Co-evolutionary coupling leads a way to a novel concept of R&D - Lessons from digitalized bioeconomy

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ABSTRACT

Given the increasing role of research and development (R&D) in competitive markets in the digital economy while confronting the dilemma between R&D expansion and a productivity decline, transformation of the R&D model has become a crucial subject for global digital leaders. The authors of this paper postulate that neo open innovation harnessing the vigor of external innovation resources and transforming the R&D model to become a crucial subject for global digital leaders.

The authors further develop these postulates by proposing the embedding of a growth characteristic identical to biological coupling. An empirical analysis focusing on the forefront endeavors of global bioeconomy firms and also by Amazon was conducted.

A notable endeavor toward a circular economy initiated by its global leader UPM-Kymmene Corporation (UPM) demonstrated the significance of a coupling effect with downstream digital commerce leader Amazon. This effect can be attributed to harnessing the function of the growth characteristic identical to biological coupling through co-evolution of the dual coupling of bioeconomy and digitalization and of upstream and downstream operations.

This co-evolutionary coupling is expected to provide a novel concept of R&D that grows its function in a self-propagating way during the R&D process. An insightful suggestion supporting to a novel concept of R&D in the digital economy is thus proposed.

1. Introduction

While research and development (R&D) expansion has become crucial for competitiveness in the digital economy, as a fatal consequence of the fundamental nature of digital innovation with logistic growth [1,2] and the two-faced nature [3], global digital leaders have been confronting the dilemma between R&D expansion and a productivity decline [4]. Thus, transformation of the R&D model has become a crucial subject.

The authors postulated that neo open innovation harnessing the vigor of external innovation resources [5,6] which then developed into a new concept of R&D that transformed routine or periodic alteration activities (non-R&D) into significantly improving ones (substantial R&D) during an R&D process initiated by Amazon [7,8].

Inspired by biological coupling, this paper was designed to further develop these postulates by embedding a growth characteristic in an R&D process.

First, an empirical analysis focusing on the forefront endeavors of 50 global bioeconomy firms was conducted.

A notable endeavor toward a circular economy initiated by its global leader UPM-Kymmene Corporation (UPM) demonstrated the significance of the coupling effect with downstream digital commerce leader Amazon [9], which is also keen to a circular economy corresponding to the shift of customer preferences to ecological behavior [10].

This effect can be attributed to harnessing the function of a growth characteristic identical to biological coupling through the co-evolution of the dual coupling of bioeconomy and digitalization and of upstream and downstream operations.

Thus, a novel concept of R&D that grows its function in a self-propagating way during its R&D process can be expected to move...
to be coupled when they are interacting with each other, biological organisms can achieve a variety of biological functions efficiently by using the coupling effects of multiple factors and they can demonstrate optimal adaptations to the environment [20]. Since a growth characteristic is one of the core functions of biological coupling, this provides insightful suggestions to R&D management in the digital economy regarding R&D growth by avoiding the dilemma between R&D expansion and productivity decline, and also by minimizing the financial burdens and risks that have become critical problems.

Harnessing a growth characteristic via biological coupling involves such functions as leveraging awakening and activating latent self-propagating functions indigenous to ICT [21] and essential to sustainable innovation in the digital economy. Thus, co-evolutionary coupling leads the way to a novel concept of R&D in the digital economy.

To date, while many studies analyzed the systems nature of the forest-based bioeconomy (e.g., Refs. [3,14,22–26], none has presented an empirical analysis with a view to demonstrate the above co-evolutionary coupling embedding a growth characteristic as biological coupling.

The authors of this paper aimed to conceptualize this coupling with a growth characteristic and attempted to provide a practical insight for its operationalization. By means of a stepwise empirical analysis taking 50 global forest-based bioeconomy leaders, elucidation of a unique feature of the co-evolutionary coupling toward circular economy embedding a growth characteristic was attempted together with the analyses of the reaction of downstream leader Amazon.

An insightful suggestion supporting a novel concept of R&D in the digital economy was thus provided.

Organization of this paper is as follows: Section 2 reviews new global streams of the digitalized bioeconomy. The market value of the digitalized bioeconomy is examined in Section 3. In section 4 analysis of co-evolutionary coupling is presented. In section 5 the authors demonstrate the significance of self-propagating function. In Section 6 is a summary of noteworthy findings, policy suggestions, and future research.

2. Global new streams of digitalized bioeconomy

Given a transformative endeavor of the digitalized bioeconomy identical to geopolitical regions, leading challenges emerge in each of four respective regions: America, Europe, Asia, and Africa were identified first from both growth potential and business prospects.2

2.1. Development trajectory of global bioeconomy firms

In line with the advancement of the digital economy, global bioeconomy firms have been endeavoring to create digital solutions, which inevitably urges them to an R&D-driven, income-seeking strategy as illustrated in Fig. 2. Fig. 2 illustrates the R&D-driven operating income (OI)-seeking trajectory in 50 global bioeconomy firms encompassing forest, paper and packaging firms in 2017 (see the details of the 50 firms in Table A1 in Appendix 1).

Given that R&D increase depends on a revenues (sales) increase, this strategy leads these firms to R&D and sales-driven income (operating income) seeking a trajectory (R-S-driven OI-seeking trajectory).3

Table 1 shows results of the analysis of this trajectory in 50 global bioeconomy firms in 2017 by applying their OI increasing trajectory to an R-S-driven logistic growth function.

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1 Established in 2004, SPC brings together 455 businesses, educational institutions, and government agencies to collectively strengthen and advance the business case for more environmentally friendly sustainable packaging through strong member support, an informed and science-based approach, supply chain collaborations, and continuous outreach to build eco-friendly packaging systems that encourage economic prosperity and the sustainable flow of materials.

2 As a prelude aiming at identifying the focal actor of the analysis, this section depends on the authors’ preceding analysis with a similar objective [49].

3 Revenues and net income can be appropriated by sales and operating income, respectively as Revenues Sales Interest income Dividend income. Net income Operating income investment income–interest expense onetime extraordinary income–onetime extraordinary expenses–taxes.
Table 1 demonstrates statistically significant values where respective coefficients indicate $a_1$ and $a_2$: velocity of OI increase; $b$: initial state of OI level; and $c$: adjustment of Domtar’s low level of OI, which is exceptional to 49 other firms, in the regression analysis.

Table 1 suggests that rapid OI increase in 50 global bioeconomy firms in the digital economy significantly depends on R&D and sales.

Inspired by this finding, with the understanding that rapid income increase is decisive to global firms in the digital economy [27], Table 2 identifies the top 20 prospecting global bioeconomy firms from growth potential. This potential was analyzed based on the potential of rapid OI increase by utilizing a synchronized index (SI) that demonstrates the velocity of OI increase.

### 2.2. Leading bioeconomy firms in geopolitical regions

Given the geopolitical significance of bioeconomy firms in the digital economy, Table 3 shows classifications of the top 20 prospecting firms in four regions: America, Europe, Asia, and Africa. In order to evaluate the comparative advantage and prospects of values that top firms will realize, Table 3 also shows comparisons of market capitalization which represent business prospects [28] between the top two SI value firms in each respective region over the last 5 years.

Based on the comparison both by growth potential and business prospects using SI values and market capitalization between the top two SI value firms in each respective region, the following four firms with higher market capitalization were chosen to represent prospecting firms.

### Table 1

<table>
<thead>
<tr>
<th>Development Trajectory of OI in 50 Global Bioeconomy Firms (2017)</th>
<th>OI (ml. US$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>$N$</td>
<td>6360.86</td>
</tr>
<tr>
<td>$b_{he} \times 10^3$</td>
<td>0.004</td>
</tr>
<tr>
<td>$a_1$</td>
<td>0.0001</td>
</tr>
<tr>
<td>$a_2$</td>
<td>29.02</td>
</tr>
<tr>
<td>$b$</td>
<td>729.68</td>
</tr>
<tr>
<td>$c$</td>
<td>0.828</td>
</tr>
<tr>
<td>$D$</td>
<td>Domtar</td>
</tr>
</tbody>
</table>

Table 2 shows the development trajectory of OI in 50 global bioeconomy firms (2017). OI

![Co-evolutionary coupling in the value chain of the forest-based bioeconomy.](image1)

**Fig. 1.** Co-evolutionary coupling in the value chain of the forest-based bioeconomy.

![R&D-driven OI-seeking trajectory in 50 global bioeconomy firms (2017).](image2)

**Fig. 2.** R&D-driven OI-seeking trajectory in 50 global bioeconomy firms (2017).
3. Market value of digitalized bioeconomy

3.1. Market capitalization (MC)

Aiming at measuring the potential and prospects of the market value of a digitalized bioeconomy in transition, market capitalization (MC) and its sales ratio (MC/S) were used. MC is obtained by multiplying the number of a publicly traded firm’s outstanding shares by the current share price. Since this represents the comparative advantage and prospects of values that the firm will realize, it is generally highly appraised as a good indicator of firms about their business prospects [28].

Fig. 3 illustrates trends in MC (in a logarithmic scale) in the four firms representing the four geopolitical regions. Fig. 3 demonstrates KC’s highest level followed by UPM, Oji, and Sappi.

However, if we compare the recent growth rate after 2012, we note UPM’s conspicuously high growth rate over the last five years as demonstrated in Figs. 4 and 5. UPM demonstrated a notably high rate of growth from the beginning of the second decade of this century toward a circular economy [9]; see the details in Section 4.

3.2. Price-to-sales ratio (ratio of MC and sales: MC/S)

While MC represents the value of business prospects, it depends not only on the qualitative value of business prospects but also on the quantity of business activities. Therefore, in case when evaluating the value of business prospects placed on firm’s sales, the price-to-sales ratio is used. This is the ratio of a firm’s market capitalization and its sales (MC/S), thereby used as an indicator of the value placed on the firm’s sales. MC/S is also known as a sales multiple. Contrary to the enterprise value-to-sales ratio (EVSR), it is supportive in making comparative prospects to assess each firm’s business model. Figs. 6 and 7 illustrate the trends of MC/S in recent years in the four firms; these demonstrate a clear contrast between UPM’s rapid increase and KC’s decline in MC/S.

3.3. Governing factors of market capitalization

Market capitalization is a dependent variable determined by other variables, both by indigenous efforts and external stimulations. Co-evolutional advancement of these efforts and stimulations are essential for sustainable growth of MC and also of MC/S.
Table 4
Bioeconomy firms in the 4 regions (2017).

<table>
<thead>
<tr>
<th>Firm</th>
<th>Country</th>
<th>SI value</th>
<th>OI</th>
<th>Sales</th>
<th>R&amp;D</th>
<th>OI/S</th>
<th>R/S</th>
<th>OI/R</th>
<th>Business type/segments</th>
</tr>
</thead>
<tbody>
<tr>
<td>KC</td>
<td>US</td>
<td>3.07</td>
<td>3299</td>
<td>18259</td>
<td>311</td>
<td>0.18</td>
<td>0.017</td>
<td>10.61</td>
<td>Personal care (disposable diapers, training and youth pants, swim pants, baby wipes, feminine and incontinence care products, and other related products)  Consumer tissues (facial and bathroom tissue, paper towels, napkins and related products)  K-C professional (wipers, tissue, towels, apparel, soaps and sanitizers.)  Forest-based bio products (biochemicals, biocomposites, biofuels, energy, labels, pulp and paper, plywood and timber).  Acquisition of Myllykoski and Rhein Papier in 2010 accelerated the transformation into a circular economy-based business model consists of five principles: (i) circular supplies, (ii) resource recovery, (iii) product life extension, (iv) sharing platforms, and (v) products as a service.</td>
</tr>
<tr>
<td>UPM</td>
<td>Finland</td>
<td>1.36</td>
<td>1419</td>
<td>11285</td>
<td>57</td>
<td>0.13</td>
<td>0.005</td>
<td>24.89</td>
<td>Household and industrial materials (packaging materials and products, household papers and disposable diapers)  Functional materials (specialty papers, thermal papers, adhesive products)  Forest resources (pulp, power generation, and lumber processing)  Printing and communication (newsprint, printing and publication paper, copying paper)  Forest-based bio products (printing paper, packaging and specialty papers, casting and release paper, dissolving wood pulp, biomaterials and bioenergy)</td>
</tr>
<tr>
<td>Oji</td>
<td>Japan</td>
<td>1.62</td>
<td>633</td>
<td>12838</td>
<td>83</td>
<td>0.05</td>
<td>0.006</td>
<td>7.63</td>
<td></td>
</tr>
<tr>
<td>Sappi</td>
<td>South Africa</td>
<td>0.65</td>
<td>526</td>
<td>5296</td>
<td>30</td>
<td>0.10</td>
<td>0.006</td>
<td>17.53</td>
<td></td>
</tr>
</tbody>
</table>

Fig. 3. Trends in MC in the 4 firms in a logarithmic scale.

Fig. 4. Trend in increase ratios of MC in the 4 firms (2012–2017) – index: 2012 = 100.

3.3.1. Indigenous efforts
In conducting a comparative prospects assessment of a firm’s business model, the following indigenous efforts should be taken for governing factors decisive to MC [28]:

(1) Sales and Operating Income

A firm’s growth, generally measured by the rate of growth in sales, has a positive effect on the market value of a firm as this growth usually leads to an increase in operating income and R&D. Since the operating income (close to net income as net income operating income investment income – interest expense one-time extraordinary income – one-time extraordinary expenses – taxes) enables firms’ new activities and/or rewards to shareholders by providing dividends, investors expect the firm to do well in the future. Therefore, if operating income goes up, the stock price and subsequently the MC increases.

(2) R&D

While R&D decreases the firm’s profit in the short term, it creates the potential for higher profits in the medium and long terms. Therefore, its increase is considered a positive sign for the firm’s future profits leading to the MC increases. However, since R&D incorporates a pregnant period before commercialization and it carries the risk of failure, an R&D
challenge without investors’ confidence results in an MC decrease [29, 30].

### 3.3.2. External stimulations

In addition to the above indigenous efforts, the MC as a dependent variable, is subject to external stimulations such as external market conditions, both global and local. Furthermore, as a consequence of the unique feature of value chain structure of the forest-based bioeconomy, the MC of the upstream firm is subject to coupling effects with downstream environments [31].

1) Global Market Conditions
   (i) Macro-economic factors such as interest rates, inflation, economic growth, trends in oil prices, and exchange rates.
   (ii) Political factors such as control of the government, elections, and also uncertainty stemming from a change in political circumstances.
   (iii) Natural and man-made disasters with economic consequences.
2) Local Market Conditions
   Irregular happenings such as changes in business, its administrative system, acquisitions, and geo-political changes specific to the firm.
3) International Policies and Commitments

International policies and commitments influence and bind ways of production and consumption.

(2) Coupling Effects with Downstream Firms

Coupling effects with downstream environments cannot be overlooked as a consequence of the economy with a value chain structure. In line with advancement of the digital economy and the subsequent increasing dependence on digital solutions, these effects have been significantly increasing [14]. The advancement of digital innovation has been transforming the influencer platform across the countries.

Augmented Reality (AR) and Virtual Reality (VR) accelerate this transformation. Amazon is trying multiple approaches to leverage influencer marketing and the influencer economy [32].

In addition, increasing concerns regarding the circular economy and its impact on consumer ecological behaviors inevitably drive the coupling with partners who are leading the circular economy [15].

### 3.4. Institutional structure governing leading forest-based bioeconomy firms

Following the above review, the MC for leading forest-based bioeconomy firms can be depicted as follows, paying special attention to external stimulations both by external market conditions and coupling effects with downstream firms:

\[
MC = F \times S, OI, R, Ex, CE
\]  

(1)

where \( S \): sales; \( OI \): operating income; \( R \): R&D investment; \( Ex \): external market conditions; \( CE \): coupling effects with downstream firms.

Given the \( R-S \)-driven, \( OI \)-seeking trajectory in global bioeconomy firms as reviewed in Table 1, \( OI \) and strong inducement by \( R \) are considered as providing significant impacts on MC, and \( S \) can be treated as a dependent variable of \( OI \) and \( R \) in these impacts. Therefore, equation (1) can be transformed into equation (2) as follows:

\[
MC \times F \times OI, R, Ex, CE
\]  

(2)

Translog (transcendental logarithmic) expansion on the first term:

\[
\ln MC = a + b \ln OI + c \ln R + d \ln Ex + e \ln CE + f D
\]  

(3)

where \( a - f \): coefficients; and \( D \): dummy variables for local market conditions (irregular happenings identical to the firm).

Utilizing equation (3), governing factors of MC in the four firms over the last two to three decades were analyzed. A summary is presented in Table 5.

In this analysis, external market conditions (\( Ex \)) are proxied by the S&P 500 Index, while coupling effects with downstream firms (\( CE \)) were examined by analyzing the interacting effects of market value of downstream leaders [14]. Given Amazon’s conspicuously higher stock...
price compared to other global e-commerce leaders in 2017 as demonstrated in Fig. 8, the trend in its stock price was used as a proxy of this effect.

The backward elimination method with 10% significance criteria was used.

Table 5 demonstrates the following notable features in the four firms (figures in the parentheses indicate elasticity):

1. **KC** (America): (i) R&D constantly induced MC (0.80 by 2008, 0.50 after 2009); (ii) Of inducement by 2008 (0.44) substituting with the coupling effect after 2009 (0.28).
2. **UPM** (Europe): (i) R&D and Of constantly induced MC (0.40 and 0.09, respectively); (ii) Sensitive to external stimulations as external market conditions that induced MC significantly by 2010 (0.65, 0.37) which shifted to a coupling effect with downstream leader Amazon from 2011 (0.13, 0.38).
3. **Oji** (Asia): (i) R&D constantly induced MC (0.60); (ii) Inducement of the coupling effect by 2007 (0.10) substituted to Of after 2008 (0.04).
4. **Sappi** (Africa): (i) Of and the coupling effect changed to positive inducement after 2008 (0.3 and 0.55); (ii) Of and R&D reacted negative inducement by 2007 (–0.12 and –1.60) demonstrating failure to gain confidence from investors.

Among four firms, it is noted that UPM demonstrated a sophisticated R&D-driven virtuous cycle utilizing all resources including the coupling with downstream firms and also external market inducement [34]. This led to its conspicuous performance of MC/S increases as reviewed in Figs. 6 and 7. This was driven by an extremely high level of R&D productivity to MC (MC/R) after 2011 with the transition into a circular-economy-based business model [35,36], as demonstrated in Fig. 9. This transition significantly increased the coupling effect.

![Fig. 9. Trends in MC/R in the 4 firms (2000–2017).](image-url)

### Table 5

<table>
<thead>
<tr>
<th>Factors governing MC in the 4 firms. ln MC</th>
<th>a</th>
<th>b ln Of</th>
<th>c ln R</th>
<th>d ln Ex</th>
<th>e ln CE</th>
<th>f1 D1</th>
<th>f2 D2</th>
<th>adj. R²</th>
<th>DW</th>
<th>Dummy variables</th>
<th>Dummy period</th>
</tr>
</thead>
<tbody>
<tr>
<td>Date</td>
<td>2008</td>
<td>2009-</td>
<td>2008</td>
<td>2009-</td>
<td>2008</td>
<td>2009-</td>
<td>2008</td>
<td>2009-</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>KC(America)</td>
<td>2.35</td>
<td>0.44</td>
<td>–</td>
<td>0.80</td>
<td>0.50</td>
<td>–</td>
<td>–</td>
<td>0.28</td>
<td>0.29</td>
<td>0.21</td>
<td>0.922</td>
</tr>
</tbody>
</table>

(continued)
Fig. 10. Trend in marginal productivity of R&D to MC in the 3 firms (2000–2017).

Table 6

<table>
<thead>
<tr>
<th></th>
<th>MC/R</th>
<th>MC/S</th>
<th>MC</th>
<th>adj $R^2$</th>
<th>DW</th>
</tr>
</thead>
<tbody>
<tr>
<td>ln MC</td>
<td>6.27</td>
<td>1.16</td>
<td>0.32D1</td>
<td>0.25D2</td>
<td>0.936</td>
</tr>
<tr>
<td>(20.44)</td>
<td>(19.21)</td>
<td>(4.34)</td>
<td>(-3.00)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>ln MC</td>
<td>2.98</td>
<td>1.16</td>
<td>0.45D3</td>
<td></td>
<td></td>
</tr>
<tr>
<td>(7.47)</td>
<td>(14.93)</td>
<td>(6.36)</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

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

3.5. Sophisticated R&D-driven Co-evolution initiated by UPM

The above comparative analysis highlights sophisticated R&D-driven, co-evolutionary cycles utilizing external resources (both in downstream and external markets) that UPM may incorporate as follows:

(1) Sophisticated R&D system in inducing MC
   (i) Consistent R&D elasticity
   UPM: 0.40; KC: 0.80–0.60; Oji: 0.60; Sappi: negative.
   (ii) Maintains conspicuously high marginal productivity of R&D to MC (MPRMC) that corresponds to R&D price relative to stock price as demonstrated in Fig. 10.

$$
\varepsilon_{\text{MC/R}} = \frac{\partial \text{MC}}{\partial R} = \frac{\partial \text{MC}/\partial R}{\text{MC}}
$$

Elasticity of R&D to MC

$$
\text{MPRMC} = \frac{\partial \text{MC}}{\partial R} = \frac{\varepsilon_{\text{MC}}}{\text{R}} = \frac{\rho_{\text{R}}}{\rho_{\text{MC}}}
$$

where $\rho_{\text{R}}$: R&D price; $\rho_{\text{MC}}$: Stock price.

(iii) Such a high level of MPRMC leads to a high level of MC/R ($\text{MPRMC}/c$: proportional to R&D price) that induces MC/S as well as MC strongly, as demonstrated in Table 6.

Since MC/R is proportional to the R&D price as depicted in equation (4), this suggests the R&D price increase induces MC/S significantly.

Such an R&D-driven MC and MC/S inducing dynamism - beyond the dilemma between R&D expansion and productivity decline - prompts us to conduct an effective utilization of external resources for innovation and also the self-propagating new market value creation as growth proceeds indigenous to ICT [21] as illustrated in Fig. 11.

(2) Well balanced resources allocation to MC creation

R&D contributes to MC not only directly but also via OI (Table 1) as OI constantly induced MC.

(3) Effective utilization of external stimulations

External stimulations by external market conditions (Ex) and coupling effects with downstream firms (CE) steadily contribute to MC with a noteworthy increase in the latter after 2011.

These inducements prompt the co-evolutionary coupling, the co-evolution of the dual coupling of bioeconomy and digitalization and of upstream and downstream operation in activating the above function. Particularly, coupling effects with downstream firms significantly increased after 2011. This can be attributed largely to UPM’s new circular-economy-seeking R&D challenge [14,34–37] and downstream leader Amazon’s strategic change toward circular economy4 (see the details of this background in Section 5).

Table 7 highlights UPM’s R&D challenge toward the circular economy by comparing it with other global bioeconomy leaders.

4 UPM made its first commitment for BSAG in 2010 and a subsequent shift towards a circular-economy-based business model in 2013 by undertaking a circular economy-seeking R&D challenge in 2011. Similarly, Amazon’s strategic change toward a circular economy commenced full-fledged operations in 2011. It insisted on offering the least environmental impact shopping experience on the planet and introduced its frustration-free packaging program in 2008 to accelerate the use of sustainable packaging. Frustration-free packaging differentiates and optimizes the customer’s experience with easy-to-open packaging. It minimizes the environmental impact with 100% recyclable materials and reduces packaging costs by shipping products in their original packaging to eliminate the need for an extra box. Amazon tripled the number of items shipped with frustration-free packaging in 2011. Under this program, Amazon works with supply chain partners worldwide and helps them innovate sustainable packaging solutions [50]. In addition, Amazon launched Amazon Tote Pilot in 2011 as a new eco-friendly program. While this program concluded shortly, it demonstrated Amazon’s strong consciousness to the circular economy.
Table 7
Major R&D focus in the 4 firms.

<table>
<thead>
<tr>
<th>Company</th>
<th>Focus</th>
</tr>
</thead>
<tbody>
<tr>
<td>KC</td>
<td>Kimberly Clark R&amp;D activities include researching materials and technology innovations to deploy a more circular business model. KC emphasizes the zero-waste mindset across the value chain and adopts circular design principles to keep post-consumer waste out of landfills. In addition, they reduce and eliminate the materials of concern to ensure the safety and well-being of their customers.</td>
</tr>
<tr>
<td>UPM</td>
<td>The eco-design approach is at the core of R&amp;D efforts in the development of new technologies and products. UPM invests in bioeconomy innovations, forest biodiversity and the circular economy to create sustainable solutions by minimizing dependency on fossil-based materials. UPM collaborates with customers, research institutions, universities and technology providers to develop creative circular economy solutions and user-friendly digital tools and services. The first commitment for the Baltic Sea Action Group (BSAG) in 2010 triggered these endeavors.</td>
</tr>
<tr>
<td>Oji</td>
<td>Oji aims to develop new possibilities, skills and high-tech materials in the paper and forest sectors. They are devoting their R&amp;D efforts in developing cellulose fibers as they can potentially be used in many fields such as construction, chemicals, packaging and so on. Oji is introducing cutting-edge, continuous process technology for biochemical material development as well as highly-function film production technologies and medicinal plant cultivation techniques.</td>
</tr>
<tr>
<td>Sappi</td>
<td>Sappi’s R&amp;D efforts are adhered to consolidation and growth in the industry through cost competitiveness and optimization of equipment and forestry assets. They promote the innovation culture to develop sustainable solutions for the company. Sappi follows the partnership approach and develops long-term relationships with global firms and customers. They are growing their nanocellulose competency due to its wide range of application in construction, chemicals, personal and homecare products, composites and packaging papers.</td>
</tr>
</tbody>
</table>

4.2. Assimilation of external innovation resources

Such an R&D-driven virtuous cycle notwithstanding the dilemma between R&D expansion and productivity decline suggests a significant role that assimilated external resources in innovation, particularly absorption of soft innovation resources (SIRs) from external markets in both upstream and downstream businesses [5,6].

Here, SIRs are considered as a condensate and crystal of the advancement of the Internet and consist of Internet-based resources that have been either sleeping or untapped or are the results of multisided interactions in the markets where consumers are looking for functionality beyond an economic value. The common feature of SIRs is that they are not accountable in the traditional GDP terms [5,6]. In the context of co-evolutionary coupling toward a circular economy, harnessing such resources particularly through circular suppliers, resource recovery, product life extension, sharing platforms, and the involvement of downstream firms’ potential is considered to play a significant role [9]. The advancement of the Internet plays a pivotal role for this harnessing [38].

Prompted by such a hypothetical view, assimilation capacity and the subsequent effect of assimilated SIRs’ contributions to MC growth were analyzed.

As reviewed earlier, MC for leading forest-based bioeconomy firms can be depicted as follows:

\[
\ln MC = a + b \ln OI + c \ln R + d \ln Ex + e \ln CE + \beta D
\]  

(5)

Here, gross R&D incorporating both indigenous R&D (R) and SIRs can be depicted as follows [7,8,9,39] where z is assimilation capacity:

\[
R = R_s \left( 1 + \frac{SIR}{\mc} \right)
\]

(6)

\[
R = \ln R + \ln R_s \left( 1 + \frac{SIR}{\mc} \right)
\]

(7)

Here, SIRs can be represented by Internet dependence as SIRs can be considered a condensate and crystal of the advancement of the Internet [5,6,9,38].

By synchronizing equations (3) and (5), the following equation is obtained:

\[
\ln MC = a + b \ln OI + c \ln R_s + \frac{SIR}{\mc} \left( d \ln Ex + e \ln CE + \beta D \right)
\]

(8)

where \( \frac{SIR}{\mc} \). Therefore, assimilation capacity z can be identified as follows:

\[
z = \frac{C}{\mc}
\]

(9)

Utilizing equation (6), the governing factors of UPM’s MC taking assimilated innovation resources explicitly over the period of 1990–2017 were analyzed, as demonstrated in Table 10.

SIRs were proxied by the Internet dependence in Finland (see Appendix 4 in Ref. [9]).

From Table 10 assimilation capacity can be identified as summarized in Table 11.

4.3. Effects of external innovation resources assimilation

By comparing the results of Table 10 (treating assimilated external innovation resources in an explicit structure) and Table 5 (treating these
Taking the balance between equation (6) and equation (3), the following equations are obtained:

$$\ln MC = 7.50 + 0.21D_1 + 0.19D_2 + 0.18D_3 + 0.25D_4$$

$$\text{adj } R^2 = 0.797$$

$$DW = 1.70$$

Equation (10)

$$\ln S = 0.21D_1 + 0.25D_2$$

$$\text{adj } R^2 = 0.815$$

$$DW = 1.43$$

Equation (11)

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

The effects of external resources on respective factors’ contributions to MC growth is summarized as tabulated in Table 12 in a way that decomposes the constitution of external resources (relative to indigenous R&D).

Table 8

<table>
<thead>
<tr>
<th>Correlation between MC and sales in UPM (1990-2017).</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\ln S = 7.50 + 0.21D_1 + 0.19D_2 + 0.18D_3 + 0.25D_4$</td>
</tr>
<tr>
<td>$\text{adj } R^2 = 0.797$</td>
</tr>
<tr>
<td>$DW = 1.70$</td>
</tr>
<tr>
<td>The figures in parentheses indicate t-statistics: All are significant at the 1% level.</td>
</tr>
</tbody>
</table>

Table 9

<table>
<thead>
<tr>
<th>Correlation between sales and R&amp;D in UPM (1990–2017).</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\ln R = 10.41 + 1.53D_1 + 1.54D_2 + 0.38D_3 + 0.23D_4$</td>
</tr>
<tr>
<td>$\text{adj } R^2 = 0.815$</td>
</tr>
<tr>
<td>$DW = 1.43$</td>
</tr>
<tr>
<td>The figures in parentheses indicate t-statistics: All are significant at the 1% level.</td>
</tr>
</tbody>
</table>

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

The effects of external resources on respective factors’ contributions to MC growth is summarized as tabulated in Table 12 in a way that decomposes the constitution of external resources (relative to indigenous R&D).
Table 10
Governing factors of UPM’s MC taking assimilated external innovation resources (1990–2017).

<table>
<thead>
<tr>
<th></th>
<th>ln MC</th>
<th>2.02</th>
<th>0.19 ln Of</th>
<th>0.74D1 ln R</th>
<th>0.42D2 ln R</th>
<th>0.22 SIRs</th>
<th>ln Ex</th>
<th>0.12D3 ln CE</th>
<th>0.22D4 ln CE</th>
<th>0.48D3</th>
<th>0.33D4</th>
</tr>
</thead>
<tbody>
<tr>
<td>(2.24)</td>
<td>(4.89)</td>
<td>(3.39)</td>
<td>(2.55)</td>
<td>(2.13)</td>
<td>(2.41)</td>
<td>(2.58)</td>
<td>(2.71)</td>
<td>(5.29)</td>
<td>(3.07)</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

D: dummy variables (D1: 1990–2010 1, others 0; D2: 2011–2017 1, others 0). The figures in parentheses indicate t-statistics: All are significant at the 1% level.

Table 11
Assimilation capacity in UPM.

|        | 1990–2010 | 0.30 | (0.22/0.74) | | 2011–2017 | 0.52 | (0.22/0.42) |

4.4. The effects of coupling with downstream firms

Tables 10 and 11 suggest a possible causality between the increase in assimilation capacity and the effect of downstream firms in inducing UPM’s MC, as illustrated in Fig. 13. Table 12 shows data to support this view.

These analyses suggest a notable coupling with downstream firms, particularly after 2011. This can be demonstrated by the significant impact of downstream firms on UPM’s R&D price (price of gross R&D) increase as follows:

As reviewed in section 3.5, under competitive circumstances where UPM seeks maximum profit, the R&D price pR can be depicted as follows:

$$ MPRMC = \frac{\partial MC}{\partial R} e^{\alpha MC} \cdot \frac{P_R}{P_{MC}} $$

where $p_{MC}$: stock price, $c$: elasticity of R&D to MC.

Therefore,

$$ p_R = MPRMC \cdot p_{MC} $$

This price increased dramatically after 2011 as demonstrated in Fig. 14. This increase was triggered by UPM’s circular economy-seeking R&D challenge from 2011 and also Amazon’s strategic change toward a circular economy commencing full-fledged operations from 2011, as reviewed earlier.

This price increase contributes to increases in MC/R and MC/S as demonstrated in Table 13 and 14.

Increased MC/S stimulates interaction with downstream firms and activates coupling with them. Fig. 15 shows results of an analysis which suggest a correlation between MC/S and the coupling effects with downstream leader Amazon, which demonstrates a notable correlation after 2011. Advanced MC/S activates the coupling effect with downstream, thereby the co-evolutionary coupling between upstream and downstream firms emerged after 2011 when UPM’s new circular economy-seeking R&D challenge and downstream leader Amazon’s strategic change toward the circular economy commenced full-fledged operations (see footnote 4).

Table 15 demonstrates such coupling effects as upstream leader UPM’s R&D-driven MC/S increase has induced downstream leader Amazon’s stock price (CE) increase significantly, particularly after 2011.

As reviewed in Section 3, the stock price of Amazon is governed by operating income and R&D investments, particularly R&D investments as an R&D-driven company. In addition, Table 15 demonstrates that upstream leader UPM’s business operations and prospects as

Table 12

<table>
<thead>
<tr>
<th>SIRs/R</th>
<th>a ln Of</th>
<th>b ln R</th>
<th>c ln Ex</th>
<th>d ln CE</th>
<th>e ln CE</th>
</tr>
</thead>
<tbody>
<tr>
<td>1990–2010</td>
<td>0.82</td>
<td>0.45</td>
<td>1.55</td>
<td>1.50</td>
<td>0.05</td>
</tr>
<tr>
<td>2011–2017</td>
<td>0.82</td>
<td>0.45</td>
<td>0.09</td>
<td>0.23</td>
<td>0.73</td>
</tr>
</tbody>
</table>

Fig. 13. Correlation between assimilation capacity and downstream firms inducement effect in UPM. represented by R&D-driven MC/S, also induces Amazon’s stock price significantly; this is particularly noted for results after 2011.

Such R&D-driven coupling effects from upstream to downstream firms, in turn, also provide significant effects to upstream by impacting UPM’s R&D structure.

Fig. 16 shows results of an analysis in which a correlation was noted between the coupling effects with downstream leader Amazon and the price of UPM’s gross R&D (see Fig. 14) which demonstrates that the coupling effects with downstream leader induced the price increase significantly after 2011.

Table 16 offers data to support analyses of the effects of external stimulations in increasing R&D prices in UPM, which demonstrates that coupling effects with downstream leader Amazon after 2011 significantly induced price increases and endorsed the above coupling effects with downstream firms.

Increased R&D prices consistently encourage R&D investments supportive of UPM’s R&D-driven circular-economy endeavors.

4.5. Utilization of external innovation resources via coupling with downstream firms

4.5.1. Assimilation of soft innovation resources via coupling

These analyses prompt a hypothetical view that such increases in UPM’s gross R&D prices can be attributed to effective utilization of assimilated soft innovation resources (SIRs) via coupling with downstream leader Amazon.

Based on the preceding analyses, the data in Fig. 17 are offered as proof of this methodological view by demonstrating the significant increase in elasticity of coupling effects to assimilated SIRs’ increases.

Elasticity of coupling effects to assimilated SIRs’ increases $\varepsilon_{SIR,CE}^i$ is depicted as follows:

From Tables 8, 13 and 14, $\frac{d \ln S}{d \ln CE} = h(0.21$ (1990–2010), 0.19 (2011–2017)), $d \ln MC/R \quad d \ln MC/S \quad d \ln MC \quad d \ln S \quad d \ln CE \quad d \ln h \quad d \ln \varepsilon_{SIR,CE}^i \quad j(0.65$, 0.67). Substitute Table 14 $\frac{d \ln S}{d \ln CE} \quad h = i \quad i(0.58, 0.61) \quad \frac{d \ln MC/S}{d \ln CE}$ from Table 13 $\frac{d \ln S}{d \ln CE} \quad h = i \quad i(0.24$ (1990–2010), 0.22 (2011–2017)).
where $S_R$, SIRs; $\pi$ 0.30 (1990–200), 0.52 (2011–2017) (Fig. 13).

Based on the results shown in Table 12,

$$\frac{\partial S_R}{\partial \ln CE} = \frac{1}{CE} \frac{\partial S_R}{\partial CE} - \frac{R}{CE} \frac{\partial R}{\partial CE} \cdot CE \cdot e^{-0.05} (1990$$

$$\frac{0.73}{2010} \frac{0.73}{2011} \frac{0.73}{2017}$$

Therefore,

$$S_R \cdot \frac{\partial S_R}{\partial CE} = \frac{R}{CE} \frac{\partial R}{\partial CE}$$

Consequently,

$$\frac{\partial S_R}{\partial CE} \cdot CE \cdot e^{-0.05} (1990$$

$D$: dummy variables ($D_1$: 1990–2010 1, others 0; $D_2$: 2011–2017 1, others 0; $D_3$: 1990–1997, 2017 1, others 0; $D_4$: 1998–2002 1, others 0).

The figures in parentheses indicate t-statistics: All are significant at the 1% level except *5% level.

### Table 13
Correlation between R&D price and R&D productivity to MC in UPM (1990–2017).

<table>
<thead>
<tr>
<th>$\ln \frac{MC}{R}$</th>
<th>$0.31 D_1$</th>
<th>$0.58 D_3$</th>
<th>$0.61 D_2$</th>
<th>$0.16 D_4$</th>
</tr>
</thead>
<tbody>
<tr>
<td>$0.18 D_1$</td>
<td>$0.16 D_3$</td>
<td>$0.18 D_2$</td>
<td>$0.16 D_4$</td>
<td>(2.15)*</td>
</tr>
<tr>
<td>$0.34$</td>
<td>$0.38$</td>
<td>$0.36$</td>
<td>$0.36$</td>
<td>(5.44)</td>
</tr>
</tbody>
</table>

### Table 14

<table>
<thead>
<tr>
<th>$\ln \frac{MC}{S}$</th>
<th>$0.61 D_1$</th>
<th>$0.67 D_2$</th>
<th>$0.41 D_3$</th>
<th>$0.47 D_4$</th>
</tr>
</thead>
<tbody>
<tr>
<td>$0.41 D_1$</td>
<td>$0.47 D_3$</td>
<td>$0.41 D_2$</td>
<td>$0.47 D_4$</td>
<td>(1.11)</td>
</tr>
<tr>
<td>$0.47$</td>
<td>$0.43$</td>
<td>$0.47$</td>
<td>$0.47$</td>
<td>(1.07)</td>
</tr>
</tbody>
</table>

$D$: dummy variables ($D_1$: 1990–2010 1, others 0; $D_2$: 2011–2017 1, others 0; $D_3$: 1990–1997, 2017 1, others 0; $D_4$: 1998–2002 1, others 0).

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

$$S_R \cdot \frac{\partial S_R}{\partial CE} = \frac{R}{CE} \frac{\partial R}{\partial CE}$$

$\epsilon_{CE} = \frac{\partial S_R}{\partial CE} \cdot CE \cdot e^{-0.05} (1990$$

$\epsilon_{CE} \cdot CE \cdot e^{-0.05} (1990$$

$\epsilon_{CE} \cdot CE \cdot e^{-0.05} (1990$$

$\epsilon_{CE} \cdot CE \cdot e^{-0.05} (1990$$

$\epsilon_{CE} \cdot CE \cdot e^{-0.05} (1990$$

$\epsilon_{CE} \cdot CE \cdot e^{-0.05} (1990$$

4.5.2. Eco-oriented resonance between upstream and downstream leaders

Considering the close direct or indirect supply chain link between UPM and Amazon [14] and also given that Amazon is sensitive to consumers’ ecological behaviors [10], extraordinary market impacts are demonstrated by its conspicuously high stock price compared to that of other global e-commerce leaders, as reviewed earlier (Fig. 9), suggest coupling between UPM and Amazon. The significant effects of such coupling can largely be attributed to the eco-oriented “resonance” with Amazon.

In Fig. 18 data are presented to demonstrate such “resonance”
between eco-leaders in both upstream and downstream, UPM and Amazon. In the context of eco-challenges, Amazon tripled its number of shipped items sent in frustration free packaging from 2011 depending on the potential import from the upstream industries as illustrated in the upper part of Fig. 18. Such eco-seeking trade can be attributed to certain “resonance” between UPM and Amazon as suggested by the correlation of stock prices between the two leaders with 2011 as an inflection point, as illustrated in the lower part of Fig. 18.

Such a resonance between upstream and downstream leaders can be traced, as illustrated in Fig. 19. Since 2008, UPM has been shifting its business model to include consciousness of energy and the environment. In 2008, it adopted a new market-driven business structure comprising three business groups: energy and pulp, paper, and engineering materials [40]. Later in 2013, UPM once again implemented a new business structure to drive a clear change in profitability. This period correspond to the UPM’s first commitment for Baltic Sea Action Group (BSAG) in 2010. Consequently, while UPM started as a resources-intensive firm, it recognized the potentially fatal shift from a fossil economy to a bio-economy within the emerging context of development toward a circular economy [35–37]. Thus, UPM has been recognized as one of the world’s circular economy leaders.

Such a pioneer endeavor in the upstream firm drew attention to downstream leader Amazon since it is sensitive to consumers’ ecological behaviors and subsequent keen concern to construct a win-win strategy with upstream leaders toward the circular economy. As Earth’s most customer-centric company, Amazon insisted on offering a shopping experience with the least environmental impact on the planet.

Consequently, it is assumed that the resonance among leaders both in the upstream and the downstream emerged in the beginning of the second decade of this century.

While further empirical and theoretical analyses are required, such resonance has been steadily shifting from a virtual, intangible one to a tangible one as summarized in Table 17. Numerical analyses of coupling effects from UPM to Amazon (Table 15) and also from Amazon to UPM (Fig. 17) support these observations.

4.6. Co-evolutionary coupling: new R&D model in the digital economy

4.6.1. Dynamism leading to Co-evolutionary coupling

On the basis of the foregoing analyses, data are included in Fig. 20 to demonstrate the co-evolutionary coupling (the co-evolution of the dual couplings of bioeconomy and digitalization and of upstream and downstream operations) that UPM has been deploying.

\[ T_n, F_n \text{ and } F_0 \text{ mean Table, footnote and Fig. number, respectively.} \]


This co-evolutionary coupling provides the following three-dimensional insights supportive of a novel concept of R&D in the digital economy:

6 A Probabilistic Partnership Index (PPI) sectoral analysis [51] may provide a constructive insight on the substantial interactions between two partners.
Table 16

<table>
<thead>
<tr>
<th></th>
<th>adj $R^2$</th>
<th>DW</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\ln P_a$</td>
<td>0.952</td>
<td>2.27</td>
</tr>
<tr>
<td>14</td>
<td>(4.62)</td>
<td>(7.29)</td>
</tr>
<tr>
<td>$D_1$</td>
<td>(6.80)</td>
<td>(3.31)</td>
</tr>
<tr>
<td>$D_2$</td>
<td>(11.12)</td>
<td>(11.12)</td>
</tr>
<tr>
<td>$D_3$</td>
<td>(7.14)</td>
<td>(-6.09)</td>
</tr>
</tbody>
</table>

$D$: dummy variables ($D_1$: 1990–2010, 1; others: 0; $D_2$: 2011–2017, 1; others: 0; $D_3$: 2018–2020, 1; others: 0; $D_{12}$: 1990–2001, 1; others: 0; $D_{13}$: 2002–2007, 1; others: 0; $D_{14}$: 1991, 1992, 1998, 2009, 1; others: 0).
The figures in parentheses indicate t-statistics: All are significant at the 1% level except *10% level.

Fig. 18. Possible resonance between UPM and Amazon by eco-trade and stock price [52].

(1) R&D-driven virtuous cycle
(i) R&D (gross R&D) induced MC.
(ii) Induced MC induced sales and MC/S.
(iii) Induced sales induced R&D, thus the R&D-driven virtuous cycle has been constructed.

(2) Coupling with downstream Leader Amazon
(i) Induced MC/S significantly induced the coupling with downstream after 2011.
(ii) Reinforced coupling reinforced assimilation of SIRs, particularly of highly-qualified SIRs after 2011, leading to a dramatic increase in the R&D price.
(iii) The R&D price increase, in turn, accelerated the MC/S increase. Thus, a virtuous cycle involving downstream leader has been constructed.

(3) Spiral increase in R&D productivity of MC (MC/R)
(i) Increases in the R&D price also accelerated the MC/R increase which induced two virtuous cycles through MC and MC/S increases, leading to a spiral increase in MC/R.
(ii) Thus, notably high levels of the MC/R structure (Fig. 9) initiated by the R&D-driven virtuous cycle have been constructed.

4.6.2. Contributors to Co-evolutionary coupling
The spiral increase in MC/R is a core source of UPM’s ability to become world leader in the circular economy [37]. This can be attributed to its success in assimilating growth characteristics identical to biological coupling [20] through the co-evolution of the dual couplings of bioeconomy and digitalization and of upstream and downstream operations.

The former coupling can be attributed to digital solutions supported by advanced digital innovations such as artificial intelligence (AI), machine learning, virtual reality (VR), augmented reality (AR), and big data analysis that can satisfy the shift in people’s preferences for eco-consciousness, which, in turn, induces coupling of upstream and downstream operations in the value chain [15–18].

The effective inducement of coupling of upstream and downstream operations can be attributed particularly to downstream leader Amazon’s eco-consciousness as Earth’s most customer-centric company. However, it should not be overlooked that UPM’s world-leading circular economy endeavor may have been triggered by such coupling by stimulating Amazon’s sensitivity to consumers’ ecological behaviors and subsequent keen concern to construct a win-win strategy with upstream leaders toward a circular economy.

5. Activation of self-propagating function

5.1. Spinoff of the Co-evolution of three mega trends

The above co-evolutionary coupling provides insights into the analysis of a new stream of innovation in the digital economy amidst the spinoff of the co-evolution of three mega trends from traditional ICT to advancement of ICT, GDP growth to uncaptured GDP and economic functionality to supra-functionality beyond economic value as shown in the upper left of Fig. 21 [4,14].

Watanabe et al. [41] previously postulated that while the advancement of the Internet has provided people with utility and happiness, it cannot be captured through GDP data that measure economic value resulting in productivity declines; hence, they defined these as uncaptured GDP. The authors then demonstrated the foregoing co-evolution as a new stream of innovation in the digital economy.

Under such circumstances, against productivity declines, global ICT firms have aimed to transform their business models by incorporating new streams of digital solutions-driven disruptive business models that spontaneously create uncaptured GDP instead of passively depending on it, as shown in the middle of Fig. 21 [42].

Locomotive power of this stream can largely be attributed to the
effective utilization of SIRs that activate latent self-propagating functions identical to ICT and that induce functionality development, leading to supra-functionality beyond economic value that encompasses social, cultural and emotional values, corresponding with a shift in people’s preferences [3]. This correspondence encourages user-driven innovation [8], which induces further advancement of the Internet. This advancement, in turn, accelerates the co-emergence, awakening, and inducement of SIRs.

Thus, a virtuous cycle involving external innovation resources functioning toward people’s shift in preferences can be constructed.

UPM’s digital solutions-driven endeavor enables realization of the long-lasting goal of achieving a circular economy and shifting away from a traditional fossil economy. This process corresponds with the transformative stream spontaneously creating uncaptured GDP by harnessing identical SIRs as (i) circular suppliers, (ii) resource recovery, (iii) product life extension, (iv) sharing platforms, and (v) involvement of downstream potentials, as illustrated in the lower right of Fig. 21. Similar to user-driven innovation in a firm level virtuous cycle, achievement of the above long-lasting goal toward a circular economy encourages societal innovation which also induces further advancement of the Internet [38]. This advancement, in turn, accelerates the co-emergence, awakening, and inducement of SIRs. Thus, a virtuous cycle involving growth characteristics by digital solutions and external

Table 17
Shifting trend in resonance between UPM and amazon.

<table>
<thead>
<tr>
<th>Year</th>
<th>Event Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>2008</td>
<td>Increase in trade of eco products corresponding to Amazon’s introduction of its frustration-free packaging program in 2008 and the launching of reusable totes in 2011.</td>
</tr>
<tr>
<td>2012</td>
<td>Demonstration of constructing a green supply chain.</td>
</tr>
<tr>
<td>2016</td>
<td>Virtual link via e-Commerce through Tieto’s coordination (UPM-Tieto Vs Tieto-Amazon)</td>
</tr>
<tr>
<td>2017</td>
<td>General collaboration as the members of Sustainable Packaging Coalition (SPC).</td>
</tr>
<tr>
<td>2018</td>
<td>Promoted green shift in transportation and petrochemicals</td>
</tr>
</tbody>
</table>

Fig. 19. Reinforcing resonance leading to the Co-evolutionary coupling between UPM and amazon (1994–2018).
innovation resources can be constructed.
This provides insights in identifying factors and actors influencing co-evolutionary coupling.

5.2. Causal effects of coupling partners

In the above analysis key factors were identified as well as actors influencing co-evolutionary coupling. In firm level coupling, user-driven innovation plays a key role in constructing a virtuous cycle typically observed in Amazon’s R&D-driven business model [8]. Such a business model has enabled Amazon to absorb external resources extensively and assimilate them into its indigenous business. Amazon has deployed the “architecture of participation,” thus making the most of digital technologies by harnessing the power of its users to create even more value [43], as illustrated in Fig. 22. The “Architecture of participation” was postulated by O’Reilly [44]; and it implies that users help extend the platform and thus are supportive in predicting the future of the host company.

Ritala et al. [45] demonstrated that, through coupling with its competitors, and collaborating with them, Amazon has succeeded in building new capabilities, gaining better leverage, and boosting its brand and technologies.

Tou et al. [8] identified that Amazon’s deployment of this strategy is quite similar to that of Canon, known as a coopetition strategy [46]. This strategy harnesses the vigor of mobile phone development in the consumer market leveraged by users, based on coopetition between Canon’s printers and personal computers (PCs) produced by its rival firms [47], as illustrated in Fig. 23. This coupling also demonstrate the supportiveness of coupling in predicting the future of the host company.

Evans et al. [54] also demonstrated Amazon’s benefit of coupling through strategic action for coopetition. They stressed that Amazon seized strategic opportunistic opportunities presented by the successive wave of disruption, ruthlessly cannibalizing its own business where necessary.

5.3. Activation of self-propagating function

The circular economy-driven restructuring enabled UPM to incorporate new functionality and to shift to a new development trajectory toward a bioeconomy-based circular economy beyond the fossil economy [14].

This shift corresponds to a shift from a simple logistic growth (SLG) trajectory that incorporates a fatality in saturating its value with the fixed upper limit to a logistic growth within a dynamic carrying capacity (LGDCC) trajectory value which continues to increase as it creates new carrying capacity during the process of development. As illustrated in Fig. 24 UPM’s trajectory shifted from SLG to LGDCC in 2012 [9].

Since this shift was enabled by activating a self-propagating function [42] that incorporated a growth engine (see Appendix 2 mathematics of this dynamism), this analysis demonstrates UPM’s circular economy-driven restructuring. This restructuring has had a full-fledged start in 2013, by activation of a self-propagating function based on the assimilation of growth characteristics vis biological coupling through co-evolutionary dual coupling of bioeconomy and digitalization and of upstream and downstream operation.

This coupling involves such functions as leveraging awakening and activating latent self-propagating functions indigenous to ICT [42] and essential to sustainable innovation in the digital economy. Demonstration of this dynamism is presented in Fig. 25.

The core function of this dynamism is to activate the latent self-propagating function through growth by incorporating such growth characteristics as leveraging a gross R&D increase.

This increase can be attributed to increases in indigenous R&D (R) and assimilated external resources centered on soft innovation resources SIRs. The latter increase depends largely on coupling effects (CE) from downstream firms as demonstrated earlier in Table 17.

Table 18 shows results from an analysis of factors contributing to activating UPM’s self-propagating function Ni R which demonstrates that R&D resources both internal (gross R&D: R) and external (CE) contributed significantly to an increase in the self-propagating function. These contributions can be attributed to co-evolutionary coupling as demonstrated in Fig. 20. It is noted that the coupling effect with downstream firms significantly increased after 2011.

Increased self-propagating function shifted SLG to LGDCC as illustrated in Fig. 24 and induced functionality development leading to bio-based circular economy beyond fossil economy corresponding to societal preferences as illustrated in Fig. 25.

On the basis of the foregoing analysis, a novel concept of R&D learning from biological coupling can be postulated as illustrated in Fig. 26.

6. Conclusion

Given the increasing role of R&D in competitive markets in the digital economy while most digital economies are now confronting the dilemma between R&D expansion and a productivity decline, transformation of the R&D model has become a crucial subject for global
The authors postulated neo open innovation that harnesses the vigor of external innovation resources which then developed into a new concept of R&D that transforms routine or periodic alteration activities into significantly improving activities during an R&D process initiated by Amazon.

With the understanding that biological organisms demonstrate optimal adaptations to the environment by using the coupling effects of multiple factors centered on growth, the authors of this paper attempted to further develop these postulates by embedding a growth characteristic inspired by biological coupling through the co-evolution of the dual coupling of bioeconomy and digitalization and of upstream and downstream operations.

Driven by digital solutions, together with the long-lasting goal of transition from a traditional fossil economy to a circular economy, the coupling of digitalization and bioeconomy is leading to a digitalized bioeconomy that can satisfy the shift in people’s preferences for eco-consciousness, which in turn, induces coupling of up-down stream operation in the value chain.

This co-evolutionary dual coupling has led to a new R&D model that absorbs external innovation resources from a broad value chain, identical to the forest-based bioeconomy, and assimilates them into various business entities.

In light of the increasing significance of such a new R&D model that may avoid the dilemma and may also provide relief from increasing the fiscal and environmental burdens of R&D investments, the authors of

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**Fig. 21.** Shifting trends in the Co-Evolution of three mega trends: Contrasts among the individual level, Firm level and societal level.
An empirical analysis of leading, global, forest-based bioeconomy firms was conducted first with special attention to the relevance of geopolitical regions fatal to the foot-tight nature of the forest-based-bioeconomy.

It was identified that bioeconomy firms have been present amidst transforming endeavors in the new global stream in the digital economy, which inevitably elects leaders of geopolitical regions by respective growth potential and business prospects.

KC, UPM, Oji, and Sappi represent America, Europe, Asia and Africa, respectively.

Among these four leaders, it is UPM that leads the world’s circular economy. This is demonstrated by sophisticated R&D-driven, co-evolutional cycles that smartly utilize external resources. This can be attributed to its balanced contribution structure by R&D, OI, and coupling effects with downstream leader.

With this structure, UPM’s R&D induces MC, which in turn, induces sales and MC/S. Increased sales induce R&D, which, together, when assimilated with SIRs, increases its price leading to an MC/S increase. Increased MC/S activated coupling effects in the downstream firm, which, in turn, increased R&D prices. Thus, the co-evolutionary dual coupling of digitalization and bioeconomy and of upstream and downstream operations in the value chain have been created. Therefore, a notably high level of MC/R structures have been constructed.
Fig. 24. Trend in UPM’s trajectory of technology-driven increase in market value (1990–2017).

Fig. 25. Dynamism in activating the self-propagating function.

### Table 18

<table>
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<tr>
<th>lnN/L</th>
<th>R</th>
<th>0.04 ln O</th>
<th>0.47 ln R</th>
<th>0.03D1</th>
<th>ln CE</th>
<th>0.05D2</th>
<th>ln CE</th>
<th>0.14D3</th>
<th>0.11D4</th>
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<th>DW</th>
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<td>(3.84)</td>
<td>(8.64)</td>
<td>(3.52)</td>
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<td>(5.09)</td>
<td></td>
<td></td>
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</table>

The figures in parentheses indicate t-statistics: All are significant at the 1% level.
A spiral increase in MC/R is a core source of UPM enabling it as a world leader in the circular economy. This can be attributed to its success in assimilating a growth characteristic of biological coupling through the co-evolutionary function of dual coupling of bioeconomy and digitalization and of upstream and downstream operations.

Coupling with downstream firms can be attributed to downstream leader Amazon’s eco-consciousness. However, it should not be overlooked that UPM’s endeavor as a global, circular economy leader may have triggered this coupling by stimulating Amazon’s eco-conscious concerns to the upstream circular economy leaders.

The above co-evolutionary coupling provides insights into the new stream of innovation in the digital economy amidst the spinoff of the co-evolution of three mega trends from traditional ICT to advancement of ICT, GDP growth to uncaptured GDP and economic functionality to supra-functionality beyond economic value.

UPM’s digital solutions-driven endeavor enables the long-lasting goal of achieving a circular economy. This process corresponds with the transformative stream spontaneously creating uncaptured GDP by harnessing such SIRs as (i) circular suppliers, (ii) resource recovery, (iii) product life extension, (iv) sharing platforms, and (v) involvement of downstream potentials. Achievement of the above goal toward a circular economy encourages societal innovation which induces further advancement of the Internet, which in turn, accelerates the awakening and inducement of SIRs. Thus, a virtuous cycle involving a growth characteristic can be constructed.

This success can be attributed to biological coupling that awakens and activates the latent self-propagating function indigenous to ICT that is essential to sustainable innovation in the digital economy through growth by incorporating such a growth characteristic as leveraging gross R&D increase.

These findings give rise to the following insightful suggestions with respect to dynamism for a new R&D model beyond the existing concept of the digital innovation:

(i) Incorporation of the growth function into the R&D model should be devised.

(ii) Dual co-evolutional coupling should be applied to disruptive business models aiming at overcoming the dilemma between R&D expansion and productivity declines.

(iii) Dynamism enabling co-evolutionary coupling with the vigor of downstream should be elucidated and conceptualized.

(iv) A new four-dimensional sphere encompassing time and space with growth characteristic beyond the existing concept of the digital innovation should be applied in the ecosystem platform.

(v) Co-evolutional innovation among digital innovation, paradigm change, and shifts in people’s preferences should be further elaborated by using the dual co-evolutional coupling concept.

Future work should focus on further elucidation, conceptualization and operationalization of the coupling effects derived from growth characteristics identical to biological functions and application of these effects to broad disruptive business models.

In this paper, resonance between upstream and downstream leaders was estimated by the inducing impacts on each counterpart’s growth potential and business prospects functions with empirical support of noteworthy strategic actions in respective leaders. Simultaneous interaction analysis by developing PPI sectoral analysis would be worth attempting as this may provide additional constructive insight on the substantial interactions between two partners.

In addition, effects of SIRs were analyzed using the trend in the Internet advancement with the understanding that SIRs are the condensate and crystal of this advancement. Further comprehensive conceptualization and operationalization efforts should be continued.

Acknowledgements

The research leading to these results is part of a project titled, “Platform Value Now: Value capturing in the Fast Emerging Platform Ecosystems,” supported by the Strategic Research Council at the Academy of Finland [grant number 293446].
### Table A1
Top 50 Global Forest-based Bioeconomy Firms (2017) - by OI order

<table>
<thead>
<tr>
<th>Firm Name</th>
<th>Short Name</th>
<th>Country</th>
<th>Oil</th>
</tr>
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<tbody>
<tr>
<td>Kimberly-Clark</td>
<td>KC</td>
<td>US</td>
<td>3299</td>
</tr>
<tr>
<td>International Paper</td>
<td>Int. Paper</td>
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<td>2069</td>
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<td>UPM</td>
<td>Finland</td>
<td>1419</td>
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<tr>
<td>Mondi Group</td>
<td>Mondi</td>
<td>UK</td>
<td>1148</td>
</tr>
<tr>
<td>Shandong Chemning</td>
<td>Shandong</td>
<td>China</td>
<td>1023</td>
</tr>
<tr>
<td>Stora Enso</td>
<td>Stora</td>
<td>Finland</td>
<td>1019</td>
</tr>
<tr>
<td>Packaging Corp of America</td>
<td></td>
<td>US</td>
<td>931</td>
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<tr>
<td>Smurfit Kappa</td>
<td></td>
<td>Ireland</td>
<td>924</td>
</tr>
<tr>
<td>Hengen International</td>
<td></td>
<td>Hong Kong</td>
<td>780</td>
</tr>
<tr>
<td>Unicharm</td>
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<td>Japan</td>
<td>774</td>
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<tr>
<td>West Fraser Timber</td>
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<td>Canada</td>
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</tr>
<tr>
<td>Metsalitto</td>
<td></td>
<td>Finland</td>
<td>655</td>
</tr>
<tr>
<td>Oji Paper</td>
<td></td>
<td>Japan</td>
<td>633</td>
</tr>
<tr>
<td>DS Smith</td>
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<td>Shan Dong Sun Paper</td>
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<td>Arauco</td>
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<td>Chile</td>
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<td>Sumitomo Forestry</td>
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<td>Klin</td>
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<td>Brazil</td>
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<td>Canfor</td>
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<td>Canada</td>
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<td>Lenzing</td>
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<td>Austria</td>
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<tr>
<td>Sonoco</td>
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<td>US</td>
<td>367</td>
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<tr>
<td>Graphic Packaging</td>
<td></td>
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<td>343</td>
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<td>Svenska Cellulosa</td>
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<td>Billerud</td>
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<td>Sweden</td>
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<td>Mayr-Melnhof Karton</td>
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<td>Svenskog</td>
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<td>Thailand</td>
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<td>Rengo</td>
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<td>Japan</td>
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<td>Daio Paper</td>
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<td>Japan</td>
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<td>ENCE</td>
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<td>Mercer International</td>
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<tr>
<td>Nippon Paper Group</td>
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<td>The Pack Corporation</td>
<td></td>
<td>Japan</td>
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<td>Resolute Forest Products (Formerly Abitibi Bowater)</td>
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<td>Domtar</td>
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</table>

**Oil**: operating income, R&D: research and development, S: sales.

Forest-based bioeconomy firms encompass forest, paper and packaging firms.

Sales, R&D and Oil unit: mil. US$ (nominal).

OECD exchange rate was used to convert the currency units into US$.

### Table A2
Techno-market Indicators in the Leading 4 Firms (2000–2017)

<table>
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<tr>
<th></th>
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<th>UPM</th>
<th>Oji</th>
<th>Sappi</th>
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<td>Year</td>
<td>MC/R MC/OI MC/S</td>
<td>MC/R MC/OI MC/S</td>
<td>MC/R MC/OI MC/S</td>
<td>MC/R MC/OI MC/S</td>
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<td>106.34 11.20 0.47</td>
<td>215.97 5.11 0.99</td>
<td>58.89 24.76 0.59</td>
<td>118.13 2.64 0.38</td>
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<td>111.75 14.11 0.44</td>
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<td>43.48 7.51 0.43</td>
<td>99.60 8.33 0.48</td>
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<td>2002</td>
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<td>173.06 9.24 0.76</td>
<td>50.39 16.85 0.50</td>
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<tr>
<td>2003</td>
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<td>2004</td>
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<td>182.50 12.52 0.87</td>
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<td>151.67 16.94 0.67</td>
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<td>2005</td>
<td>93.27 12.90 0.53</td>
<td>173.30 27.25 0.93</td>
<td>51.80 6.99 0.50</td>
<td>98.22 15.87 0.53</td>
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<td>2006</td>
<td>94.02 13.46 0.59</td>
<td>228.24 18.65 1.00</td>
<td>57.98 9.66 0.59</td>
<td>77.08 14.80 0.37</td>
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<tr>
<td>2007</td>
<td>110.11 11.66 0.60</td>
<td>142.51 14.66 0.71</td>
<td>55.84 10.13 0.50</td>
<td>64.59 5.73 0.41</td>
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<td>2008</td>
<td>83.84 9.78 0.78</td>
<td>95.17 11.88 0.49</td>
<td>39.33 10.85 0.34</td>
<td>42.21 4.57 0.24</td>
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</tbody>
</table>

(continued on next page)
1. Growth

\[ \frac{\Delta V}{V} = \frac{\partial V}{\partial T} T + \frac{T}{T} \frac{\Delta T}{\partial T} + \frac{\partial V}{\partial R} R \]  

Table A3

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<td>39882.55</td>
<td>7922.39</td>
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<td>30809.30</td>
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<td>32791.37</td>
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<td>2011</td>
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<td>2012</td>
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<td>2013</td>
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<td>7966.25</td>
<td>3608.53</td>
<td>1106.13</td>
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<tr>
<td>2014</td>
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<td>2015</td>
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<td>9082.23</td>
<td>4029.01</td>
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<td>2016</td>
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<td>2017</td>
<td>40695.39</td>
<td>13647.66</td>
<td>4552.42</td>
<td>2440.51</td>
</tr>
</tbody>
</table>

Market capitalization unit: mil. US$ (real values based on 2010).
World bank GDP deflator was used.
The OECD exchange rate was used to convert currency units into US$.
Source: Firm’s Annual report
2017. Source: Firms’ annual reports. Source: Firms’ annual reports.

Appendix 2. Dynamism of Emerging Self-propagating Function

1. Bi-polarisation Fatality of ICT-driven Development

ICT, in which network externalities function to alter the correlation between innovations and institutional systems, creates new features of the innovation leading to exponential increases. Schelling [1] portrayed an array of logistically developing and diffusing social mechanisms stimulated by these interactions. Advancement of the Internet further stimulates these interactions and accelerates ICT’s logistically developing and diffusing feature which is typically traced by the Sigmoid curve [2].

Digital values created by the Internet of things (IoT) can be depicted as follows [42,48]:

\[ V = F X T \]

where \( T \): gross ICT stock; \( X \): other production factors; and \( R \): R&D investment. In this long run, since \( \frac{R}{T} \), the growth rate can be depicted as follows:

\[ \frac{\Delta V}{V} = \frac{\partial V}{\partial T} T + \frac{T}{T} \frac{\Delta T}{\partial T} + \frac{\partial V}{\partial R} R \]  

where \( \rho \) : rate of obsolence of technology and \( g \): R&D growth rate at the initial period.

Given the logistic growth nature of ICT, the R&D-driven developmental trajectory \( V_{s}(R) \) can be depicted by the following epidemic function that leads to a simple logistic growth function (SLG):

\[ \frac{dV}{dR} = aV \frac{dV}{V} \]  

(A3)
where \( N \): carrying capacity; \( a \): velocity of diffusion; and \( b \): coefficient indicating the initial level of diffusion.

Given the ICT-driven development, its growth follows a Sigmoid trajectory which continues to grow until it reaches carrying capacity (upper limit of growth). In this trajectory, while the growth rate continues to increase before reaching the inflection point corresponding to the half-level of carrying capacity, it changes to decrease after exceeding the inflection point. Thus, ICT-driven logistic growth incorporates the bi-polarization fatality and the increasing and decreasing of marginal productivity before and after the inflection point \([5,48]\).

2. Dilemma between R&D Expansion and Productivity Decline

This causes the dilemma between R&D expansion and productivity declines as R&D expansion exceeding the inflection point results in productivity declines and subsequent growth rate decreases \([5]^{[b]}\).

Confronting such a dilemma, global ICT-leaders have been endeavoring to find a practical solution by transforming their traditional business model into a new business model.

Given that this dilemma stems from the unique feature of ICT, logistic growth, this feature should be transformed.

3. Transformation of the Unique Feature of ICT: Self-propagating Function

As far as the development trajectory depends on the simple logistic growth (SLG) trajectory, its digital value, \( V_s(R) \), saturates with the fixed upper limit which inevitably results in the above dilemma. However, once the trajectory shifts to logistic growth within a dynamic carrying capacity (LDGCC), its digital value, \( V_s(R) \), can continue to increase as it creates new carrying capacity during the process of development.

In particular innovation which creates the new carrying capacity \( N_s(R) \) during the diffusion process, equation \((A3)\) is developed as follows:

\[
\frac{dV_s}{dR} = \frac{dV}{R} \left( \frac{V}{N_s} - \frac{V_s}{R} \right)
\]

Equation \((A5)\) develops the following LDGCC which incorporates the self-propagating function as carrying capacity increases corresponding to the \( V(R) \) increase as depicted in equation \((A6)\) and \((A7)\) \([2]\):

\[
V_s(R) = \frac{N_s}{1 - b e^{-aR}} \left( \frac{N_s}{a} e^{-aR} - \frac{V_s}{R} \right)
\]

where \( N_s \): ultimate carrying capacity; \( a \), \( b_a \), and \( b_s \): coefficients.

The dynamic carrying capacity \( N_s(R) \) in this LDGCC is depicted as follows:

\[
\Delta N_s(R) = \frac{dV_s}{dR} \left( \frac{V}{N_s} - \frac{V_s}{R} \right)
\]

References

