CO-EVOLUTIONARY COUPLING VIA A DIGITAL-BIO ECOSYSTEM – A SUGGESTION FOR A NEW R&D MODEL IN THE DIGITAL ECONOMY

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ABSTRACT

Driven by digital solutions, the bioeconomy has taken major steps forward in recent years toward achievement of the long-lasting goal of transition from a traditional fossil economy to a circular economy. The coupling of digitalization and the bioeconomy is leading toward a digitalized bioeconomy that can satisfy a shift in people's preferences for eco-consciousness, which in turn induces coupling of up-down stream operation in the value chain.

This dual couplings has led to a new R&D model that absorbs external innovation resources from a broad value chain and assimilates them into various entities.

In light of the increasing significance of such a new R&D model that may avoid the dilemma between R&D expansion and productivity decline, this paper elucidated dynamism enabling dual couplings.

An empirical analysis of global forest-based bioeconomy firms was conducted, thereby providing an insightful suggestion with respect to dynamism emerging from a new R&D model.

KEYWORDS

Co-evolutionary coupling, digitalized bioeconomy, R&D model, circular economy, UPM,

1. INTRODUCTION

Driven by digital solutions, the bioeconomy is taking major steps forward in recent years toward achievement of the long-lasting goal of transition from a traditional fossil economy to a bioeconomy-based circular economy [1].

Almost 50 years have passed since the similar goal was proposed in Japan amidst an industrial society in the early 1970s with the world highest economic growth. Highly material-intensive and energy-intensive industries resulted in serious environmental problems which led to reexamination of industrial policy [2]. Recognizing the need for a change in direction, Japan formulated a new plan for its industrial development by proposing a shift to a knowledge-intensive industrial structure, which would place a lesser burden on the environment by depending less on energy and materials while depending more on technology [3].

In order to identify the basic concept of the required industrial structure, Japan's MITI (Ministry of International Trade and Industry) depended on the concept of industry-ecology as a comprehensive method for analyzing and evaluating the complex mutual relationship between human activities and its surrounding environment [4, 5]. Industry-ecology inspired to recognize the following five basic principles for constructing a circular economy-oriented platform [6]: (i)

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System boundaries, (ii) Relationships in the system, (iii) Redundancy in the system, (iv) Dose-response relationships in the system, and (v) The need for self-control.

While the forest-based bioeconomy incorporates the potential broad cross-sectoral benefits with sophisticated function satisfying all these principles, the natural environment, locality constraints, and incessant challenge of distance have impeded the balanced development of this economy [7, 8, 9, 10].

However, driven by digital solutions, the bioeconomy has taken big steps forward in recent years. Digitalization has enabled real-time, end-to-end supply chain visibility, improved delivery accuracy as well as stock level optimization and alignment with demand planning.

Supported by the advanced digital innovation such as artificial intelligence (AI), machine learning, virtual reality (VR), augmented reality (AR), and big data analysis, the coupling of digitalization and bioeconomy is leading towards 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 [11, 12, 13]. This dual coupling enables VR and AR to practical business.

Thus, the co-evolution of the coupling of digitalization and bioeconomy and of upstream and downstream operations is transforming the forest-based bioeconomy into a digital platform industry, which accomplishes the required basic principles postulated half a century ago in reality, and explores a new four-dimensional sphere beyond the existing concept of the digital innovation.
To date, while many studies analyzed the systems nature of the forest-based bioeconomy [10, 14, 15, 16, 17, 18], none has undertaken the empirical analysis with a view to demonstrate the above co-evolutionary coupling.

This paper aimed at conceptualizing the above new four dimensional sphere. By means of stepwise empirical analyses taking 50 global forest-based bioeconomy leaders, elucidation of a unique feature of the co-evolutionary coupling toward circular economy was attempted.
An insightful suggestion supportive to constructing disruptive business model in the digital economy [19, 20] was thus provided.

Organization of this paper is as follows: Section 2 over reviews global new streams of the digitalized bioeconomy. Market value of the digitalized bioeconomy is examined in Section 3. Section 4 analyzes co-evolutionary coupling. Section 5 summarizes the noteworthy findings, policy suggestions, and future research.

2. Digitalized Bioeconomy – Global New Streams

Given a transformative endeavor of the digitalized bioeconomy identical to geopolitical regions, leading challenges in the region were identified first from both growth potential and business prospects.

2.1. Development Trajectory of Global Bioeconomy Firms

In line with the advancement of the digital economy, global bioeconomy firms have been endeavoring digital solutions, which inevitably urges them *R&D-driven income-seeking* strategy as illustrated in **Fig. 1**. Fig. 1 illustrates *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 the **Appendix**).

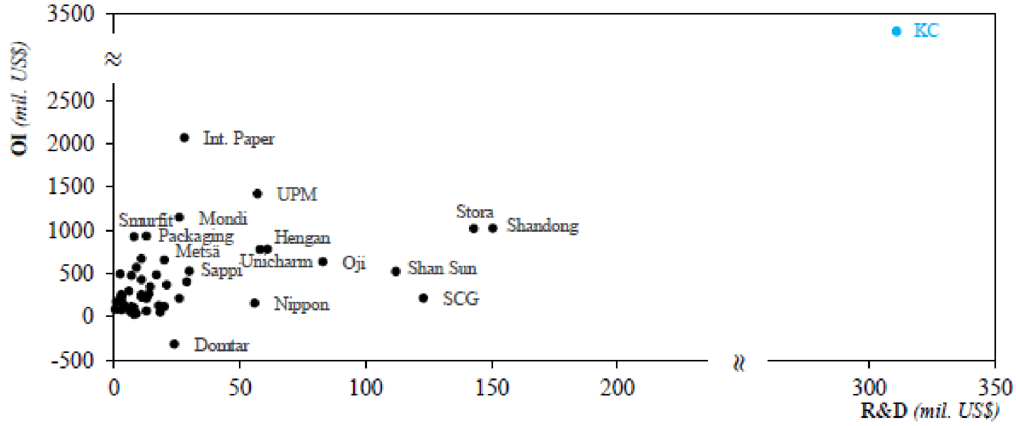

Figure 1. R&D-driven *OI*-seeking trajectory in 50 global bioeconomy firms (2017).

Given that R&D increase depends on revenues (sales) increase, this strategy leads these firms to R&D and sales-driven income (operating income) seeking trajectory (*R-S-driven OI-seeking trajectory*)[1].

Table 1 analyzed this trajectory in 50 global bioeconomy firms in 2017 by applying their *OI* increasing trajectory to *R-S*-driven logistic growth function.

Table 1. Development trajectory of operating income in 50 global bioeconomy firms in 2017.

$$OI = \frac{N}{1+be^{-a_1R-a_2S}} + cD$$

N	a_1	a_2	b	c	$adj.\ R^2$	D
6360.86	0.004	0.0001	29.02	-729.68	0.828	Domtar
(1.39)*	(2.39)	(5.46)	(5.35)	(-2.85)		

OI: operating income; *N*: carrying capacity; *R*: R&D expenditure; *S*: sales; *D*: dummy variable; *a1*, *a2*, *b* and *c*: coefficients.

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

Table 1 demonstrates statistically significant 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 other 49 firms, in the regression analysis.

[1] 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 + one-time extraordinary income – one-time extraordinary expenses – taxes

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, **Table 2** identifies 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.

Table 2. Top 20 prospecting global bioeconomy firms in 2017.

SI rank	Firm	Country	*SI* value	OI	Sales	R&D	OI/S	R/S	OI/R	OI rank	Sales rank	R&D rank	OI/S rank	R/S rank	OI/R rank
1	KC	US	3.07	3299	18259	311	0.18	0.017	10.61	1	2	1	3	4	13
2	Int. Paper	US	2.29	2069	21743	28	0.10	0.001	73.89	2	1	11	11	19	2
3	Stora	Finland	1.70	1019	11325	143	0.09	0.013	7.13	6	4	3	13	5	16
4	Oji	Japan	1.62	633	12838	83	0.05	0.006	7.63	11	3	6	16	7	14
5	UPM	Finland	1.36	1419	11285	57	0.13	0.005	24.89	3	5	8	7	10	8
6	Nippon	Japan	1.16	157	9330	56	0.02	0.006	2.80	19	8	9	19	8	18
7	Sumitomo	Japan	1.06	481	9926	17	0.05	0.002	28.29	15	6	16	17	17	7
8	Shandong	China	1.04	1023	4417	151	0.23	0.034	6.80	5	18	2	1	3	15
9	Smurfit	Ireland	1.00	924	9653	8	0.10	0.001	115.50	8	7	20	10	20	1
10	Mondi	UK	0.90	1148	8000	26	0.14	0.003	44.15	4	9	12	5	14	5
11	Unicharm	Japan	0.80	774	5721	58	0.14	0.010	13.34	9	12	7	6	6	12
12	SCG	Thailand	0.74	212	2517	123	0.08	0.049	1.72	17	20	4	14	1	19
13	Shan Sun	China	0.73	523	2796	112	0.19	0.040	4.67	14	19	5	2	2	17
14	Packaging	US	0.70	931	6445	13	0.14	0.002	71.62	7	10	17	4	16	3
15	DS	UK	0.65	570	6153	9	0.09	0.001	63.33	12	11	19	12	18	4
16	Sappi	S. Africa	0.65	526	5296	30	0.10	0.006	17.53	13	14	10	9	9	9
17	Metsä	Finland	0.65	655	5682	20	0.12	0.004	32.75	10	13	15	8	13	6
18	Domtar	Canada	0.61	-317	5157	24	-0.06	0.005	-13.21	20	15	13	20	11	20
19	Sonoco	US	0.59	367	5037	21	0.07	0.004	17.48	16	16	14	15	12	10
20	Rengo	Japan	0.54	211	4863	13	0.04	0.003	16.23	18	17	18	18	15	11

SI: Synchronized index; *SI* value = $a_1 R + a_2 S = 0.004 R + 0.0001S$ See the full name of the firm in Table A1 in the Appendix.

2.2. Leading Bioeconomy Firms in Geopolitical Region

Given the geopolitical significance of bioeconomy firms in the digital economy, Table 3 classified top 20 prospecting firms into 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 compares market capitalization which represents business prospects [21] between the top two *SI* value firms in each respective region over the last 5 years.

Table 3. Geopolitical distribution of prospecting bioeconomy firms in 2017.

Region	Firms (*SI* value, numbers indicate *SI* rank among 20 firms)	Market capitalization (mil. US$, 2010 fixed prices)				
		2013	2014	2015	2016	2017
America	1. KC (3.07)	**35219**	**38692**	**35447**	**44884**	**40695**
	2. Int. Paper (2.29)	18534	20226	19309	15714	20747
	14. Packaging (0.70), 18. Domtar (0.61), 19. Sonoco (0.59)					
Europe	3. Stora (1.70)	7058	7069	6539	7908	10294
	5. UPM (1.36)	**7966**	**8749**	**9082**	**12180**	**13648**
	9. Smurfit (1.00), 10. Mondi (0.90), 15. DS (0.65), 17. Metsä (0.65)					
Asia	4. Oji (1.62)	**3609**	**4351**	**4029**	**4059**	**4552**
	6. Nippon (1.16)	1783	2147	1712	2107	2045
	7. Sumitomo (1.06), 8. Shandong (1.04), 11. Unicharm (0.80), 12. SCG (0.74), 13. Shan Sun (0.73), 20. Rengo (0.54)					
Africa	16. Sappi (0.65)	**1106**	**1611**	**1165**	**1982**	**2441**

Based on the comparison both by growth potential and business prospects using *SI* values and market capitalization between top 2 *SI* value firms in the region, following 4 firms with higher market capitalization were chosen that represent prospecting firms in each respective region both growth potential and business prospects as summarized in **Table 4**.

Table 4. Leading prospecting bioeconomy firms in the 4 regions in 2017.

Firm	Country	*SI* value	OI	Sales	R&D	OI/S	R/S	OI/R	Business type / segments
KC	US	3.07	3299	18259	311	0.18	0.017	10.61	**Personal care** (disposable diapers, training and youth pants, swimpants, 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.)
UPM	Finland	1.36	1419	11285	57	0.13	0.005	24.89	**Forest-based bio products** (biochemicals, biocompo -sites, biofuels, energy, labels, pulp and paper, plywood and timber). Acquisition of Myllykoski and Rhein Papier in 2010 accelerated the transformation into 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.
Oji	Japan	1.62	633	12838	83	0.05	0.006	7.63	**Household and industrial materials** (packaging materials and products, household papers, disposable diapers) **Functional materials** (speciality papers, thermal papers, adhesive products) **Forest resources** (pulp, power generation, lumber processing) **Printing and communication** (newsprint, printing and publication paper, copying paper)
Sappi	South Africa	0.65	526	5296	30	0.10	0.006	17.53	**Forest-based bio products** (printing paper, packaging and speciality papers, casting and release paper, dissolving wood pulp, biomaterials, bioenergy)

3. MARKET VALUE OF DIGITALIZED BIOECONOMY

3.1. MARKET CAPITALIZATION

Aiming at measuring the potential and prospects of market value of 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 [21].
Fig. 2 illustrates trend in MC (in logarithmic scale) in the 4 firms representing the 4 geopolitical regions. Fig. 2 demonstrates KC's highest level followed by UPM, Oji and Sappi.

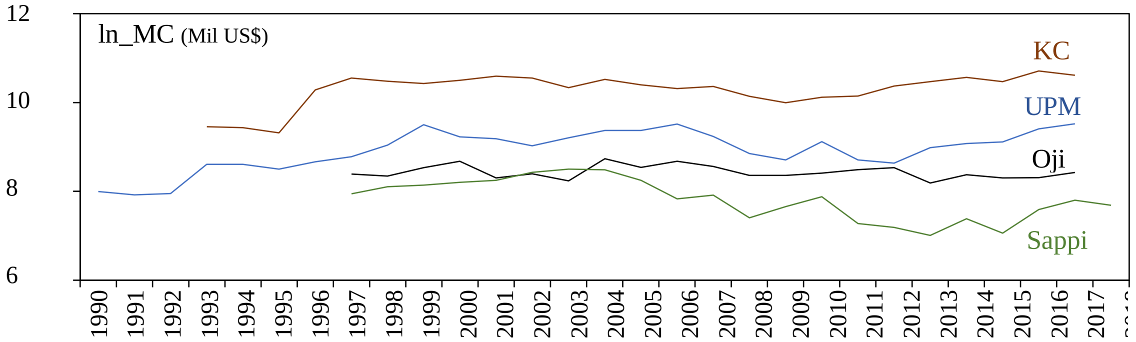

Figure 2. Trend in MC in the 4 firms in logarithmic scale.

However, if we compare the recent growth rate, we note UPM's conspicuously high growth rate over the last 5 years as demonstrated in **Figs. 3** and **4**.

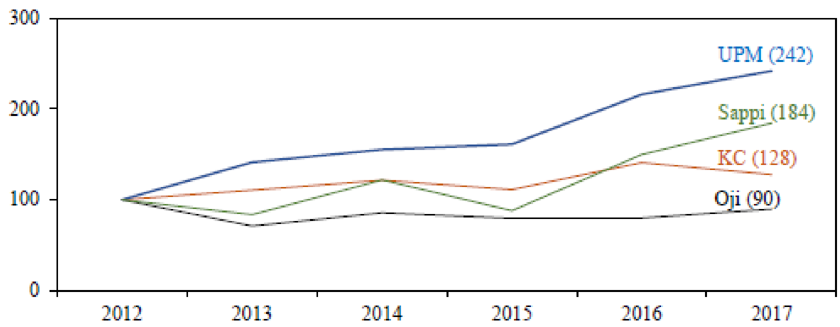

Figure 3. Trend in increase ratio of MC in the 4 firms (2012-2017) – Index: 2012 = 100.

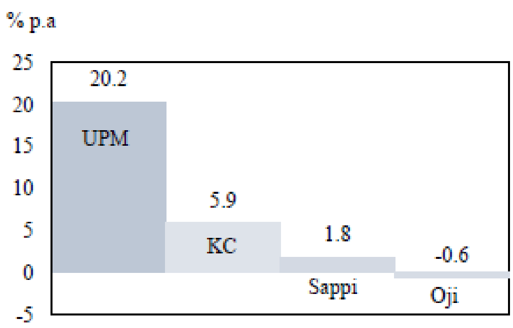

Figure 4. Average growth rate of MC in the 4 firms (2013-2017).

3.2. PRICE-TO-SALES RATIO

While MC represents the value of business prospects, it depends not only on qualitative value of the 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 (PSR) is used. PSR is a ratio of firm's market capitalization and its sales (MC/S), thereby used as an indicator of the value placed on firm's sales. PSR is also known as a sales multiple. Contrary to enterprise value-to-sales ratio (EVSR), it is supportive to make a comparative prospects assessment of firm's business model.

Figs 5 and **6** demonstrate clear contrast between UPM's rapid increase and KC's decline in PSR.

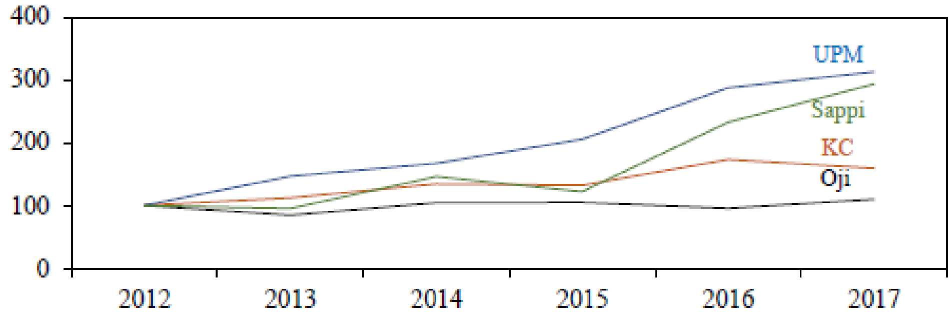

Figure 5. Trend in increase ratio of PSR in the 4 firms (2012-2017) – Index: 2012 = 100.

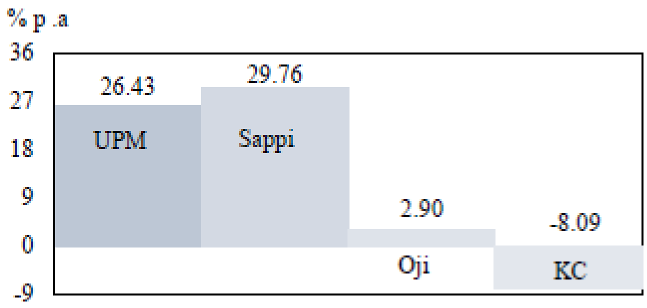

Figure 6. Average growth rate of PSR in the 4 firms (2013-2017).

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 to sustainable growth of MC and also of PSR.

3.3.1. Indigenous Efforts

In conducting a comparative prospects assessment of firm's business model, following indigenous efforts should be taken for governing factors decisive to MC [21]:

(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 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 rewarding to shareholders by providing dividend, 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 term. 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 also a risk of failure, R&D challenge without investors' confidence results in the MC decreases [22, 23].

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 the coupling effects with the downstream environments [24].

(1) External Market Conditions

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 stemmed from political circumstances change.
(iii) Natural and man-made disasters with economic consequences.

2) Local Market Conditions

Irregular happening identical to the firm such as changes in business, administration system, acquisition, and geo-political changes identical to the firm.

(2) Coupling Effects with Downstream Firms

Coupling effects with downstream environments cannot be overlooked as a consequence of the economy with value chain structure. In line with the advancement of the digital economy and subsequent increasing dependence on digital solution, these effects have been significantly increasing [10].

3.4. Institutional Structure Governing Leading Forest-Based Bioeconomy Firms

Following the above review, MC for leading forest-based bioeconomy firms can be depicted as follows:

$$MC = F(S, OI, R, Ex, CE) \quad (1)$$

where *S*: sales; *RD*: 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 to provide significant impacts on MC, and *S* can be treated as a dependent variable of *OI* and *R* in these impacts in leading forest-based bioeconomy firms. Therefore, equation (1) can be transformed into equation (2) as follows:

$$MC = F(OI, R, Ex, CE) \quad (2)$$

Translog (transcendental logarithmic) expansion on the first term:

$$\ln MC = a + b \ln OI + c \ln R + d \ln Ex + e \ln CE + f D \quad (3)$$

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

Utilizing equation (3), governing factors of MC in the 4 firms were analyzed as summarized in **Table 5.**

Table 5. Factors governing MC in the 4 firms.

$$\ln MC = a + b \ln OI + c \ln R + d \ln Ex + e \ln CE + f_1 D_1 + f_2 D_2$$

	Const.	*OI*		*R&D*		*Ex*		Coupling effect		Dummy variables				Dummy period	
	a	b_1	b_2	c_1	c_2	d_1	d_2	e_1	e_2	f_1	f_2	$adj.R^2$	DW	D_1	D_2
KC (America) (1995-2017)		*-2008*	*2009-*	*-2008*	*2009-*			*-2008*	*2009-*						
	2.35 (1.85)*2	0.44 (11.34)	-	0.80 (3.40)	0.50 (2.23)*1	-		-	0.28 (7.46)	0.29 (6.33)	-0.21 (-2.50)	0.922	2.53	1997, 1998 2014, 2015	2008
UPM (Europe) (1990-2017)								*-2010*	*2011-*						
	1.44 (1.59)*2	0.18 (5.11)		1.07 (3.84)		0.23 (1.57)*2		0.19 (3.73)	0.12 (2.77)	-0.57 (-5.82)		0.871	2.09	2009, 2010 Acquisition of MRP 2011 (before changing 2012 business model)	
Oji (Asia) (1999-2017)		*-2007*	*2008-*					*-2007*	*2008-*						
	5.37 (11.16)	-	0.04 (2.91)	0.60 (5.69)		-		0.10 (4.49)	-	0.20 (7.54)	-0.25 (-7.42)	0.920	2.47	2000, 2004 2006, 2017	2003 2013
Sappi (Africa) (1997-2018)		*-2007*	*2008-*	*-2007*	*2008-*	*-2007*	*2008-*	*-2007*	*2008-*						
	14.67 (10.20)	-0.12 (-1.99)*1	0.30 (2.98)	-1.60 (-4.22)	-	-	-1.60 (-6.04)	-	0.55 (5.58)	-0.58 (-4.97)		0.898	1.52	2006, 2015	

Coupling effect: correlation with Amazon's (downstream leader) stock price [10].

The figures in parentheses indicate *t*-statistics: all are significant at the 1% level except *1: 5%, and *2 : 10% level. Backward elimination method with 10% significant criteria was used.

Table 5 demonstrates the following notable features in the 4 firms (figures in the parentheses indicate elasticity):

(1) **KC:** (i) R&D constantly induced MC (0.80, 0.50), (ii) *OI* inducement by 2008 (0.44) substituted to coupling effect after 2009 (0.28).

(2) **UPM:** (i) R&D constantly induced MC strongly (1.07), (ii) *OI* constantly induced MC (0.18), (iii) Depended on coupling effect significantly (0.19, 0.12), (iv) External market conditions induced MC constantly (0.23).

(3) **Oji:** (i) R&D constantly induced MC (0.60), (ii) Inducement of coupling effect by 2007 (0.10) substituted to *OI* after 2008 (0.04).

(4) **Sappi:** (i) *OI* and coupling effect changed to positive inducement of MC after 2008 (0.3

and 0.55), (ii) *OI* and R&D reacted negative inducement by 2007 (-0.12 and -1.60) demonstrating failing to gain confidence from investors.

Among 4 firms, it is noted that UPM demonstrates sophisticated R&D-driven virtuous cycle utilizing all resources including coupling with downstream and also external market inducement [25]. This led to its conspicuous performance as extremely higher MC/R after 2011, after the transition into circular-economy-based business model [26, 27], as demonstrated in **Fig. 7**.

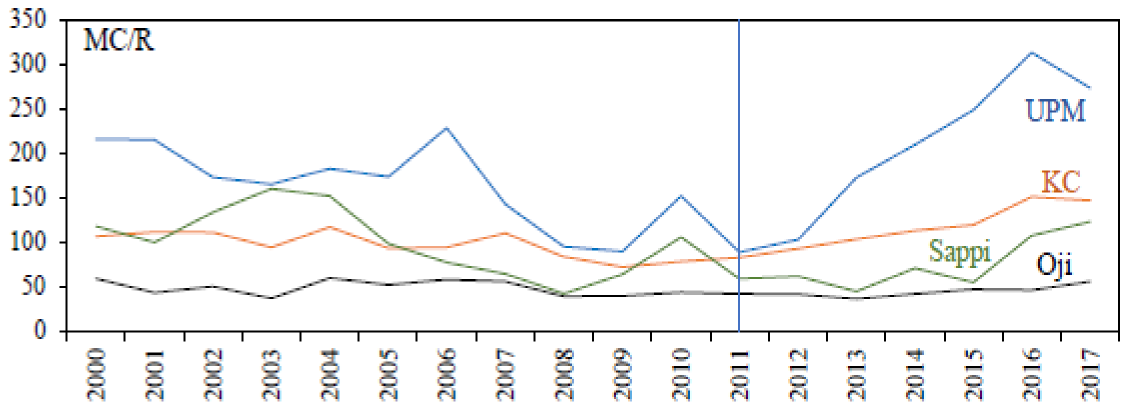

Figure 7. Trends in MC/R in the 4 firms (2000-2017).

3.5. Sophisticated R&D-Driven Co-Evolution Initiated By UPM

The above comparative analysis highlights a sophisticated R&D-driven co-evolutional cycles utilizing external resources (downstream and external market) that UPM may incorporate as follows:

(1) Sophisticated R&D system in inducing MC

(i) Highest R&D elasticity

UPM: 1.07; KC: 0.80 ~ 0.60; Oji: 0.60; Sappi: negative

(ii) Maintains conspicuously high marginal productivity of R&D to MC (MPRMC) as demonstrated in **Fig. 8**.

$$\text{Elasticity of R\&D to MC} \qquad \varepsilon_{MCR} = \quad C = \frac{\partial \ln MC}{\partial \ln R}$$

$$\text{MPRMC} = \frac{\partial \ MC}{\partial \ R} = \quad C * \frac{MC}{R} = \frac{p_R}{p_{MC}} \qquad (4)$$

where *pR*: R&D price; *pMC*: Stock price

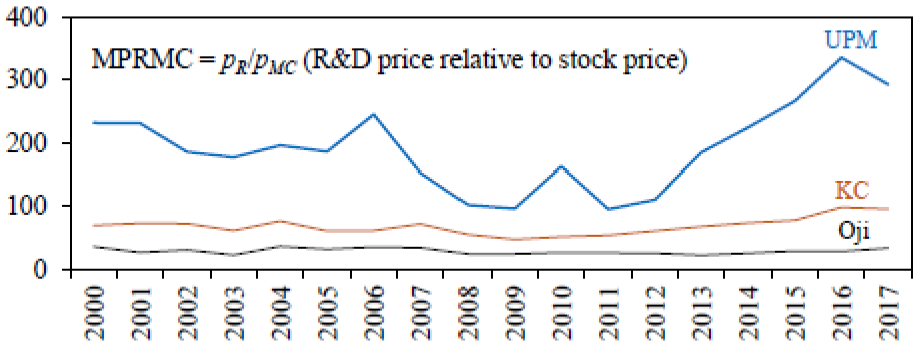

Figure 8. Trend in marginal productivity of R&D to MC in the 3 firms (2000-2017).

(iii) Such high level of MPRMC induces PSR (MC/S) strongly as demonstrated in Table 6.

Table 6. Correlation between MPRMC and PSR in UPM (1990-2017)

$$\ln \frac{MC}{S} = \underset{(-18.06)}{-6.00} + \underset{(16.91)}{1.10} \ln MRPMC + \underset{(3.42)}{0.33} D_1 - \underset{(-1.81)^*}{0.23} D_2 \qquad adj.\ R^2 = 0.915 \quad DW = 1.26$$

D: dummy variables (D_1: 2008, 2009 = 1, others = 0; D_2: 2014 = 1, others = 0)

The figures in parentheses indicate t-statistics: all are significant at the 1% level except *10% level.

Such an R&D-driven MC and PSR (MC/S) inducing dynamism beyond the dilemma between R&D expansion and productivity decline prompts us an effective utilization of external resources for innovation and also self-propagating new market value creation as growth proceeds.

(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 resources in downstream and external market

Downstream advancement and external market stimulation steadily contribute to MC.

These inducement prompts a co-evolutionary coupling in activating the above function. This can be attributed largely to UPM's new circular economy-seeking R&D challenge [1, 25, 26, 27, 28] as highlighted in **Table 7** by comparing with other global bioeconomy leaders.

Table 7. Major R&D focus in the 4 firms.

KC	Kimberly Clark R&D activities include researching materials and technology innovations to deploy more circular business model. KC emphases on the zero-waste mindset across the value chain and adopt the circular design principles to keep the post-consumer waste out of landfills. In addition, they reduce and eliminate the materials of concerns to ensure the safety and well-being of their customers.

UPM	Eco-design approach is at core of R&D efforts in the development of new technologies and products. UPM invests on the bioeconomy innovations, forest biodiversity and circular economy to create the sustainable solutions by minimizing the dependency on fossil-based materials. UPM collaborates with customers, research institutions, universities and technology providers to develop the creative circular economy solutions and user-friendly digital tools and services.
Oji	Oji aims to develop the new possibilities, skills and high-tech materials in paper and forest sector. They are devoting their R&D efforts in developing cellulose fibres as it 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.
Sappi	Sappi's R&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 the sustainable solutions for the company. Sappi follows the partnership approach and develop the 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.

4. CO-EVOLUTIONARY COUPLING

4.1. SOURCES ENABLING UPM'S HIGH PERFORMANCE IN MC CREATION

Analysis in the preceding section suggests that UPM's notable high performance in MC creation can be attributed to its balanced contributing structure by R&D, *OI*, coupling effect with downstream and also external market conditions as illustrated in **Fig. 9.**

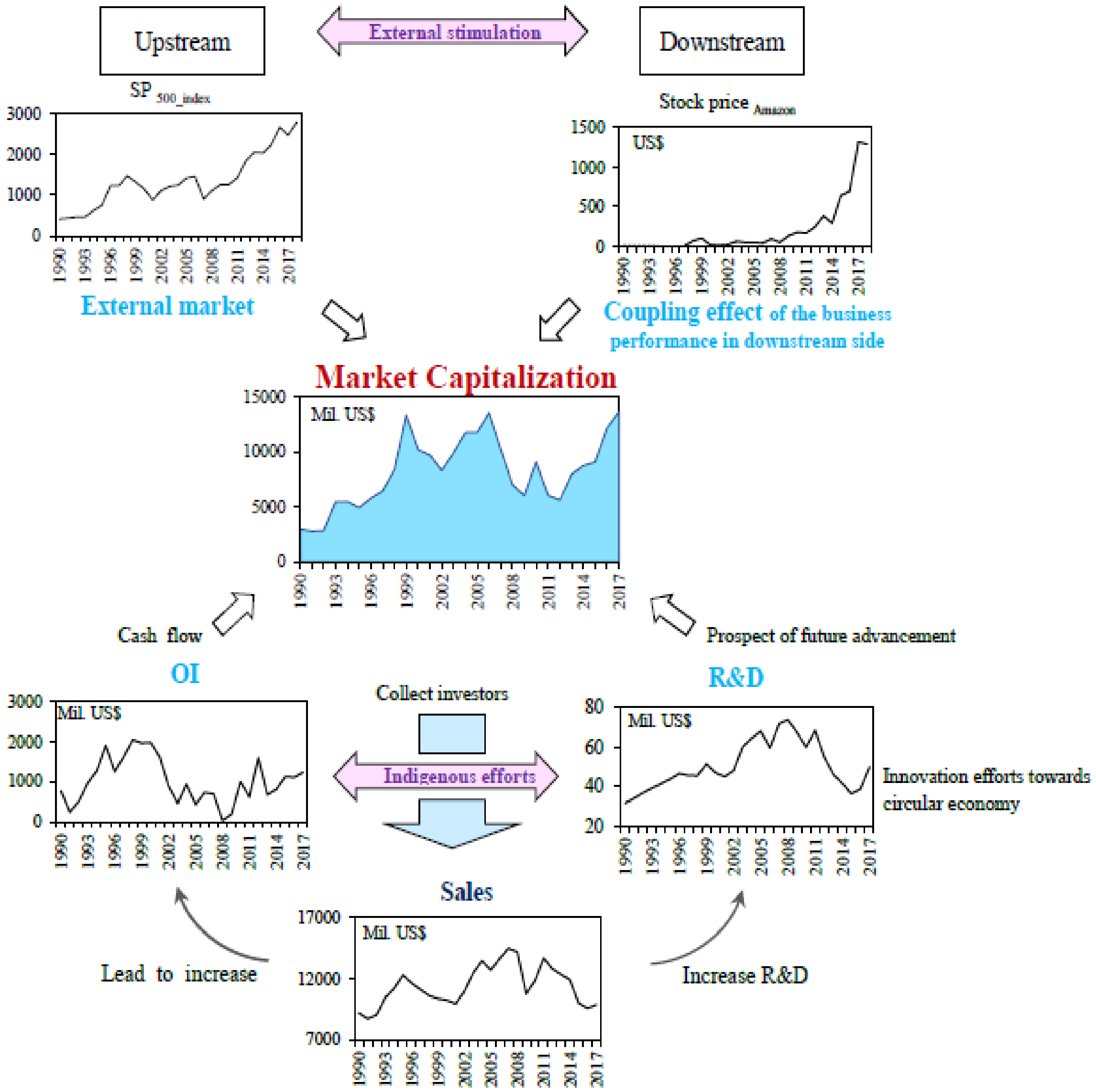

Figure 9. Co-evolutionary development of MC in UPM (1990-2017).

While Tables 5 and 6 demonstrate that R&D and its price increase induce MC and PSR (MC/S) significantly, **Tables 8** and **9** demonstrate that induced MC induces sales and PSR. In addition, induced sales induce R&D, thus R&D-driven virtuous cycle among them has been constructed.

Table 8. Correlation between MC and sales in UPM (1990-2017)

$$\ln S = 7.85 + 0.16D_1 \ln MC + 0.15D_2 \ln MC + 0.264D_3 \quad adj.\ R^2 = 0.652$$
$$(24.13)\ (4.48)\qquad (4.15)\qquad (6.51) \quad DW = 1.07$$

D: dummy variables (D_1: 1990-2010 = 1, others = 0; D_2: 2011-2017 = 1, others = 0;
D_3: 1995, 2007, 2008, 2011, 2012, 2013, 2014 = 1, others = 0)

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

This regression suggests $\ln \frac{MC}{S} \approx -7.85 + 0.85 \ln MC$

Table 9. Correlation between sales and R&D in UPM (1990-2017).

$$\ln R = -9.62 + 1.45 \ln S + 0.38 D_1 - 0.25 D_2 \qquad adj.\ R^2 = 0.799$$
$$(-7.04)\ (9.90)\qquad (3.54)\quad (-3.12) \qquad DW = 1.41$$

D: dummy variables (D_1: 2009 = 1, others = 0; D_2: 1995, 2014 = 1, others = 0)

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

4.2. Assimilation of External Innovation Resources

Such an R&D-driven virtuous cycle notwithstanding the dilemma between R&D expansion and productivity decline [29, 30] suggests a significant role that assimilated external resources in innovation, particularly soft innovation resources, may play. Prompted by such a hypothetical view, assimilation capacity and subsequent assimilated soft innovation resources were analyzed.

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

$$\ln MC = a + b \ln OI + c \ln RD + d \ln Ex + e \ln CE + fD \tag{3}$$

Here, gross R&D incorporates both indigenous R&D (R_i) and assimilated soft innovation resources (*SIRs*) as follows where *z* is assimilation capacity.

$$RD = R_i + zSIRs = R_i\left(1 + z\frac{SIRs}{R_i}\right) \qquad z\frac{SIRs}{R_i} \ll 1$$
$$\therefore \ln RD = \ln R_i\left(1 + z\frac{SIRs}{R_i}\right) \approx \ln R_i + z\frac{SIRs}{R_i} \tag{5}$$

Where *SIRs* can be represented by *ID* (Internet dependence) as *SIRs* can be considered a condensate and crystal of the advancement of the Internet [29, 30].

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

$$\ln MC = a + b \ln OI + c \ln R_i + c'\frac{ID}{R_i} + d \ln Ex + e \ln CE + fD \tag{6}$$

where $c' = cz$. Therefore, assimilation capacity *z* can be identified as follows:

$$z = \frac{c'}{c} \tag{7}$$

Utilizing equation (6), governing factors of UPM's MC taking assimilated innovation resources over the period from 1990-2017 was analyzed as demonstrated in **Table 10.**

Table 10. Governing factors of UPM's MC taking assimilated external innovation resources (1990-2017).

$$adj.\ R^2 = 0.923 \quad DW = 2.47$$
$$\ln MC = 2.02 + 0.19 \ln OI + 0.74 D_1 \ln R_i + 0.42 D_2 \ln R_i + 0.22 \frac{ID}{R_i} + 0.32 \ln Ex + 0.12 D_1 \ln CE + 0.22 D_2 \ln CE - 0.48 D_3 + 0.33 D_4$$
$$(2.42)^*\ (4.89)\quad (3.39)\quad (2.55)\quad (2.13)^*\quad (2.41)^*\quad (2.58)\quad (2.71)\quad (-5.29)\quad (3.07)$$

D: dummy variables (D_1: 1990-2010 = 1, others = 0; D_2: 2011-2017 = 1, others = 0; D_3: 2009, 2010, 2012 = 1, others = 0; D_4: 1993, 2001= 1, others = 0)

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

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

Assimilation capacity in UPM.

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

4.3 Effect of Co-Evolutionary Coupling with Downstream

Tables 10 and 11 suggest a possible casualty between increase in assimilation capacity and effect of downstream in inducing UPM's MC as illustrated in **Fig. 10**.

	1990-2010	2011-2017
Assimilation capacity	0.30	0.52
Downstream inducement effect	0.12	0.22

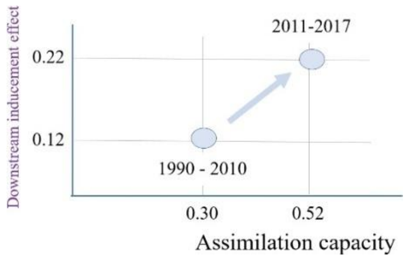

Figure 10. Correlation between assimilation capacity and downstream inducement effect in UPM.

This suggests co-evolutionary coupling with downstream. This can be demonstrated by the significant impact of downstream on UPM's R&D price (price of gross R&D) increase as follows: Under the competitive circumstances where UPM seeks profit maximum, R&D price p_R can be depicted as follows:

$$p_R = MPRMC * p_{MC} \qquad (8)$$

This price increased dramatically after transforming into circular economy-based business model in 2011 as demonstrated in **Fig. 11.**

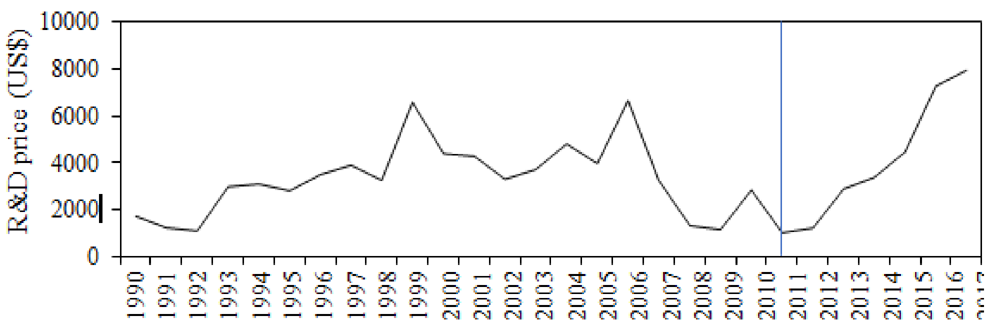

Figure 11. Trend in UPM's gross R&D price (1990 – 2017).

Fig. 12 and **Table 12** analyze correlation between coupling effect and price of UPM's gross R&D which demonstrate that coupling effect induced the price increase significantly after 2011.

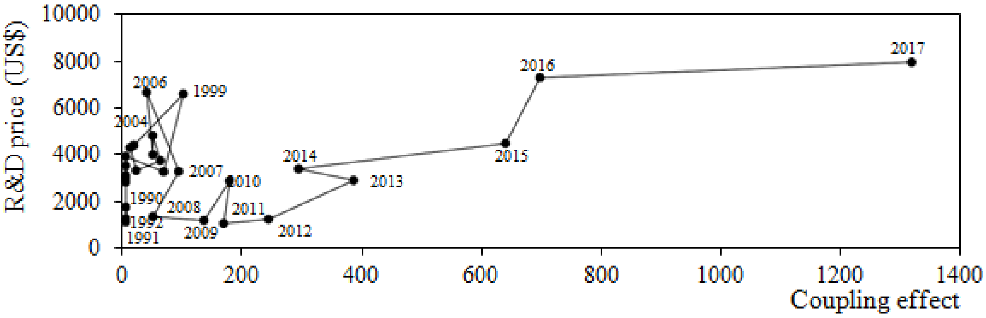

Figure 12. Correlation between coupling effect and R&D price in UPM (1990-2017).

Table 12. Correlation between coupling effect and R&D price in UPM (1990-2017).

adj. $R^2 = 0.896$ $DW = 2.42$

$$\underset{}{\ln P_R} = \underset{(2.47)}{1.37} + \underset{(3.06)}{0.22} D_1 \ln CE + \underset{(11.89)}{1.07} D_2 \ln CE + \underset{(9.72)}{0.91} D_3 \ln Ex + \underset{(9.13)}{0.87} D_4 \ln Ex + \underset{(7.37)}{0.75} D_5 \ln Ex + \underset{(5.80)}{0.58} D_6 - \underset{(-4.48)}{0.75} D_7$$

D: dummy variables (D_1:1990-2010 = 1, others = 0; D_2: 2011-2017 = 1, others = 0; D_3: 1990-2001 = 1, others = 0; D_4: 2002-2006 = 1, others = 0; D_5: 2007-2010 = 1, others = 0; D_6: 1993, 1994, 2007, 2014, 2016 = 1, others = 0; D_7: 1998, 2009 = 1, others = 0)

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

Backward elimination method with 5% criteria was used.

Such increase in UPM's gross R&D price can be attributed to effective utilization of assimilated *SIRs*. **Table 13** demonstrates that coupling effect induced assimilated *SIRs* significantly.

Table 13. Correlation between coupling effect and assimilated *SIRs* in UPM (1990-2017).

$$\ln zSIR_S = \underset{(2.65)}{1.24} + \underset{(3.14)}{0.39} D_1 \ln CE + \underset{(5.07)}{0.42} D_2 \ln CE - \underset{(-7.75)}{2.67} D_3$$

adj. $R^2 = 0.893$ $DW = 1.01$

D: dummy variables (D_1: 1990-2010 = 1, others = 0; D_2: 2011-2017 = 1, others = 0; D_3: 1990, 1991, 1992, 1993, 1994 = 1, others = 0)

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

Fig. 13 and **Table 14** analyze correlation between PSR and coupling effect in UPM which demonstrates significant correlation after 2011. Advanced PSR activates coupling effect in the downstream, thereby co-evolutionary coupling between up-down stream emerged after 2011 when UPM moved toward a circular economy.

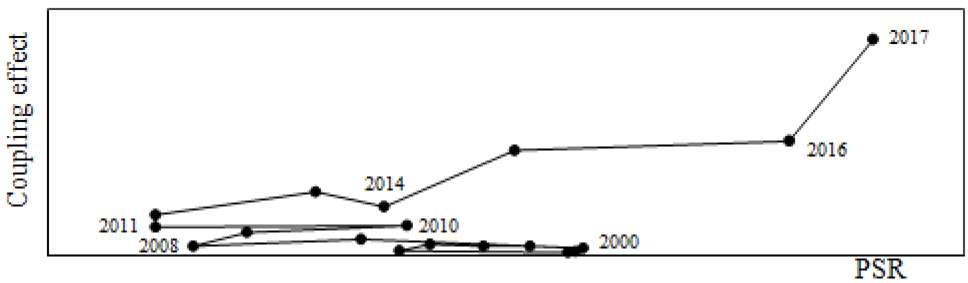

Figure 13. Correlation between PSR and coupling effect in UPM (2000-2017).

Table 14. Correlation between PSR and coupling effect in UPM (2000-2017)

$adj.\ R^2 = 0.806 \quad DW = 2.33$

$$\ln CE = 6.27 - 0.09D_{11} \ln PSR + 0.02D_{12} \ln PSR + 1.23D_2 \ln PSR - 2.63D_3$$
$$(26.21)\ (-6.00) \qquad (4.48) \qquad (2.47) \qquad (-7.36)$$

D: dummy variables (D_{11}: 2000-2006 = 1, others = 0; $D1_2$: 2007-2010 = 1, others = 0; D_2: 2011-2017 = 1, others = 0; D_3: 2000, 2001, 2005, 2006 = 1, others = 0)

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

On the basis of the foregoing analyses, **Fig. 14** demonstrates co-evolutionary coupling that UPM demonstrated. R&D induced MC, which induced sales and PSR. Increased sales induced R&D, which, together with assimilated *SIRs* increased R&D price leading to PSR increase. Increased PSR activated coupling effect in the downstream, which increased R&D price.

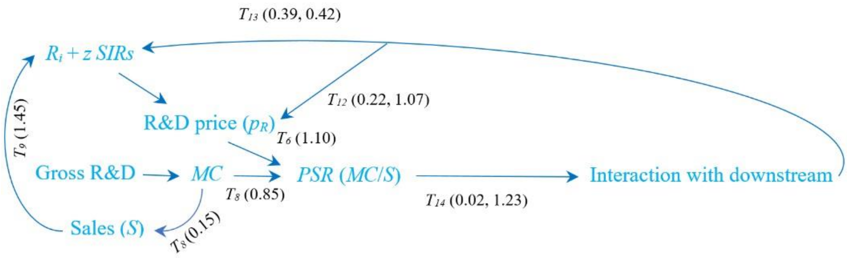

Figure 14. Co-evolutionary coupling in UPM (1990-2017).

T_n means Table number, and figures indicate elasticity (1990-2010 and 2011-2017, or 1990-2017).

5. CONCLUSION

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 towards 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 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 between R&D expansion and productivity decline, this paper elucidated a dynamism enabling such a dual coupling.

An empirical analysis of leading global forest-based bioeconomy firms was conducted with special attention to the relevance of geopolitical regions fatal to foot-tight nature of the forest-based-bioeconomy.
It was identified that in line with the advancement of the digital economy, bioeconomy firms have been amidst transforming endeavors in the global new stream, which inevitably identify leaders of geopolitical regions by respective growth potential and business prospects.

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

Among four leaders, UPM demonstrates a sophisticated R&D-driven co-evolutional cycles utilizing external resources both downstream and external market with (i) Sophisticated R&D system in inducing MC, (ii) Well balanced resources allocation to MC creation, and (iii) Effective utilization of external resources in downstream and external market. This can be attributed to its balanced contribution structure by R&D, *OI*, coupling effect with downstream and also external market conditions. With this structure, UPM's R&D induces MC, which in turn induces sales and PSR. Increased sales induce R&D, which, together with assimilated *SIRs* increases its price leading to PSR increase. Increased PSR activated coupling effect in the downstream, which in turn increases R&D price. Thus, co-evolutionary coupling of digitalization and the bioeconomy, and also of up-down stream operation in the value chain have been created.

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) Dual co-evolutional coupling should be applied to disruptive business model aiming at overcoming the dilemma between R&D expansion and productivity decline.
(ii) Dynamism enabling co-evolutionary coupling with the vigor of downstream should be elucidated and conceptualized.
(iii) New four-dimensional sphere beyond the existing concept of the digital innovation should be applied in the platform ecosystem.
(iv) Co-evolutional innovation among digital innovation, paradigm change and shift in people's preferences should be further elaborated by taking dual co-evolutional coupling concept.

Future work should focus on further elucidation, conceptualization and operationalization of the functions that the dual co-evolutional coupling play similar role of artificial intelligence (AI), machine learning, virtual reality (VR), and augmented reality (AR)

ACKNOWLEDGEMENTS

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APPENDIX BASIC STATISTICS FOR THE ANALYSIS

Table A1. Top 50 global forest-based bioeconomy firms in 2017 (by OI order).

Firm Name	**Short Name**	**Country**	**OI**	**Sales**	**R&D**	**OI/S**	**R/S**	**OI/R**
Kimberly-Clark	KC	US	3299	18259	311	0.18	0.017	10.61
International Paper	Int. Paper	US	2069	21743	28	0.10	0.001	73.89
UPM-Kymmene	UPM	Finland	1419	11285	57	0.13	0.005	24.89
Mondi Group	Mondi	UK	1148	8000	26	0.14	0.003	44.15
Shandong Chenming	Shandong	China	1023	4417	151	0.23	0.034	6.80
Stora Enso	Stora	Finland	1019	11325	143	0.09	0.013	7.13
Packaging Corp of America	Packaging	US	931	6445	13	0.14	0.002	71.62
Smurfit Kappa	Smurfit	Ireland	924	9653	8	0.10	0.001	115.50
Hengan International	Hengan	Hong Kong	780	2933	61	0.27	0.021	12.79
Unicharm	Unicharm	Japan	774	5721	58	0.14	0.010	13.34
West Fraser Timber	WFT	Canada	670	3955	11	0.17	0.003	60.91
Metsaliitto	Metsä	Finland	655	5682	20	0.12	0.004	32.75
Oji Paper	Oji	Japan	633	12838	83	0.05	0.006	7.63
DS Smith	DS	UK	570	6153	9	0.09	0.001	63.33
Sappi	Sappi	South Africa	526	5296	30	0.10	0.006	17.53
Shan Dong Sun Paper	Shan Sun	China	523	2796	112	0.19	0.040	4.67
Arauco)	Arauco	Chile	491	5238	3	0.09	0.000	188.85
Sumitomo Forestry	Sumitomo	Japan	481	9926	17	0.05	0.002	28.29
Klabin	Klabin	Brazil	473	2624	7	0.18	0.003	67.57
Canfor	Canfor	Canada	429	3589	11	0.12	0.003	39.00
Lenzing	Lenzing	Austria	403	2547	29	0.16	0.011	13.90
Sonoco	Sonoco	US	367	5037	21	0.07	0.004	17.48
Graphic Packaging	Graphic	US	343	4404	14	0.08	0.003	23.82
Svenska Cellulosa	SCA	Sweden	294	1949	6	0.15	0.003	49.00
Billerud	Billerud	Sweden	262	2614	14	0.10	0.005	18.71
Cheng Loong	Cheng	Taiwan	254	1434	3	0.18	0.002	84.67
Holmen	Holmen	Sweden	253	1887	11	0.13	0.006	23.00
Mayr-Melnhof Karton	Mayr	Austria	242	2635	3	0.09	0.001	80.67
Sodra	Sodra	Sweden	224	2400	11	0.09	0.005	20.36
Sveaskog	Sveaskog	Sweden	214	726	3	0.29	0.004	71.33
SCG Packaging (Formerly Siam Pulp and Paper)	SCG	Thailand	212	2517	123	0.08	0.049	1.72
Rengo	Rengo	Japan	211	4863	13	0.04	0.003	16.23
Daio Paper	Daio	Japan	210	4254	26	0.05	0.006	8.08
ENCE	ENCE	Spain	169	834	1	0.20	0.001	169.00
Mercer International	Mercer	Canada	167	1169	3	0.14	0.003	55.67
Nippon Paper Group	Nippon	Japan	157	9330	56	0.02	0.006	2.80
Cascades	Cascades	Canada	135	3329	4	0.04	0.001	33.75
Schweitzer-Mauduit	Schweitzer	US	125	982	18	0.13	0.018	7.02

Ahlstrom	Ahlstrom	Finland	117	2210	20	0.05	0.009	5.85
Hokuetsu Paper	Hokuetsu	Japan	115	2339	7	0.05	0.003	16.43
Yuen Fong Yu Paper	Yuen Fong	Taiwan	100	1979	8	0.05	0.004	12.50
Heinzel Holding	Heinzel	Austria	83	2048	1	0.04	0.000	166.00
Moorim group	Moorim	Korea	81	886	3	0.09	0.003	27.00
The Lecta Group	Lecta	UK	75	1645	6	0.05	0.004	12.50
The Pack Corporation	Pack Corp.	Japan	65	805	13	0.08	0.016	5.00
Resolute Forest Products (Formerly Abitibi Bowater)	Resolute	Canada	49	3513	18	0.01	0.005	2.66
Ballarpur Industries	Ballarpur	India	47	333	7	0.14	0.021	6.71
Mitsubishi Paper	Mitsubishi	Japan	38	1800	9	0.02	0.005	4.22
Corticeira Amorim	Corticeira	Portugal	25	797	8	0.03	0.010	3.13
Domtar	Domtar	Canada	-317	5157	24	-0.06	0.005	-13.21

OI: operating income, R&D: research and development, S: sales
Forest-based bioeconomy firms encompass forest, paper and packaging firms Sales, R&D and OI unit: mil. US$ (nominal).
OECD exchange rate was used to convert the currency units into US$. Source: Firm's Annual report 2017.

Table A2. Techno-market indicators in leading 4 firms (2000-2017).

	KC			UPM			Oji			Sappi		
Year	MC/R	MC/OI	MC/S	MC/R	MC/OI	MC/S	MC/R	MC/OI	MC/S	MC/R	MC/OI	MC/S
2000	106.34	11.20	0.47	215.97	5.11	0.99	58.89	24.76	0.59	118.13	2.64	0.38
2001	111.75	14.11	0.44	215.14	6.00	0.98	43.48	7.51	0.43	99.60	8.33	0.48
2002	111.07	13.03	0.42	173.06	9.24	0.76	50.39	16.85	0.50	133.65	6.65	0.72
2003	94.08	11.32	0.53	164.93	21.52	0.80	36.98	8.27	0.39	160.00	11.18	0.71
2004	116.91	13.05	0.46	182.50	12.52	0.87	59.65	9.68	0.61	151.67	16.94	0.67
2005	93.27	12.90	0.53	173.30	27.25	0.93	51.83	6.99	0.50	98.22	15.87	0.53
2006	94.02	13.46	0.59	228.24	18.65	1.00	57.98	9.66	0.59	77.08	14.80	0.37
2007	110.11	11.66	0.60	142.51	14.66	0.71	55.84	10.13	0.50	64.59	5.73	0.41
2008	83.84	9.78	0.78	95.17	11.88	0.49	39.33	10.85	0.34	42.21	4.57	0.24
2009	72.09	7.68	0.88	89.68	11.88	0.56	39.79	12.40	0.32	64.03	10.18	0.37
2010	78.23	8.94	0.80	151.74	9.10	0.77	43.85	5.36	0.34	105.56	7.74	0.40
2011	82.59	10.69	0.80	88.73	9.74	0.44	42.15	5.90	0.34	59.04	17.85	0.21
2012	92.98	12.32	0.64	102.67	3.52	0.44	41.62	7.32	0.33	61.83	3.52	0.23
2013	103.33	11.60	0.57	172.56	11.85	0.65	36.18	6.58	0.28	44.64	7.32	0.22
2014	113.04	16.50	0.47	209.49	10.78	0.74	41.80	7.36	0.34	70.80	5.85	0.34
2015	119.14	15.71	0.48	248.55	8.05	0.91	46.81	10.49	0.34	54.96	4.31	0.29
2016	150.91	14.92	0.37	313.05	10.97	1.27	46.21	6.05	0.31	107.54	5.74	0.54
2017	146.62	13.82	0.40	273.30	10.98	1.38	55.47	7.27	0.36	123.15	6.91	0.69

MC: market capitalization, R: research and development, S: sales, OI: operating income Source: Firm's Annual reports.

Table A3. Trend in market capitalization in leading 4 firms (2000-2017).

Year	KC	UPM	Oji	Sappi
2000	36465.07	10160.64	5879.31	3660.21
2001	39882.55	9722.39	4036.96	3823.85
2002	38208.30	8326.85	4424.85	4571.52
2003	30809.30	9915.19	3781.66	4914.46
2004	37140.26	11752.58	6224.58	4833.39
2005	32791.37	11777.76	5120.93	3816.57
2006	30212.59	13594.53	5890.12	2505.65
2007	31717.17	10212.24	5230.00	2732.47
2008	25395.52	7005.25	4295.18	1640.67
2009	21965.03	6029.41	4293.76	2111.07
2010	24800.00	9104.64	4516.16	2639.00
2011	25572.03	6054.94	4887.16	1440.88
2012	31843.85	5638.47	5075.49	1323.11
2013	35219.46	7966.25	3608.53	1106.13
2014	38692.47	8749.22	4351.36	1611.38
2015	35446.67	9082.23	4029.01	1164.99
2016	44883.60	12179.75	4058.57	1982.24
2017	40695.39	13647.66	4552.42	2440.51

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

REFERENCES

[1] Watanabe, C., Naveed, N. and Neittaanmäki, P., 2018*d*. Digitalized Bioeconomy: Planned Obsolescence-driven Economy Enabled by Co-evolutionary Coupling. *Technology in Society* 56, 8-30.

[2] Watanabe, C., 1973. Ecological Analysis of Japanese Economy. The Economic S eminar 211, 29-43.

[3] Ministry of International Trade and Industry (MITI), Japan, 1972*a*. Ecology and Application of Its Concept to Industrial Policy. MITI Journal 5 (2), 63-68.

[4] Watanabe, C., 1972. A Guideline to the Ecolo-utopia: Basic Suggestion to Japanese Economy in the Face of the New Crisis. Analyst 9, 34-56.

[5] Watanabe, C., 1999. Systems Option for Sustainable Development: Effect and Limit of the Ministry of International Trade and Industry's Efforts to Substitute Technology for Energy. *Research Policy*, 28 (7), 719-749.

[6] Ministry of International Trade and Industry (MITI), Japan, 1972*b*. Industry-Ecology: Introduction of Ecology into Industrial Policy. MITI, Tokyo.

[7] Finnish Forest Industries Federation, 2012. Forest Industry Regenerating through Innovation, *https://www.forestindustries.fi/* Retrieved 8 April. 2018.

[8] Hetemäki, L., Hoen, H.F., and Schwarzbauer, P., 2014. Future of the European Forest-based Sector and Bioeconomy, in Hetemaki, L. edt., *Future of the European Forest-based Sector: Structural Changes towards Bioeconomy*. European Forest Institute, Joensuu.

[9] Hetemäki, L., 2016. *Role of Sustainable Forest-based Bioeconomy in Europe*. Think Forest, 15 November 2016, Brussels.

[10] Watanabe, C., Naveed, N., and Neittaanmäki, P., 2018*a*. Digital Solutions Transform the Forest-

based Bioeconomy into a Digital Platform Industry: A Suggestion for a Disruptive Business Model in the Digital Economy. *Technology in Society* 54, 168-188.

[11] VTT Visions 11, 2017. Bittejä ja Biomassaa: Tiekartta Digitalisaation Vauhdittamaan Biotalouteen. Juvenes Print, Helsinki.

[12] Tieto, 2017. UPM Biochemicals Targets to Enhance its Global Market Reach a nd Business Agility Through New B2B eCommerce Solution by Tieto. https://w ww.tieto.com/news/upm-biochemicals-targets-to-enhance-its-global-market-reach-an d-business-agility-through-new-b2b Retrieved 02 August, 2018.

[13] Tieto, 2018. *Amazon Web Services – public cloud*. https://www.tieto.com/node/85026/awspubliccloud Retrieved 02 August, 2018.

[14] EC (European Commission), Innovating for Sustainable Growth: a Bioeconomy for Europe. COM(2012) 60 Final, (2012) Brussels.

[15] Ministry of Economic Affairs and Employment of Finland (MEE), 2014. *The Finnish Bioec onomy Strategy*, Ministry of Economic Affairs and Employment of Finland.

[16] Ellen Macarthur Foundation (EMF), 2015. *Towards a Circular Economy: Business Rationale for an Accelerated Transition*. EMF, Cowes, UK.

[17] Wolfslehner, B., Linser, S., Pulzl. H., Bastrup-Birk, A., Camia, A and Marchetti, M., 2016. Forest Bioeconomy – A New Scope for Sustainability Indicators. *European Forest Institute*. From Science to Policy 4, 1-31.

[18] MISTRA, 2017. Bioeconomy and Digitalization. MISTRA, Stockholm.

[19] Watanabe, C., Tou, Y., and Neittaanmäki, P., 2018*b*. A New Paradox of the Digital Economy: Structural Sources of the Limitation of GDP Statistics. *Technology in Society* 55, 9-23.

[20] Watanabe, C., Naveed, K., Tou, Y., and Neittaanmäki, P., 2018*c*. Measuring GDP in the Digital Economy: Increasing Dependence on Uncaptured GDP. *Technological Forecasting and Social Change* 137, 226-240.

[21] Bae, S.C. and Kim, D., 2003. The Effect of R&D Investments on Market Value of Firms: Evidence from the U.S., Germany, and Japan. *The Multinational Business Review*, 11 (3), 51-77.

[22] Obeng, G.K. and Bao, H.P., 2014. Consideration of Technological Obsolescence in Quantitative Forecasting and Economic Life Analysis. *International Conference on Engineering and Applied Sciences Optimization*, Kos Island, Greece.

[23] Satyro, W.C., Sacomano, J.B., and Contador, J.C., 2018. Planned Obsolescence or Planned Resource Depletion? A Sustainable Approach. *Journal of Cleaner Production*, 195, 744-752.

[24] Pelli, P., Haapala, A. and Pykalainen, J., 2017. Services in the Forest-based Bioeconomy: Analysis of European Strategies. Scandinavian *Journal of Forest Research*, online 17 Feb March 2017.

[25] UPM, 2016. Aiming Higher with Biofore: Annual Report 2016. http://hugin.info/165629/R/2081401/784910.pdf Retrieved 30 June 2017.

[26] UPM, 2017*a*. UPM Kaukas Leads the Way in Promoting the Circular Economy. *Biofore*, 23 May 2017.

[27] UPM, 2017*b*. *Aiming Higher with Biofore: Annual Report 2017*.

[28] UPM, 2018. *UPM Circular Economy*, http://www.upm.com/circulareconomy/Pages/default.aspx Retrieved 02 August 2018.

[29] Tou, Y., Watanabe, C., Moriya, K. and Neittaanmäki, P., 2018. Neo Open Innovation in the Digital Economy: Harnessing Soft Innovation Resources. International Journal of Managing Information Technology 10 (4), 53-75.

[30] Tou, Y., Watanabe, C., Moriya, K. and Neittaanmäki, P., 2019. Harnessing Soft Innovation Resources Leads to Neo Open Innovation. Technology in Society, in print.

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