{e}^{-aR}} + cD$$

where *S*: sales, *R*: R&D investment, *N*: carrying capacity, *a, b, c*: coefficients, *D*: dummy variable (*D* = 1 for designated outlier firms, *D* = 0 for other firms).

	N	***a***	***b***	***c***	***adj. R^2***	***D*** (outlier firms treated by dummy variable)
A	68.72 (17.92)	1.21 (10.70)	16.36 (20.02)	96.87 (22.07)	*0.695*	Apple
B	58.24 (18.04)	1.44 (10.31)	15.55 (18.75)	97.82 (25.09)	*0.734*	Apple, Samsung
C	**59.62 (17.39)**	**1.32 (10.98)**	**15.91 (21.87)**	**99.09 (29.74)**	***0.784***	**Apple, Samsung, Hon Hai**
D	61.23 (16.77)	1.01 (10.72)	13.30 (21.63)	99.69 (29.22)	*0.780*	Apple, Samsung, Hon Hai, HP
E	50.38 (15.95)	1.33 (9.41)	12.71 (17.93)	90.72 (27.83)	*0.766*	Apple, Samsung, Hon Hai, HP, Microsoft
F	53.91 (14.63)	1.03 (9.27)	11.99 (18.87)	87.80 (27.79)	*0.766*	Apple, Samsung, Hon Hai, HP, Microsoft, Hitachi

* In addition to the above firms, Amazon and McKesson are included as outliers.
The figures in parentheses indicate t-statistics: All are significant at the 1% level.

Table 5 suggests that Case *C* (sales top 3 gigantic firms, Apple, Samsung and Hon Hai distort 500 global ICT firms' *SLG* trajectory most significantly) demonstrates statistically most significant.

2) Results of the analysis

By conducting the similar assessment, **Table 6** tabulates results of the estimation of *SLG* function over the period of 2005 and 2016. All results are statistically significant.

Table 6 Estimation of Development Trajectory of the 500 Global ICT Firms (2005–2016)

$$S = \frac{N}{1 + b\mathrm{e}^{-aR}} + cD$$

where *S*: sales, *R*: R&D investment, *N*: carrying capacity, *a*, *b*, *c*: coefficients, *D*: dummy variable (*D* = 1 for designated outliers, *D* = 0 for other firms).

	N	***a***	***b***	***c***	***adj. R^2***	***D*** (outlier firms treated by dummy variable)
2005	53.80 (21.18)	1.55 (16.96)	22.02 (29.44)	42.63 (18.13)	*0.734*	Dell
2006	57.62 (22.19)	1.47 (16.30)	18.97 (30.62)	51.13 (20.52)	*0.757*	General Electric, Dell
2007	52.67 (22.11)	1.73 (15.05)	18.51 (27.09)	53.86 (22.08)	*0.735*	Metro, General Electric
2008	45.55 (20.81)	1.81 (13.43)	15.06 (25.10)	54.97 (23.72)	*0.741*	Metro, General Electric, Siemens
2009	54.96 (20.07)	1.58 (12.91)	15.49 (25.34)	58.68 (22.20)	*0.724*	Metro, General Electric
2010	55.46 (17.26)	1.35 (13.84)	14.70 (27.25)	58.53 (24.34)	*0.742*	Metro, HP, General Electric
2011	58.59 (20.32)	1.46 (13.88)	14.57 (26.74)	61.07 (22.58)	*0.738*	Hon Hai, Metro, HP, General Electric
2012	55.55 (16.31)	1.14 (11.73)	12.56 (24.50)	65.44 (23.38)	*0.727*	Samsung, Apple, Hon Hai, Metro, HP
2013	49.11 (17.90)	1.53 (10.52)	12.56 (21.04)	74.38 (25.86)	*0.730*	Samsung, Apple, Hon Hai, Amazon, McKesson, Tesco
2014	44.14 (17.18)	1.69 (9.46)	12.42 (19.45)	73.88 (26.29)	*0.725*	Samsung, Apple, NTT, AT&T, Hon Hai, Amazon, Tesco
2015	53.22 (17.81)	1.53 (10.94)	14.37 (20.82)	82.98 (27.32)	*0.739*	Samsung, Apple, Hon Hai, Amazon, McKesson, Metro, Tesco
2016	59.61 (19.45)	1.32 (11.40)	15.94 (21.04)	99.09 (29.68)	*0.784*	Samsung, Apple, Hon Hai, Amazon, McKesson

The figures in parentheses indicate t-statistics: All are significant at the 1% level.

3.2 Trend in Marginal Productivity of ICT in Global ICT Firms

3.2.1 Declining Trend in the Marginal Productivity of ICT

Utilizing equation (6) in Section 3.1, **Fig. 7** demonstrates a trend in the marginal productivity of ICT in global ICT firms over the period 2005–2016. Fig. 7 demonstrates explicit bi-polarization between high R&D-intensive firms (HRIF: D_1 in Fig. 6) out of 500 global ICT firms and remaining low R&D-intensive firms (LRIF: D_2 and D_3 in Fig. 6). HRIFs have fallen into a vicious cycle between R&D investment centered by ICT and its marginal productivity, as the former increase results in declining the latter. On the contrary, LRIFs have been enjoying a virtuous cycle between them, as R&D increase leads to marginal productivity increase.

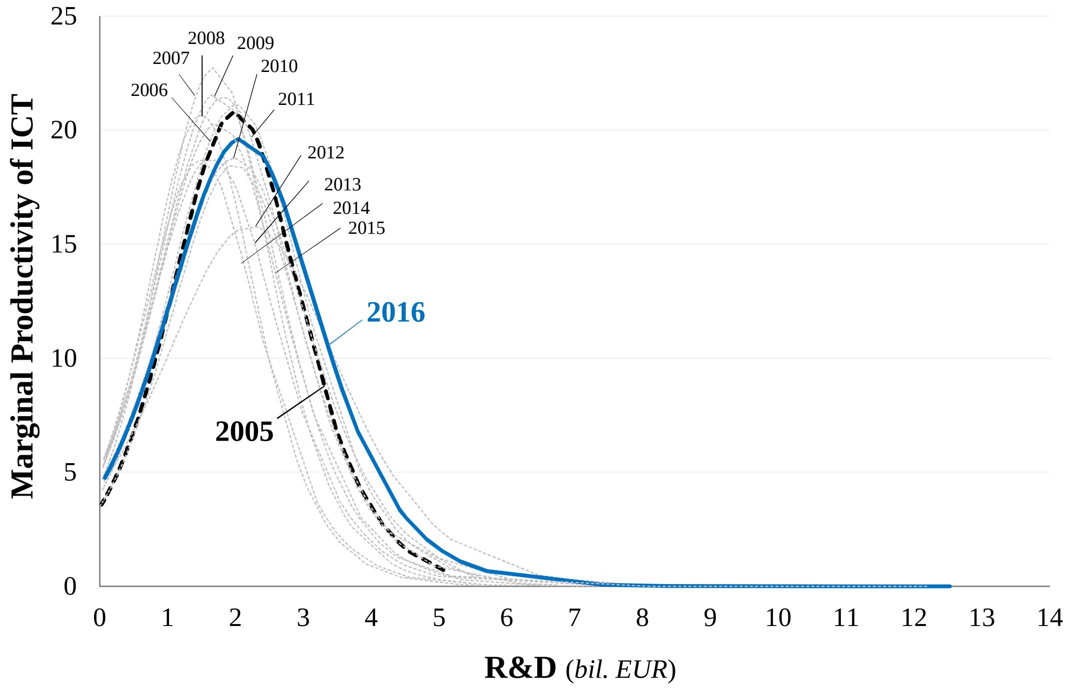


Fig. 7. Trend in Marginal Productivity of ICT in Global ICT Firms (2005–2016).

Fig. 8 compares this bipolarization between 2005 and 2016. Looking at Fig. 8, we note that the inflection point shifted slightly higher from EUR 2.0 billion in 2005 to EUR 2.1 billion in 2016, corresponding to the increase in R&D investment during this period. However, the maximum level of marginal productivity of ICT at the inflection point decreased during this period, reflecting the declining trend in this productivity in global ICT firms.

Table 7 compares HRIFs that have fallen into a vicious cycle between R&D investment and marginal functionality of ICT between 2005 and 2016. Numbers of HRIFs that have fallen into a vicious cycle have increased significantly from 16 in 2005 to 25 in 2016.

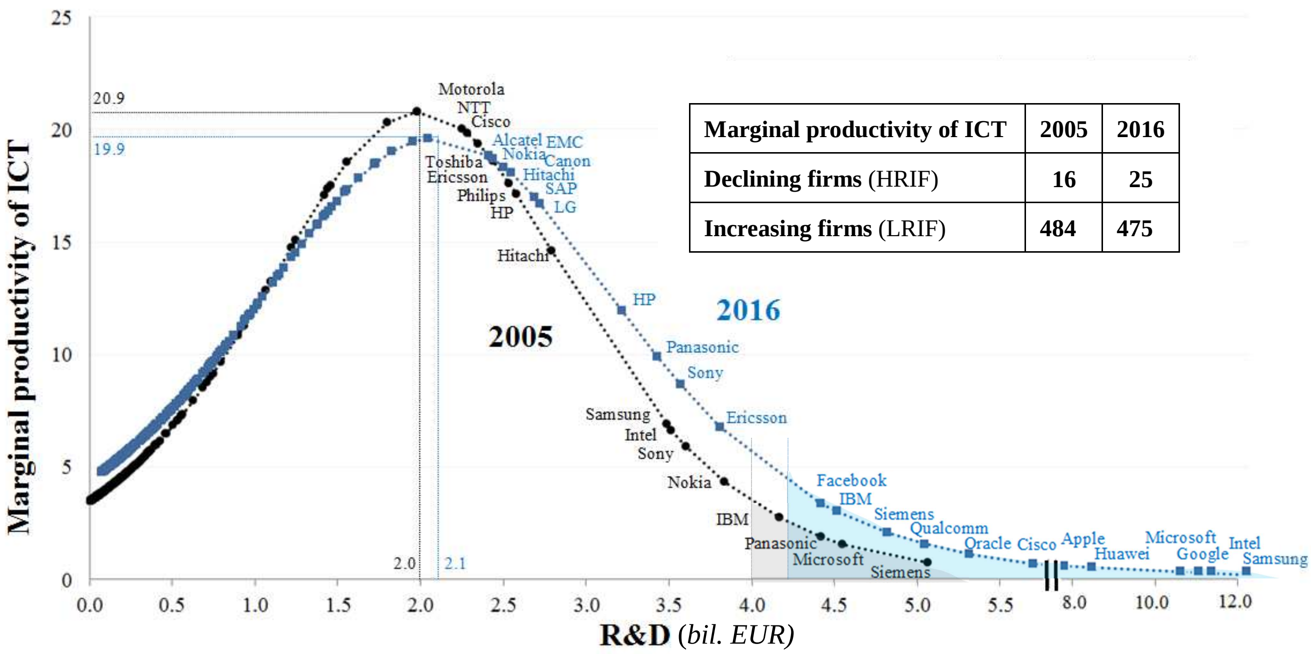


Fig. 8. Comparison of Marginal Productivity of ICT in 500 Global ICT Firms (2005, 2016).

Table 7 Comparison of HRIFs with R&D Investment in 2005 and 2016

	2005		2016	
	Firm	**R&D** (bil. EUR)	**Firm**	**R&D** (bil. EUR)
1	Siemens	5.06	Samsung Electronics	12.53
2	Microsoft	4.55	Intel	11.14
3	Panasonic	4.42	Google	11.05
4	IBM	4.17	Microsoft	11.01
5	Nokia	3.83	Huawei	8.36
6	Sony	3.60	Apple	7.41
7	Intel	3.52	Cisco Systems	5.70
8	Samsung Electronics	3.48	Oracle	5.32
9	Hitachi	2.79	Qualcomm	5.04
10	Hewlett-Packard	2.58	Siemens	4.82
11	Philips Electronics	2.53	IBM	4.51
12	Ericsson	2.44	Facebook	4.42
13	Toshiba	2.42	Ericsson	3.81
14	Cisco Systems	2.35	Sony	3.57
15	NTT	2.28	Panasonic	3.43
16	Motorola	2.25	Hewlett-Packard	3.22
17			LG Electronics	2.72
18			SAP	2.69
19			Hitachi	2.54
20			Canon	2.50
21			Nokia	2.50
22			EMC	2.44
23			Alcatel-Lucent	2.41
24			Toshiba	2.40
25			Amazon	0.59*

Order by level of R&D investment.

* Amazon is included in top 25 list as its market capitalization is conspicuous while its R&D investment is small and ranked 95th in 2016.

3.2.2 Structural Source of Decline in Marginal Productivity of ICT

Decline in marginal productivity of ICT can be attributed to the dependency on the Internet and its subsequent two-faced nature (Watanabe et al., 2015). Advances in ICT can largely be attributed to the dramatic advancement of the Internet (McKinsey Global Institute, 2011; ITU, 2013), which has changed the computer-initiated world significantly.

Advancement of ICT generally contributes to enhanced prices of technology by increasing new functionality development[7]. However, the dramatic advancement of the Internet actually causes a decrease in the price of technology due to its nature of freebies, easy copying, and mass standardization (Cowen, 2011; Watanabe et al., 2015). Consequently, prices of technology in highly ICT-advanced firms change to a declining trend, as illustrated in **Fig. 9**.

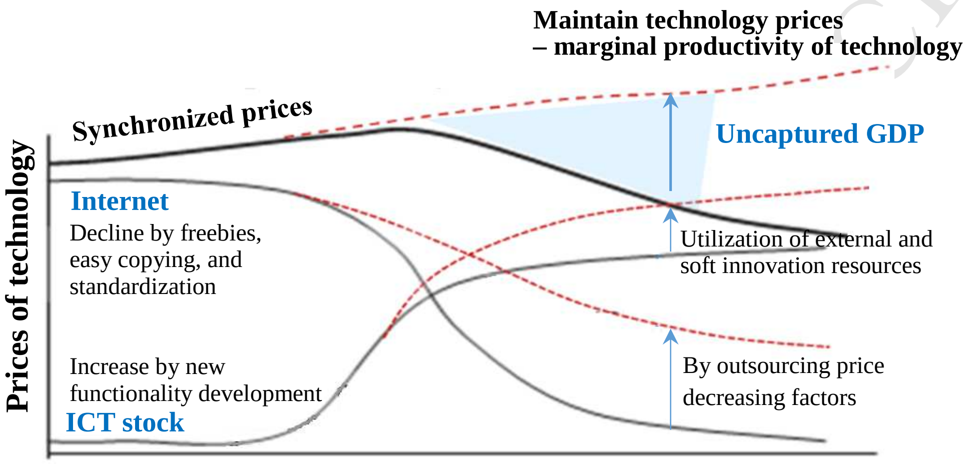


Fig. 9. Two-Faced Nature of ICT and Uncaptured GDP Emergence.

Note: At the initial stage of Internet commercialization, its price is extremely higher than that of ICT.

3.2.3 ICT Leaders Endeavor Against Marginal Productivity of ICT Decline

Given that the firms seek maximum profit in the competitive market, marginal productivity of technology corresponds to relative price of technology (ratio of technology prices and prices of product). Therefore, the Internet-driven price decrease corresponds to marginal productivity decline.

This can be the structural source of marginal productivity decline in ICT leaders. Given such circumstances, ICT leaders endeavor to accelerate price increase by means of successive, efficient, new functionality development by minimum expenditures and minimizing price-decrease factors by outsourcing them to other parties (Watanabe et al., 2015). Activating the ICT-inherent self-propagating function can lead to increasing uncaptured GDP[8] (Watanabe et al., 2016, 2017) as explained in Fig. 9.

---

[7] Functionality development is generally defined as the ability to dramatically improve performance of production process, goods, and services by means of innovation (Watanabe et al., 2005).

[8] Uncaptured GDP can be defined as added value providing utility (satisfaction of consumption) and happiness beyond economic value to people but cannot be measured by traditional GDP accounting (captured GDP) that measures economic value.

3.3 Trend in Dependency on Uncaptured GDP in the Global ICT Leaders

3.3.1 Self-Propagating Dynamism

As reviewed in 3.1, the development trajectory of the global ICT leaders can be traced by the R&D-driven simple logistic growth function, as depicted by equations (4) and (5). While the level of carrying capacity (*N*) is assumed constant through the development process in this function, in particular innovations, the correlation of the interaction between innovation and institutions displays a systematic change in the process of growth and maturity. This leads to the creation of a new carrying capacity in the process of its development, similar to equation (7) as follows:

$$\frac{dS(R)}{dR} = aS(R)\left(1-\frac{S(R)}{N(R)}\right) \quad (7)$$

This equation leads to the following logistic growth within a dynamic carrying capacity (*LGDCC*) function, which demonstrates the level of carrying capacity enhancement as the development proceeds (Meyer et al., 1999):

$$S(R) = \frac{N_k}{1 + be^{-aR} + \dfrac{b_k}{1 - \dfrac{a_k}{a}e^{-a_k R}}} \quad (8)$$

where N_k: ultimate carrying capacity, and a_k and b_k: coefficients similar to *a* and *b*.

Equation (8) demonstrates that the third term of the denomination governs the dynamic carrying capacity and, without this term, results in *SLG* with a constant carrying capacity.

From equation (7), dynamic carrying capacity can be expressed as follows:

$$N(R) = S(R)\left(\frac{1}{1-\frac{1}{a}\cdot\frac{dS(R)}{dR}/S(R)}\right) \quad (9)$$

This demonstrates that *N(R)* increases together with that of *S(R)* and its R&D-driven growth rate. This implies that the *LGDCC* function demonstrates functionality development in the context of the self-propagating behavior (Watanabe et al., 2004: Watanabe et al., 2009).

This self-propagating function plays a vital role of the engine in spinning-off from the traditional co-evolutional of three mega-trends in the world of the PoT[9] to the new co-evolution toward the IoT, as illustrated in Fig. 1. This spin-off plays a significant role in inducing ICT-driven innovation (Watanabe et al., 2015, 2016). Here, spin-off is defined as jumping to more sophisticated co-evolutional dynamism from traditional co-evolutional dynamism in inducing innovation (Watanabe et al., 2011).

Since the potential of functionality development can be traced by the ratio of

[9] Under the PoT, computer- and semiconductor-initiated mass production played a vital role.

development state and its upper limit (carrying capacity) (Watanabe et al., 2009), functionality development in the *LGDCC* function can be depicted from equation (9) as follows:

$$\text{Functionality development} = \; FD = \frac{N(R)}{S(R)} = \frac{1}{1 - \frac{1}{a} \cdot \frac{dS(R)}{dR} / S(R)} \quad (10)$$

This equation demonstrates that functionality development can be accelerated as its growth rate increases. This explains functionality development in the context of self-propagating behavior. Since functionality development plays a locomotive role in leveraging spin-off (Watanabe et al., 2011), equation (10) indicates that the self-propagating function leverages spin-off by inducing functionality development (see Appendix C dynamism in developing self-propagating function).

With the understanding that this self-propagating function can be attributed to its adaptability to ICT-driven logistic growth within a dynamic carrying capacity (*LGDCC*) function that increases functionality as it grows rather than a simple logistic growth (*SLG*) function that fades out functionality as it grows (Watanabe et al., 2004), **Table 8** estimates the *LGDCC* function of 500 global ICT firms in 2005 and 2016[10] and results are statistically significant.

Table 8 *LGDCC* Function in 500 Global ICT Firms in 2005 and 2016

LGDCC $$S(R) = \frac{N_k}{1 + be^{-aR} + \frac{b_k}{1 - \frac{a_k}{a} e^{-a_k R}}}$$

	N_k	a	b	a_k	b_k	$adj.R^2$
2005	75.28	1.27	26.65	0.35	0.34	0.999
	(30.37)	(177.19)	(25.42)	(2.50)	(6.71)	
2016	102.23	0.77	15.84	0.43	1.32	0.999
	(178.83)	(26.13)	(9.72)	(7.06)	(2.53)	

S(R): sales; N_k: carrying capacity; *R*: R&D investment; a, b, a_k, b_k: coefficients.
Results are based on the third step approximation.
The figures in parentheses indicate t-statistics: All are significant at the 1% level.

The self-propagating function can be attributed to dynamism of functionality development (*FD*) increase as growth proceeds (*S* increase) (Watanabe et al., 2004). *FD* can be estimated by the ratio of *N* (carrying capacity) and *S* (Watanabe et al., 2009). Therefore, the magnitude of the self-propagation function can be estimated by the ratio of $N_k(R)$ (dynamic carrying capacity that leads development trajectory after

[10] Estimation of *LGDCC* depended on the three-step approximation approach (see Appendix D).

incorporating the self-propagating function) and $S_s(R)$ (development trajectory estimated by *SLG* that demonstrates development level when no self-propagating function incorporates) (Watanabe et al., 2017c).

Fig. 10 demonstrates trends in marginal productivity of ICT and magnitude of the self-propagating function in global ICT firms in 2016. This figure shows that, in repulsion to marginal productivity of ICT decline, self-propagating function increase in high R&D-intensive global ICT firms such as Samsung, Intel, Google, Microsoft, Huawei and Apple. Thereby these firms correspond to peoples' preference shift to supra-functionality beyond economic value as demonstrated in Fig. 1. This survival strategy can be called the long tail of the global ICT leaders (Anderson, 2006).

The above analyses demonstrate the following noteworthy structural changes in global ICT firms toward the IoT acceleration after 2010:

- Dramatic decrease in ICT prices
- Subsequent decline in marginal productivity of ICT
- Intensive efforts in increasing functionality development by activating the self-propagating function.

It is postulated that this activation can be attained by harnessing the vigor of soft innovation resources, including sleeping/untapped resources, thus leading to increasing dependency on uncaptured GDP.

The next section demonstrates this hypothetical view.

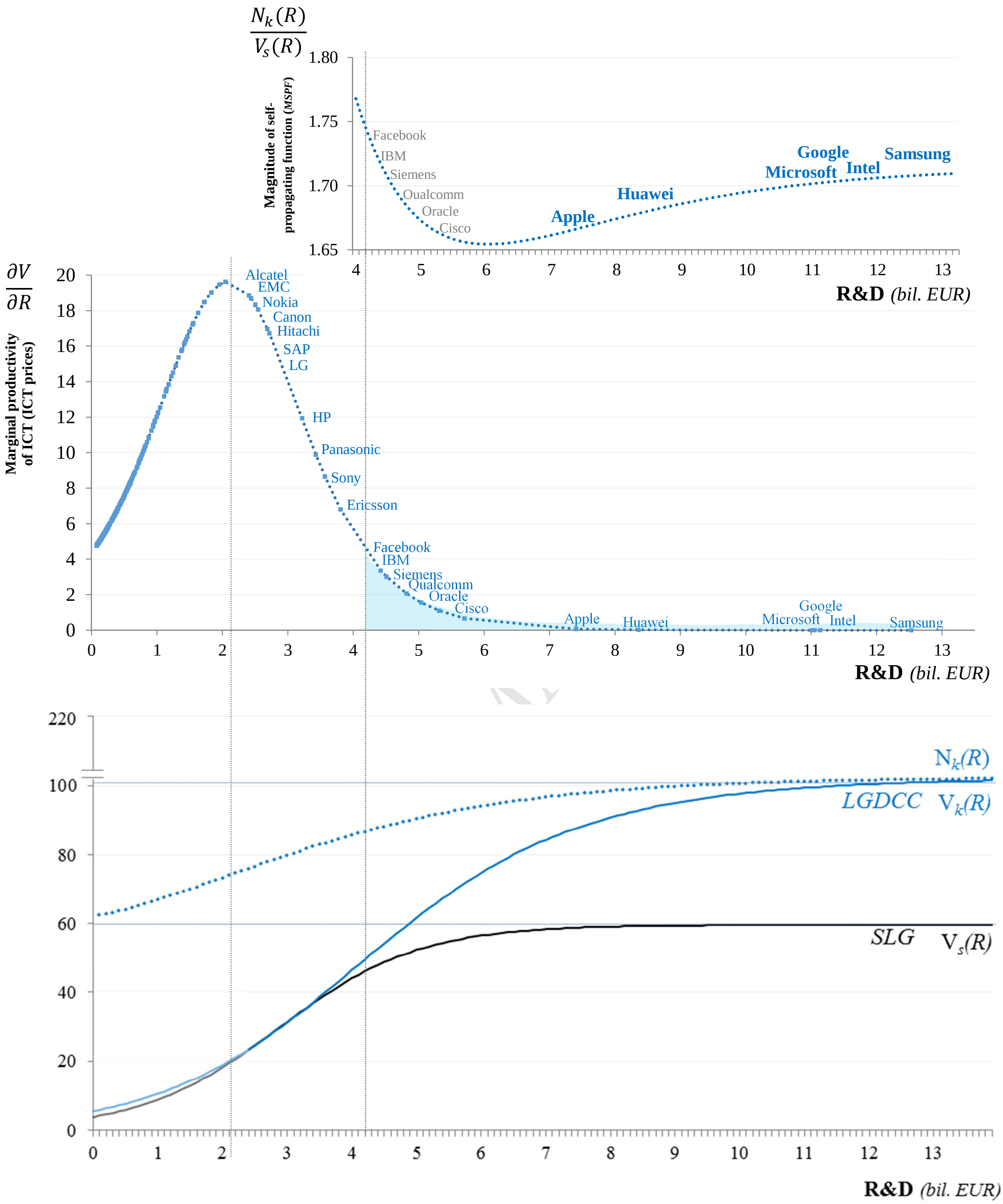


Fig. 10. Dynamism in Transforming Productivity Decline into Supra-functionality (2016) – New Open Innovation by Harnessing Soft Innovation Resources.

4. Functionality Development and the Transformative Direction of Innovation

4.1 Scheme of Functionality Development

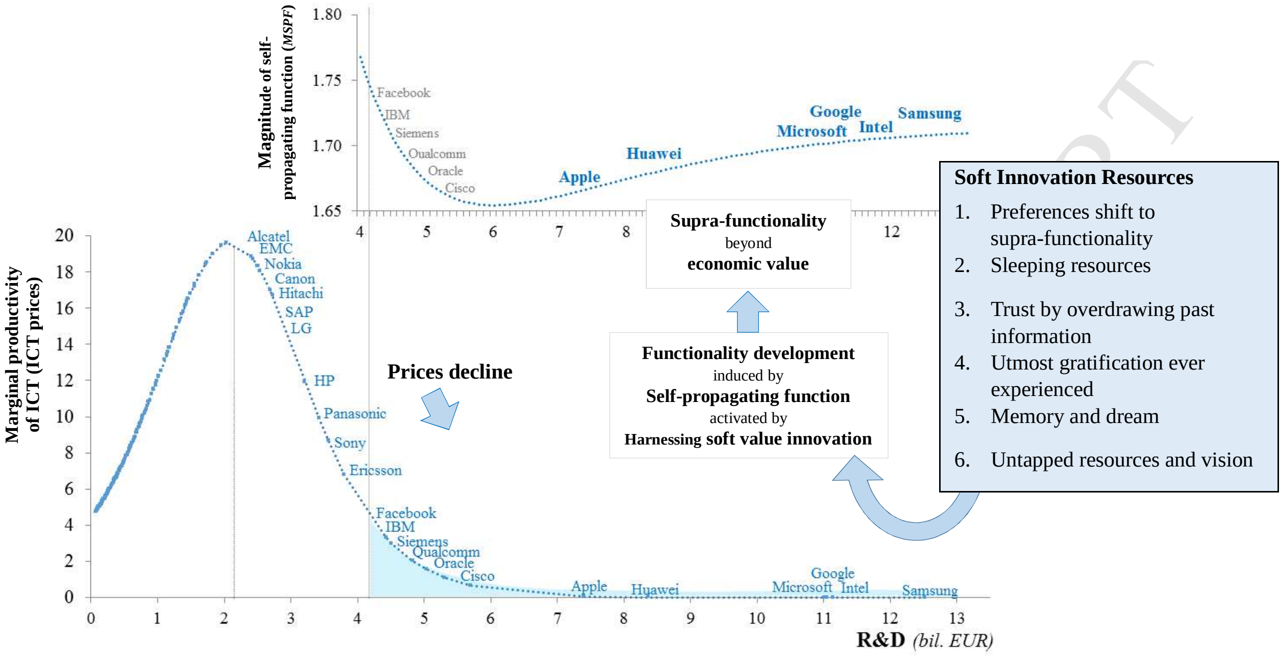


Fig. 11. Scheme of Functionality Development by Harnessing Soft Innovation Resources - High R&D Intensive Global ICT Firms (2016).

Fig. 11 demonstrates the dynamism of functionality development (which presents supra-functionality beyond economic value) induced by the self-propagating function which can be activated by harnessing the vigor of the following soft innovation resources:

- People's preferences shift to supra-functionality beyond economic value
- Sleeping resources (similar to ridesharing revolution by Uber)
- Trust by overdrawing past information
- Utmost gratification ever experienced
- Memory and dream
- Untapped resources and vision

This can be attained in reaction to marginal productivity of ICT decline due to the high dependency on ICT that incorporates a two-faced nature.

4.2 Transformative Direction of Leading Global ICT Firms

With the understanding of such dynamism aiming at demonstrating that high R&D-intensive global ICT firms succeeded in harnessing the vigor of soft innovation resources, **Table 9** reviews the transformative direction of seven leading global ICT firms in harnessing such innovation resources over the period 1970–2020[11].

Table 9 Transformation Direction of Seven Leading Global ICT Firms

	1970–1980	1981–1990	1991–2000	2001–2010	2011–2020
1. Samsung	**Mechatronics**	**Computers**	**Mobile Phones, Digital TVs**	**Smartphones, Smart TVs**	**Tablets, Wearables, VR, IoT**
	1938: Samsung founded **1969:** Samsung-Sanyo electronics established **1970:** Black-and-white TV **1972:** Washing machine Refrigerator **1977:** Color television **1979:** Microwave ovens	**1980:** Air conditioner **1983:** Personal computers (PCs) **1984:** Export of VCRs **1986:** Smallest video tape recorder **1987: SAIT established**	**1992:** Mobile phones HDD, DRAMs Industrial robots **China expansion** **1993:** Digital video recorder (DVD-R) **1994:** Electric car (SEV-III) **1995:** MPEG-3 technology **1996:** Fastest CPU (alpha chip) 33" double-screen TV **1997:** World lightest TVs 30" TFT-LCD display **1998:** Digital TV, flat-screen TV **1999:** Smartphone, wireless internet phone, multi-function phone **2000:** 50 millionth mobile phone	**2004:** World largest LCD TV (46") Smartphones **2008:** World's 1st dual-color bezel TV **2009:** World's slimmest LED TV **2010: World's 1st TV app store** World's 1st FHD 3D TV	**2011:** Galaxy tablets Hard disk biz sold to Seagate **2012:** Samsung and Apple patent infringement controversy Samsung shares on the KOSPI index fell 7.7% **2013:** World's 1st curved TV **2014:** Gear VR devices Galaxy Note 4 World's 1st bendable UHD TV Stopped music streaming business, Music Hub app **2015:** Granted world's most patents World's largest curved UHD TV **2016:** IoT, partnership with Microsoft Smartwatch (Gear Fit 2, etc.) Icon-X, Galaxy Note 7
2. Intel	**Integrated Electronics**	**Computer Boards, Chips**	**Processors**	**Cell Phone Microchips**	**Supporting Technologies for IoT and Wearables**
	1968: Co-founded by Gordon Moore and Robert Noyce **1969:** Worlds 1st MOS **1970:** First property, first board **1971:** New era in integrated electronics **1972:** First international factory in Malaysia **1975:** Computers get personal **1979:** 486th position in Fortune 500	**1982:** PC industry takes off **1983:** US$1 billion annual revenue **1984:** One of the 100 best companies to work for in America **1985:** Super computer, Intel 386 processor **1987:** Second-generation super computer **1988:** Intel foundation established **1990:** Robert Noyce died	**1992:** Largest semiconductor supplier in the world **1993:** Intel Pentium processor **1995:** Became a chipset leader **1998:** Intel strong ARM processor **1999:** Intel Pentium III, Xeon Processor **2000:** Intel Pentium 4 processor	**2002:** Hyper-threading technology, more power at lower cost **2003:** Cellular phone microchips **2004:** 46th in Fortune 100 Best Companies to work for **2005:** 40th anniversary of Moore's law **2006:** World's 1st quad-core processor **2008:** 45-nm transistor **2009:** Intel atom processor Going Green Paid US$1.25 billion to AMD in lawsuit settlement **2010:** Buys McAfee i7 Processor, Intel App-Up store	**2011:** Intel Ultrabook **2012:** 450-nm manufacturing technology **2013: New generation of processors** i3, i5, i7 **2014:** Intel Quark chip powering IoT and wearable devices **2016:** Announces withdrawal from smartphone market
3. Google			**Information Search**	**Gmail, Earth, YouTube, Smartphones, OS, Apps**	**Google (Play store, Glass, Balloons), Cloud, IoT**
			1998: Google founded **2000:** World's largest search engine	**2001:** Image Search **2002:** Google News **2004:** Gmail **2005:** Google Earth, Maps, Talk, Video, Books, Mobile Search, Scholar **2006:** Android, Google Trends **2007:** YouTube **2008:** Google Chrome, Street View **2009:** Google Translate **2010:** Google Nexus phone	**2011:** Google Panda, acquired Motorola, Google + **2012:** Google Play store **2013:** Google Nexus 7 tablet Google Hangouts, Google Balloons **2014:** **2015:** **2016**
4. Microsoft			**Software**	**Software, Play Stations**	**Cloud, Platforms, Analytics, IoT**
	1975: Microsoft founded **1979:** Shifted from New Mexico to Washington	**1981:** Microsoft incorporates IBM 1st PC with MS-DOS 1.0 **1986:** Moves to Redmond, Washington Microsoft stock goes public **1989:** Earliest version of Office suite **1990:** Microsoft launches Windows 3.0	**1995:** Microsoft launches Windows 95 Bill Gates outlines Microsoft's commitment to the Internet **1998:** Microsoft launches Windows 98 **2000:** Steve Ballmer named president and CEO for Windows 2000	**2001:** Windows XP, Office XP Xbox play station **2002:** Tablet PC **2003:** Windows Server 2003 MS Office System **2004:** Xbox 360 next generation **2006:** Zune music player **2007:** Windows Vista MS Office 2007 **2008:** Windows server, SQL server Visual Studio **2010:** Windows phone OS MS Office 2010	**2011:** Windows Phone, Xbox Kinect Office 365 **2012:** Surface tablets Windows 8, Windows phone 8, Windows Server **2013:** Surface 2, Pro 2, Xbox one Office 2013 **2014:** Buys Nokia devices & services Buys Minecraft, Office iPad, Android, Surface Pro 3 **2015:** Windows 10, Office 2016, Lumia 950, Lumia 95 XL Surface 3, Pro 4 **2016:** LinkedIn, Surface Studio, Dial, Book, Visual Studio 2017

[11] Seven selected ICT firms include the top six high R&D-intensive firms in 2016 as demonstrated in Fig. 10 and Amazon. Amazon was included in this review due to its conspicuously high market value in 2016 (ranked fourth, see Table 2) while R&D investment was limited.

5. Huawei		**Distributor**	**Fixed-Line and Digital Network Products**	**Mobile Networks**	**Smartphones, Cloud, IoT**
		1988: Huawei founded as distributor of imported PBX products	**1993:** Digital telephone switch with capacity over 10,000 circuits **1996:** Wins first big overseas contract for fixed-line network products from Hong Kong's Hutchison-Whampoa	**2003:** Joint venture with 3Com Cisco Systems sues for copyright violations **2004:** Overseas sales surpass domestic sales for first time **2008:** Contract orders rose 46% to US$23.3 billion World's 3rd largest mobile network gear maker **2009:** World's top patent seeker Head the UN WIPO list	**2011** **2012** **2013** **2014** **2015:** Smartphones, Huawei P8 Huawei P8 Max
6. Apple	**Computers, Printers**	**Computers**	**Laptop Computers**	**iPod, iTunes, Smartphones, Tablets**	**Smart Devices, Platforms, IoT**
	1976: Apple I **1977:** Apple II **1978:** Apple (Writer, file type) **1979:** **1980:** Apple III	**1981:** Apple ProFile **1982:** Apple printers (dot matrix, letter quality)	**2000:** PowerBook Prismo Cinema Display 22"	**2001:** iPod 1st gen **2002:** iPod 2nd gen, iBook 14", iMac **2003:** iPod 3rd gen, PowerBook G4 **2004:** iPod Mini (1st gen) iPod (4th gen) **2005:** iPod Mini, (2nd gen) iPod Nano (1st gen) iPod (4th gen) iPod Shuffle **2006:** MacBook Pro (15", 17") iPod Hi-Fi, iPod Nano (2nd gen) iPod Shuffle (2nd gen) **2007:** Apple TV (1st gen) iPhone (4, 8 GB) **2008:** iPhone 3G (8, 16 GB) iPhone (16 GB) **2009:** iPhone 3GS **2010:** iPad (WiFi + 3G), iPhone 4	**2011:** iPad 2 (16, 32, 64 GB) iPhone 4S **2012:** iPad, iPad Mini, iPhone 5 **2013:** iPhone 6, iPhone 6 Plus iPad Air 2, iPad Mini 3 **2014:** Apple Watch, iPhone 6S iPad Mini 4, iPad Pro **2015:** iPhone 7, iPhone 7 Plus iPad Pro
7. Amazon			**Book Store**	**Top Online Retail Store**	**Fusing Physical and Digital**
			1995: Amazon launched **1997:** Amazon on NYSE, Nasdaq Buys bookpages.co.uk Launches Amazon UK **1998:** CDs and DVDs **1999:** Toys and electronics	**2000:** Marketplace, Amazon's third-party business **A to the Z** in Amazon launches **2001:** Takeover Borders.com Borders collapses 10 years later Amazon makes its first profit **2002:** Amazon Web Services cloud computing platform **2003:** Selling jewelry **2004:** Selling shoes **2005:** Amazon Prime membership **2006:** Amazon Fresh (food online) **2007:** Kindle e-reader **2008:** Games **2009:** Buys Zappos **2010:** Logistics infrastructure scaling Amazon Studios to create original television content	**2011:** Kindle Fire tablet **2012:** Buys Kiva, a robotics company, for US$775 million to contain technology just for itself **2013:** Big cloud systems contract of US$600 million for 17 US intelligence agencies Prime Air drone delivery plans **2014:** Amazon Echo voice device 8th generation fulfillment centers **2015:** Amazon brick-and-mortar store Amazon Flex a-piece-rate delivery (Uber model) Amazon passes Walmart in market capitalization **2016:** Amazon captures 50% of online spending in US Amazon doubles its distribution facilities **2017:** Amazon buys Whole Foods

Based on the preceding review, **Fig. 12** summarizes the noteworthy transformative direction of ICT-driven disruptive business models accomplished by seven leading global ICT firms in response to marginal productivity decline. Such accomplishments are correlated with soft innovation resources identified as a soft value addition corresponding to uncaptured GDP and essential for the spin-off from traditional PoT-driven innovation to new IoT-oriented co-evolutional innovation as reviewed in section 1.6.

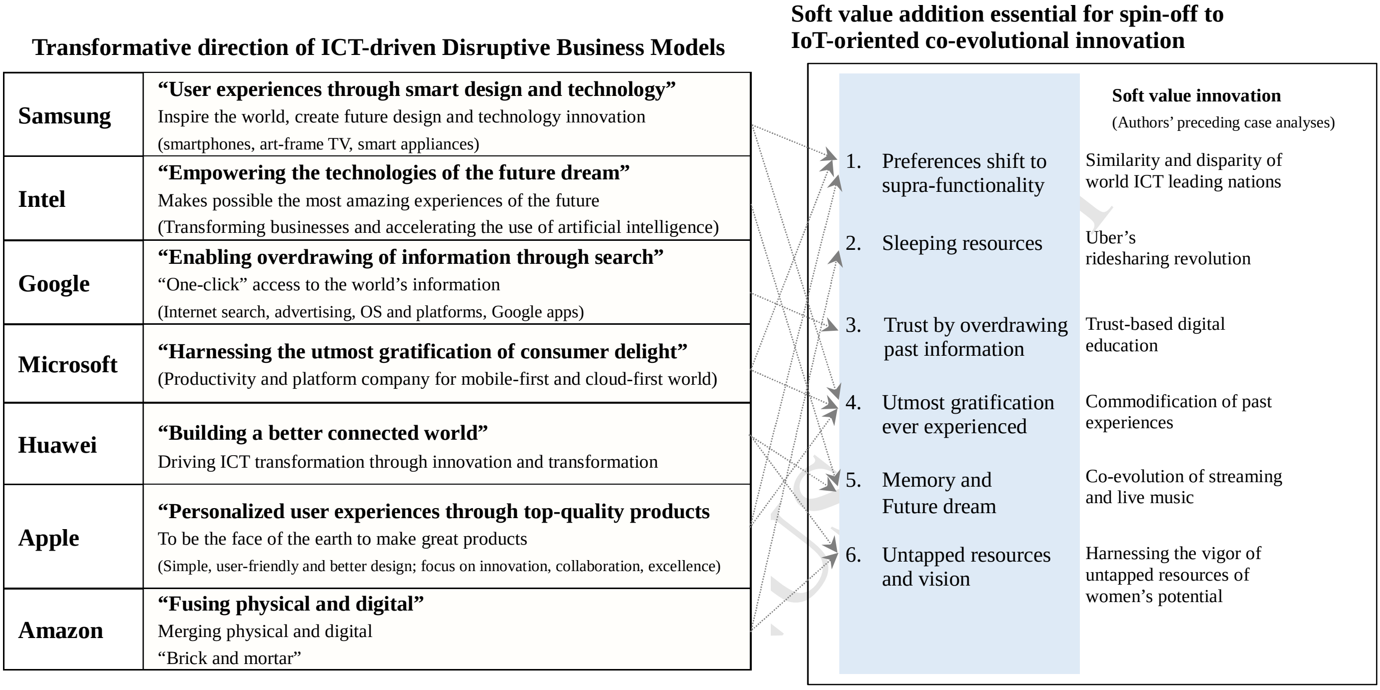


Fig. 12. Noteworthy Direction of ICT-Driven Disruptive Business Models.

With respect to the transformative direction of IDBM, all seven leading global ICT firms demonstrate their success in harnessing the vigor of the soft innovation resources identified as soft value-addition corresponding to uncaptured GDP and an essential element for the spin-off from traditional PoT-driven innovation to a new IoT-oriented co-evolutional innovation.

4.3 Noteworthy Lessons for Harnessing the Soft Innovation Resources

Supported by the success of self-propagating functionality development by harnessing the soft value innovation resources as demonstrated by seven leading global ICT firms, the transformative direction of trust-based IDBM with CCSD can be envisioned as illustrated in **Fig. 13.**

Soft innovation (Authors' preceding case analyses)	Past	Current	Future
1. Similarity and disparity of world ICT leaders	**PoT** Captured GDP Economic functionality	**IoT** Uncaptured GDP Supra-functionality	**Beyond IoT** New concept of GDP Digital supra-functionality
2. Uber's ridesharing revolution	Sleeping resources (cars, drivers)	Effectively utilization of sleeping resources through technology platforms Trust-based tripartism cooperation frameworks	Driverless cars Autonomous electric taxi fleets In-road inductive charging
3. Trust-based digital education	Knowledge and experiences	Overdrawing of past information, developing trust	AI, VR Realtime language processing Teaching avatar assistants Brain computer interfaces Machines gain statistical intuition
4. Commodification of past experiences	Utmost gratification ever experienced	Conceptualization of invisible voice of consumers	Commodification of experiences
5. Co-evolution of streaming and live music	Past unforgettable memories and experiences	Invoking memories Live entertainment Participative creativity Synthesizing future dream	Collaborative value creation Virtual participation Augmented reality Machine-generated art and music
6. Harnessing the vigor of un-tapped resources by activating women's potential	Untapped resource Domestic responsibilities Limited participation and opportunities	Harnessing the women's potential Giving responsibilities Gender-balance equality	Ambitious vision for harnessing women's potential together with men to generate economic and social value

Accomplishments by Seven Leading ICT Firms

Noteworthy accomplishments initiated by the seven leading global ICT firms		
	Samsung	**"User experiences through smart design and technology"** Inspire the world, create future design and technology innovation (smartphones, art-frame TV, smart appliances)
	Intel	**"Empowering the technologies of the future dream"** Makes possible the most amazing experiences of the future (Transforming businesses and accelerating the use of artificial intelligence)
	Google	**"Enabling overdrawing of information through search"** "One-click" access to the world's information (Internet search, advertising, OS and platforms, Google apps)
	Microsoft	**"Harnessing the utmost gratification of consumer delight"** (Productivity and platform company for mobile-first and cloud-first world)
	Huawei	**"Building a better connected world"** Driving ICT transformation through innovation and transformation
	Apple	**"Personalized user experiences through top-quality products** To be the face of the earth to make great products (Simple, user-friendly and better design; focus on innovation, collaboration, excellence)
	Amazon	**"Fusing physical and digital"** Merging physical and digital "Brick and mortar"

Fig. 13. Transformative Direction of Trust-Based ICT-Driven Disruptive Business Models with Consolidated Challenge to Social Demand.

5. Conclusion

This analysis focused on the increasing significance of the restructuring of business models in the global ICT firms toward an IoT-based society, the dynamism emerging this transformation, and optimal digital business strategies corresponding to this dynamism.

An empirical analysis was conducted by evaluating digital business solutions in 500 global ICT firms over the period 2005–2016 with special attention to their specific features initiated by particular gigantic “mutation” firms.

Noteworthy findings include:

- R&D-intensive firms have fallen into a trap in ICT advancement resulting in declining their marginal productivity of ICT and suggest a new productivity paradox in the digital economy.
- This can be considered a consequence of two-faced nature of ICT, which, together with people’s preference shift to supra-functionality beyond economic value, leads to increasing dependency on uncaptured GDP.
- To counterchallenge such situation these firms endeavor to activate the self-propagating function that induces functionality development sublimating sophisticated digital business strategies.
- This activation can be achieved by harness the vigor of soft innovation resources.
- This dynamism can be considered the soft value addition corresponding to uncaptured GDP.
- Firms with higher market value increase the self-propagating function efficiently which, in turn further increase their market value.
- This can generally be attributed to their sophisticated digital business strategies in increasing the high level of operating income to R&D.

These findings give rise to the following insightful suggestions to global ICT firms for transformation of their business models toward an IoT-based society:

- The significance of the transformation from traditional ICT-driven functionality development strategy to digital business strategy should be recognized.
- A trap in ICT advancement and subsequent increasing dependency on uncaptured GDP should be realized.
- High functionality development induced by a sophisticated self-propagating function should be endeavored by recognizing the consequences of uncaptured GDP.
- It should be noted that higher operating income corresponds to higher market value.
- Trust-based IDBM with CCSD should be realized corresponding to a business model inducing a sophisticated self-propagating function.
- Every effort should be focused on effective utilization of soft-innovation resources

to correspond to the effects of uncaptured GDP.

This analysis explores a new insight for ICT firms for their transformative strategy toward an IoT-based society. Future work should focus on detailed case analyses on further exploring the soft-innovation resources beyond anticipation suggested by the success and failure of other firms in addition to the seven ICT firms examined in this paper. In this context, Amazon's unique business model which accomplishes extraordinary digital value notwithstanding limited R&D investment should be further elucidated.

The further identification of similar novel business concepts as suggested by the seven leading global ICT firms (e.g., *"overdrawing information through search"*, *"merging net and real"*, and *"fusing art and technology"*) should be made a priority.

The development of road maps toward the envisioned future would be another important responsibility and subject for future research. Challenge to the limitation of GDP in the digital economy would correspond to the current worldwide concerns.

Appendix A. Influence of R&D-Driven Growth in Global ICT Firms

Given that sales (S) of the global ICT firms are governed by their ICT stock (T), their sales can be depicted as follows:

$$S = F(X, T) \tag{A.1}$$

where X: production factors other than T.

This equation can be approximated as follows by conducting Taylor expansion to the first term.

$$\ln S = a + b \ln X + c \ln T \tag{A.2}$$

where a, b, c: coefficients

Since X is governed by T in global ICT firms, it can be developed as follows:

$$X = F(T) \qquad \ln X = a_x + b_x \ln T \tag{A.3}$$

where a_x, b_x: coefficients

By substituting equation (A3) for ln X in equation (A2),

$$\begin{aligned} \ln S &= a + b\,(a_x + b_x \ln T) + c \ln T \\ &= (a + b \cdot a_x) + (b \cdot b_x + c) \ln T \\ &\equiv \alpha + \beta \ln T \end{aligned} \tag{A.4}$$

where $\alpha = a + b \cdot a_x$, $\beta = b \cdot b_x + c$

Since (T) can be approximated by R&D investment (R) as follows (see footnote 5):

$$T \approx \frac{R}{\rho + g} \tag{A.5}$$

where ρ: rate of obsolescence of technology and g: increased rate of R&D investment at the initial stage

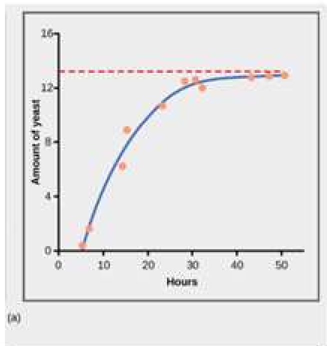
Therefore, equation (A4) can be described as follows:

$$\begin{aligned} \ln S &= \alpha + \beta \ln \frac{R}{\rho + g} \\ &= \alpha + \beta \ln R - \beta \ln(\rho + g) \\ &= [\alpha - \beta \ln(\rho + g)] + \beta \ln R \\ &\equiv \alpha' + \beta \ln R \end{aligned} \tag{A.6}$$

where $\alpha' = \alpha - \beta \ln(\rho + g)$

With such understanding, correlation between (R) and (S) in 500 global ICT firms was analyzed in section 2.1.

Appendix B. *SLG* (Simple Logistic Growth) Estimate with Dummy Variables – Avoidance of Bias by Gigantic Firms in *SLG* Estimation



(*a*) Yeast grown in ideal conditions in a test tube show a classical S-shaped logistic growth curve (SLG), whereas

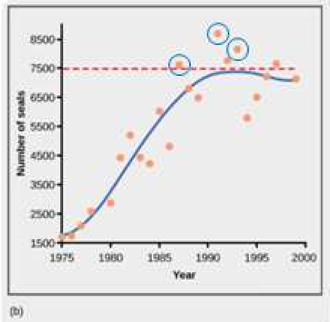
(*b*) Natural population of seals shows real-world fluctuation.

(*c*) Population growth estimate avoiding bias by unusual level (*c.f.,* outlier expansion of gigantic firms) by means of dummy variable treatment.

Sources

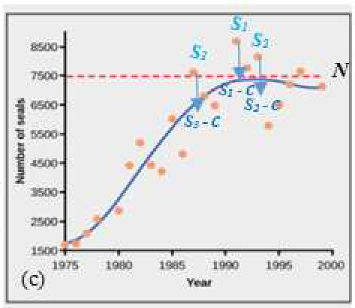
(*a*) and (*b*): Environmental limits to population growth by OpenStax College, Biology, CC BY 4.0.

(*c*): Authors interpretation and development



Treatment of bias avoidance by means of *SLG* with dummy variables

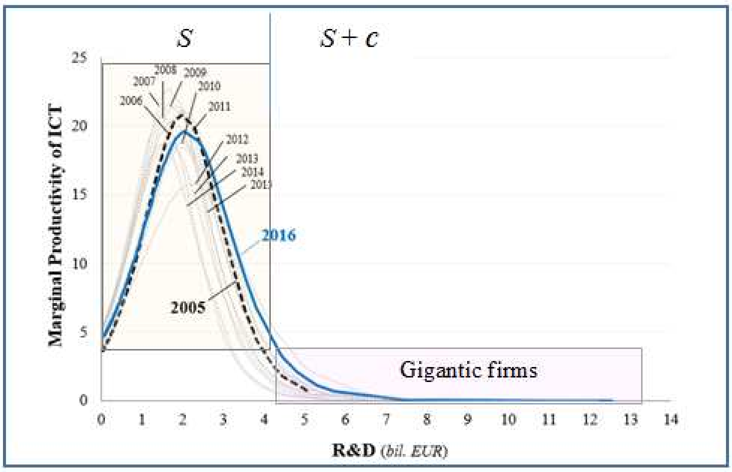
$$S = \frac{N}{1 + be^{-aR}} + cD$$



Un-usual	S	Dummy variable D X_1	X_2	X_3	Others	Adjusted S
X_1	S_1	1	0	0	0	$S_1 - c$
X_2	S_2	0	1	0	0	$S_2 - c$
X_3	S_3	0	0	1	0	$S_3 - c$

Marginal productivity of ICT

$$\frac{\partial S}{\partial R} = aS\left(1 - \frac{S}{N}\right)$$



Appendix C. Dynamism in Developing Self-Propagating Function

Diffusion trajectory of innovative goods *Y*

$$\frac{dY(t)}{dt} = aY(t)(1 - \frac{Y(t)}{N})$$

Simple Logistic Growth (*SLG*) with fixed carrying capacity (*N*)

$$Y(t) = \frac{N}{1 + be^{-at}}$$

Particular innovation which create new *N* during the process of diffusion.

$$\frac{dY(t)}{dt} = aY(t)(1 - \frac{Y(t)}{N(t)})$$

Logistic Growth within a Dynamic Carrying Capacity (*LGDCC*)

$$Y = \frac{N_k}{1 + be^{-at} + \frac{b_k}{1 - a_k / a} e^{-a_k t}}$$

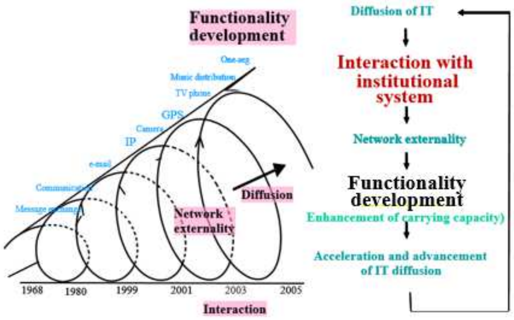
Carrying capacity increases as *Y* increases.

$$N(t) = Y(t)\left(\frac{1}{1 - \frac{1}{a} \cdot \frac{\Delta Y(t)}{Y(t)}}\right)$$

Functionality spirally increases as *Y* increases.

$$FD = \frac{N(t)}{Y(t)} = \frac{1}{1 - \frac{1}{a} \cdot \frac{\Delta Y(t)}{Y(t)}} \qquad \Delta Y(t) = \frac{dY(t)}{dt}$$

Generate self-propagating dynamism



Appendix D. Three-Step Approximation Approach of Logistic Growth Within a Dynamic Carrying Capacity

$$S = \frac{N_k}{1+be^{-aR} + \frac{b_k}{1-\frac{a_k}{a}e^{-a_k R}}}$$

$$\approx \frac{N}{1+b'e^{-a'R}}$$

$$a' = a\left(1 - \frac{b_k}{b}\right) < a,$$

$$b' = b\left(1 + \frac{b_k}{b} \cdot \frac{1}{1-\frac{a_k}{a}}\right) > b$$

Source: Watanabe et al., 2009

Step 1. Estimate simple logistic growth *(SLG)*

$$S_{(Actual)} = \frac{N \pm \varepsilon}{1+b'e^{-a'R}}$$

Step 2. Estimate a_e', b_e' by using plausible $N \pm \varepsilon$

Estimate *S* in logistic growth with dynamic carrying capacity *(LGDCC)*

$$\overline{S} = \frac{N \pm \varepsilon}{1+b_e'e^{-a_e'R}}$$

Step 3. Estimate *LGDCC* by using $\overline{S}$

$$\overline{S} = \frac{N_k}{1+be^{-aR} + \frac{b_k}{1-\frac{a_k}{a}e^{-a_k R}}}$$

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Highlights

Transformative direction of innovation toward an IoT-based society was teased out..

Digital business solutions in 500 global ICT firms over 2005-2016 were analyzed.

Increasing dependency on uncaptured GDP in the global ICT leaders was identified.

Transformative direction of leading global ICT firms against uncaptured GDP was revealed.

Noteworthy lessons for harnessing the soft innovation resources were extracted.