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Co-evolutionary Dynamism between Innovation and Institutional Systems in the BRICs

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1. Introduction

It is well known that the BRICs, consisting of Brazil, Russia, India and China are the four largest developing countries with the most prospective economic growth in the next generation in the world. The BRICs generated 27% of the world GDP (PPP) in 2005 by sharing 28.9% of land space and 43.2% of population. The huge potential of BRICs economic growth can be attributed to their advantages of affluent natural resources and land, together with a large and cheap labor market as well as high density of foreign direct investment.

However, as the development trajectories for industrialized countries suggest, sustainable development in BRICs requires innovation for effective utilization of potential resources. Given the co-evolutionary dynamism between innovation and institutional systems is decisive to innovation driven economy, sustainability of BRICs economic growth is subject to such co-evolution.

2. Analytical Framework

2.1 Constitution of institutional systems

Institutional systems (IS) are constituted of the following three dimensions (Watanabe, 2004):

(i) National strategy and socio-economic system,
(ii) Entrepreneurial organization and culture, and
(iii) Historical perspectives.

Therefore, institutional systems (IS) can be depicted by the following equation:

$$IS = F(X, Y, Z) \quad (1)$$

where *X, Y, Z:* three dimensions of institutional systems; and $X = X(X_1, X_2, \ldots, X_n)$, $Y = Y(Y_1, Y_2, \ldots, Y_n)$, $Z = Z(Z_1, Z_2, \ldots, Z_n)$ with major components X_i, Y_i, and Z_i (i = 1~n).

Using Principle Component Analysis (PCA) for the three dimensions respectively, institutional systems can be depicted by means of the governing Principle Components (PCs) as follows:

$$\begin{aligned} X &= X(PCx_1, PCx_2, PCx_3, \Lambda, PCx_n) \\ Y &= Y(PCy_1, PCy_2, PCy_3, \Lambda, PCy_n) \\ Z &= Z(PCz_1, PCz_2, PCz_3, \Lambda, PCz_n) \end{aligned} \quad (2)$$

where PCx_i, PCy_i, and PCz_i (i = 1~n) are principle components of three dimensions, respectively.

Figure 1 demonstrates the constitution of the main Principle Components (PCs) of each respective three dimensions with major proxies demonstrating the significant loading of variables.

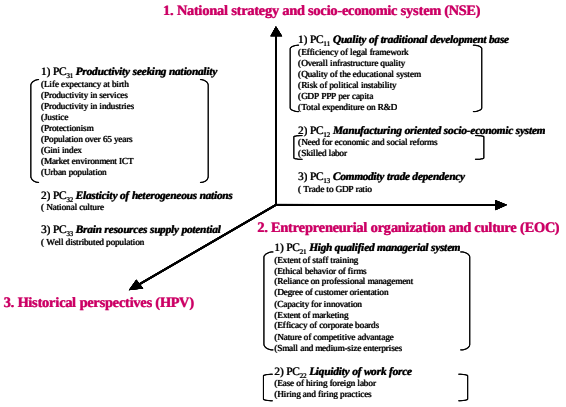

Fig. 1. Structure of Institutional Systems in 40 Countries *(2004).*

2.2 Measurement of co-evolutionary dynamism between innovation and institutional systems

In light of the significance of the co-evolutionary dynamism between innovation and institutional systems, principal components regression analysis is conducted to identify the correlation between innovation and PCs of the institutional systems in 40 countries (BRICs, OECD, 6 Asian newly industrializing and developing countries) by taking MT, ICT and software (SW) for innovation as follows. Characteristics of co-evolutionary dynamism in BRICs are highlighted by comparison with Japan and USA.

$$MT = F(PC_{\alpha\beta}, ICT, SW) \quad (3)$$
$$ICT = F(PC_{\alpha\beta}, MT, SW) \quad (4)$$
$$SW = F(PC_{\alpha\beta} MT, ICT) \quad (5)$$

where $PC_{\alpha\beta}$: governing principal components of institutional systems; α: three dimensions of institutional systems, $\alpha = x, y, z$; and β: number of principal components in three dimensions, β = 1~n.

3. Empirical Analysis of Co-evolution between Innovation and Institutional systems

Aiming at examining the co-evolutionary dynamism between institutional systems and innovation, on the basis of equations (3)-(5), principal components regressions between the principal components of institutional systems and MT, ICT as

well as software between 40 countries in 2004 are conducted. MT, ICT and software are represented by *Production Process Sophistication* (WEF, 2005), *Network Readiness Index* (WEF, 2005), and *Potential of Software Development* (SCI, 2005, IMD, 2005), respectively. The Potential of Software Development is computed by utilizing the ratio of the number of publications concerning software and GDP PPP per capita.

3.1 Manufacturing technology (MT)

Aiming at identifying the significant impacts of institutional factors on MT, on the basis of equation (3), cross-country multi-regression analysis is conducted. Using Backward Eliminating Method (BEM) with 5% significant level criteria[1], the principal components that have significant influences on MT are identified as follows:

$$MT = \underset{(148.31)}{4.960}+(\underset{(3.66)}{0.480}-\underset{(-3.26)}{3.587}SW)PC_{11}+(\underset{(4.71)}{0.200}ICT+\underset{(1.05)}{2.630}SW)PC_{12}+(\underset{(4.61)}{0.620}+\underset{(2.82)}{2.138}SW)PC_{21}-\underset{(-2.46)}{0.082}ICTPC_{22}+(\underset{(-4.41)}{-0.157}-\underset{(-2.35)}{0.125}ICT-\underset{(-1.29)}{3.778}SW).\quad adj.\ R^2\ 0.967 \tag{6}$$

The regression result is statistically significant, and indicates that ICT, software and institutional factors contribute to the development of MT. In addition, quality of traditional development base (PC_{11}), manufacturing oriented socio-economic system (PC_{12}), high qualified managerial system (PC_{21}), liquidity of work force (PC_{22}) and elasticity of heterogeneous nations (PC_{32}) are significant governing institutional factors to the development of MT in the 40 countries examined. Contributions of these factors to MT in BRICs are summarized in **Table 1.** Japan and USA have been included for comparison.

Table 1 Contribution of Institutional Factors to MT in 6 Countries *(2004)*

	PPS	Const.	PC_{11}	PC_{12}	PC_{21}	PC_{22}	PC_{32}
Brazil	4.23	4.96	-0.59	0.00	-0.50	0.01	0.35
Russia	3.17	4.96	-0.65	-0.04	-1.17	0.00	0.07
India	3.85	4.96	-0.16	0.11	-0.46	0.02	-0.62
China	2.91	4.96	-0.24	0.04	-1.36	-0.01	-0.48
Japan	6.44	4.96	0.26	0.11	0.51	0.13	0.47
USA	6.11	4.96	0.24	-0.03	1.22	-0.06	-0.22

Table 1 demonstrates clear contrast between BRICs and Japan/USA with respect to negative or positive impacts of PC_{21} and PC_{11} on their MT developments. While these institutional factors induced MT in Japan and USA, they impeded MT advancement in the BRICs.

In light of the significant contrasting negative impacts of PC_{21} and PC_{11} on MT in the BRICs, **Figures 2** and **3** analyze the constitutions of PC_{21} and PC_{11} in the four BRIC countries by comparing scores of 12 and 9 variables constituting these components, respectively.

Figure 2 suggests that India and Brazil developed better than China and Russia in PC_{21}, and the factors of efficacy of corporate boards, degree of customer orientation, large corporations reliance on professional management and extent of staff training are the weakest factors in China, this urges it strong enhancement. On the other hand, factors of capacity for innovation, extent of marketing, nature of competitive advantage, ethical behavior of firms, small and medium-size enterprises, extent of staff training and reliance on professional management are extremely weak in Russia requiring it urgent development.

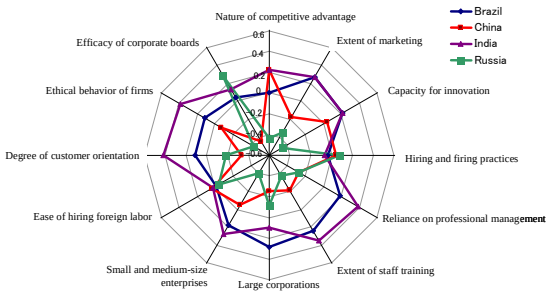

Fig. 2. Contribution of High Qualified Managerial System (PC_{21}) in BRICs *(2004)*.

Similarly, Figure 3 suggests that China developed better than other three BRICs countries in quality of traditional development base (PC_{11}). However, the factors of skilled labor, GDP per capita and quality of the educational system require further development. India is required to improve its balance between factors by enhancing total expenditure on R&D, trade to GDP ratio, GDP per capita, as well as overall infrastructure quality. Factors of risk of political instability and need for economic and social reforms are extremely weak in Russia, requiring it urgent improvement. Brazil should pay attention on reinforcing quality of the educational system and overall infrastructure quality.

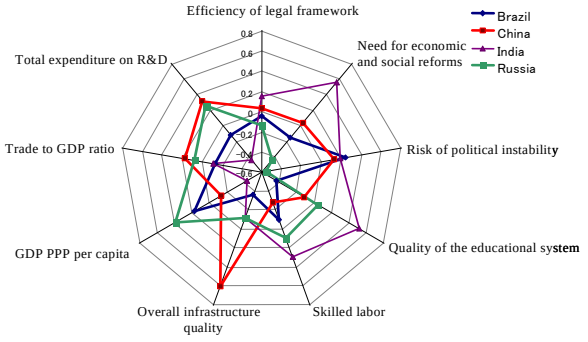

Fig. 3. Contribution of Quality of Traditional Development Base (PC_{11}) in BRICs *(2004)*.

3.2 Information and communication technology (ICT)

Aiming at identifying the significant impacts of institutional factors on ICT, on the basis of equation (4), cross-country multi-regression analysis is

[1] Due to significant differences in the growth rate of SW depending on countries examined, certain interactions between software and particular institutional factors permit 10-15% significant level.

conducted. Using Backward Eliminating Method (BEM) with 5% significant level criteria (see footnote 1 in 3.1), the principal components that have significant influences on ICT are identified as follows:

$$\begin{aligned} ICT = {} & 0.730+0.559PC_{11}+(-0.650+0.110MT-2.960SW)PC_{13}+(-0.120 \\ & (29.4) \quad (19.44) \quad (-3.87) \quad (3.43) \quad (-1.51) \quad (-3.60) \\ & -2.000SW)PC_{13}+0.010MTPC_{22}+(0.400-0.060MT)PC_{32} \\ & (-1.10) \quad (1.78) \quad (2.39) \quad (-1.75) \end{aligned} \qquad adj.\ R^2\ 0.947 \qquad (7)$$

The regression result is statistically significant, and indicates that MT, software and institutional factors contribute to the development of ICT. Quality of traditional development base (PC_{11}), manufacturing oriented socio-economic system (PC_{12}), commodity trade dependency (PC_{13}), liquidity of workforce (PC_{22}) and elasticity of heterogeneous nations (PC_{32}) are significant governing institutional factors to ICT. **Table 2** summarizes contributions of these factors to ICT in BRICs, Japan and USA.

Table 2 Contribution of Institutional Factors to ICT in 6 Countries *(2004)*

	NRI	Const.	PC_{11}	PC_{12}	PC_{13}	PC_{22}	PC_{32}
Brazil	-0.33	0.73	-0.80	0.00	0.07	-0.05	-0.28
Russia	-0.27	0.73	-0.82	-0.17	0.10	0.01	-0.12
India	0.61	0.73	-0.27	-0.37	0.12	-0.03	0.43
China	0.18	0.73	-0.67	-0.08	-0.01	0.02	0.20
Japan	1.20	0.73	0.33	0.01	0.22	-0.08	-0.01
USA	1.66	0.73	0.53	0.01	0.35	0.03	0.01

Table 2 demonstrates a clear contrast between the BRICs and Japan/USA with respect to positive or negative impacts of PC_{11} on their developments of ICT (see Figure 6). Furthermore, contrary to the strong inducement of PC_{13} in Japan and USA, this inducement is weak in the BRICs and even impedes in China. Similar to MT, while PC_{11} consisting of efficiency of legal framework, overall infrastructure quality, quality of the educational system, risk of political instability, GDP per capita and total expenditure on R&D, it reacted to impediment in BRICs.

High positive scores of PC_{32} (elasticity of heterogeneous nations) in India and China suggest that a large population, cheap labor, rapid economic growth, high income imparity and development of urbanization contribute to the advancement of ICT in these two countries characterized by the world highest diffusion velocity in PC, Internet and mobile phone. Contrary to India and China, scores of PC_{32} in USA, Japan as well as Brazil and Russia are negative or negligibly small. In light of such a clear contrast in PC_{32} between India/China and Brazil/Russia, **Figure 4** analyzes the constitution of PC_{32} in the four BRIC countries by comparing scores of 12 variables constituting this component.

Figure 4 demonstrates that the factors of market environment ICT, population over 65 years, justice, protectionism and national culture are all extremely weak in Russia requiring it urgent improvement. Factors requiring enhancement in Brazil are related to economic growth, construction of market environment as well as population and urbanization.

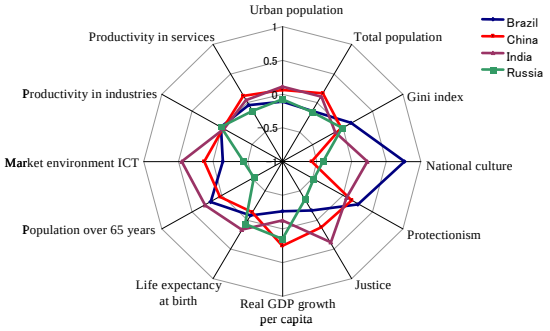

Fig.4. Contribution of Elasticity of Heterogeneous Nations (PC_{32}) in BRICs *(2004)*.

3.3 Software (SW)

Similar to MT and ICT, aiming at identifying the significant impacts of institutional factors on software, cross-country multi-regression analysis is conducted based on equation (5). Using Backward Eliminating Method (BEM) with 5% significant level criteria, the principal components that have significant influences on software are identified as follows:

$$\begin{aligned} SW = {} & 0.040+(-0.009MT+0.016ICT)PC_{12}+(0.008MT-0.011ICT)PC_{22}+ \\ & (62.16) \quad (-39.79) \quad (10.76) \quad (36.15) \quad (-10.10) \\ & (0.007MT-0.011ICT)PC_{32}+0.011D_{jp} \\ & (31.54) \quad (-6.50) \quad (2.84) \end{aligned} \qquad adj.\ R^2\ 0.994 \qquad (8)$$

The regression result is statistically significant, and indicates that MT, ICT and institutional factors contribute to the development of software. In addition, manufacturing oriented socio-economic system (PC_{12}), liquidity of workforce (PC_{22}) and elasticity of heterogeneous nations (PC_{32}) are significant governing institutional factors to the development of software. Contributions of these factors to software in the BRICs, Japan and USA are summarized in **Table 3.**

Table 3 demonstrates that while USA is positive in all factors, it is the opposite for Japan. Among six countries compared, China indicates the highest value of potential of software development demonstrating its rapid development of software, which can be attributed to the highest impacts of PC_{32} and PC_{22} on its software development. India demonstrates the highest contribution of PC_{12} and significant positive impact of $PC_{32,}$ which contribute to its conspicuous software development. All the four BRIC countries demonstrate positive impacts of $PC_{12,}$ while Russia and Brazil demonstrate negative impacts in PC_{32} and PC_{22} as well as $PC_{32,}$ respectively.

The forgoing analysis demonstrates that (i) The advantage of ICT talent's training and talent supply market of software contribute to the development of the software industry in China and India; and (ii) Characteristic of “high-quality work force,” “cheap pay” and “English sphere" in software industry contribute to India for its competitive edge in the

world.

Table 3 Contribution of Institutional Factors to Software in 6 Countries *(2004)*

	SW	Const.	PC_{12}	PC_{22}	PC_{32}
Brazil	1.82	5.37	0.06	-3.56	-0.06
Russia	0.99	0.96	0.16	0.05	-0.17
India	4.51	3.10	0.83	-0.25	0.83
China	7.77	3.51	0.54	1.32	2.40
Japan	1.11	4.72	-0.52	-1.53	-1.56
USA	6.36	3.53	0.48	1.23	1.12

4. Co-evolutionary dynamism between Innovation and Institutional Systems

Based on the foregoing analysis of correlation between institutional systems and MT, ICT as well as software, it can be identified that institutional factors, MT, ICT and software are interconnected and significantly contribute to each other. This demonstrates that a strong interacting dynamism between innovation represented by MT, ICT as well as software and institutional systems functioned well in these 40 countries as illustrated in **Figure 5**.

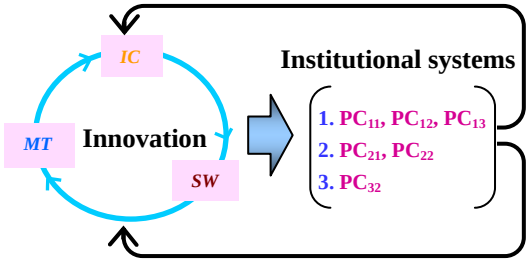

Fig. 5. Co-evolutionary Dynamism between Innovation and Institutional Systems.

Figure 10 demonstrates that institutional systems play an important role in cultivating emerging innovation similar to soil, if the foregoing interaction reacts positively, leading to a virtuous cycle. In this case, emerged innovation contributes to a change in institutional systems, which in turn induces further innovation leading to a co-evolution between them. This co-evolution is a driving force of innovation driven economy on which BRICs sustainable development depends.

5. Conclusion

In light of the conspicuous economic growth demonstrated by the BRIC countries in the early 2000s and their significant contribution to the world economy, this paper analyzed the co-evolutionary dynamism and conditions of the BRICs' sustainable development. With the understanding that advancement of technology induced by a co-evolutionary dynamism between innovation and institutional systems is indispensable for the BRICs' sustainable development through effective utilization of their potential resources, empirical analyses of the development trajectories in 40 countries centered by the BRIC countries were conducted and demonstrated the following noteworthy findings:

(i) The major factor impeding BRICs' substantial technology innovation can be attributed to their low MT level.

(ii) While BRICs have constructed a strong interacting relationship between innovation including MT, ICT and software and their institutional systems, and therefore, advancement of MT depends on the way of interaction between ICT, software and institutional systems. Certain institutional factors impede this interaction to lead to a virtuous cycle constructing a co-evolution between innovation and institutional systems.

(iii) Strong impediment factors in their institutional systems common to the BRICs include the weakness of advanced management system such as enterprise management, education and training of employees, reliability of professional management and degree of efforts for consumer satisfaction.

(iv) Contrary to the low level of MT, the level of BRICs ICT and software demonstrates noteworthy growth. While the current levels of BRICs ICT and software have remained lower than that of Japan and USA, the conspicuous growth rates of ICT market environment, labor source and human resource supply in China and India suggest their potential in rapid development.

(v) Given the strong interaction between MT and ICT/SW as well as institutional systems, further advancement of ICT/SW in BRICs can leverage the co-evolution between innovation and institutional systems leading to substantial advancement of technology essential for the effective utilization of potential resources for their sustainable development.

Reference

[1] IMF. World economic Outlook Database. IMF; April 2006.

[2] IMD. World Competitiveness Yearbook 2005. Lausanne, Switzerland: IMD; 2005.

[3] Kondo R, Watanabe C. The Virtuous Cycle between Institutional Elasticity, IT Advancement and Sustainable Growth: Can Japan Survive in a Information Society? Technology in Society 2003; 25(3): 319-335.

[4] Watanabe C, Kondo R. Institutional elasticity towards IT waves for Japan's survival: The significant role of an IT Testbet. Technovation 2004; 23(4): 307-320.

[5] World Economic Forum (WEF), The Global Competitiveness Report 2005-2006.

[6] International Telecommunication Union (ITU). World Telecommunication Indicators 2004. Switzerland: ITU; 2005.

[7] Wilson D, Purushothaman R. Dreaming with BRICs: The Path to 2050. Goldman sachs: Global Economics Paper, N0. 99, 2003.

[8] O'Neill J, Wilson D, Purushothaman R, Stupnytska A. How solid are the BRICs? Goldman Sachs: Global Economics Paper, No. 134, 2005.