Technology in Society 31 (2009) 9–28

Contents lists available at ScienceDirect

Technology in Society

journal homepage: www.elsevier.com/locate/techsoc

Institutional structure of sustainable development in BRICs: Focusing on ICT utilization

Xuening Yao, Chihiro Watanabe*, Ying Li

Department of Industrial Engineering and Management, Tokyo Institute of Technology, 2-12-10 W9-49 Oo-okayama, Meguro-ku, Tokyo 152-8552, Japan

Keywords:
BRICs
Innovation
Institutions
ICT
Co-evolution
Sustainable development

ABSTRACT

In contrast to the relative stagnation of economic growth in industrialized countries with mature economies, the so-called BRIC countries have shown conspicuous economic growth in the early 21st century. Brazil, Russia, India, and China currently depend on their geographic advantages for economic development, as they possess abundant natural resources and collectively account for 28.9% of the world's land area and 43.2% of its population. However, as the development trajectories for industrialized countries suggest, sustainable development in BRICs requires innovation for effective utilization of potential resources. Given that the co-evolutionary dynamism between innovation and institutional systems is paramount to innovation driven economies, sustainability of BRICs' economic growth is subject to such co-evolution.

Institutional systems are similar to soil in that they cultivate emerging innovation. Recent dramatic advances in information and communication technology (ICT) in BRICs have had a significant impact on the advancement of their institutional systems. Therefore, ICT is expected to trigger co-evolution that will lead to sustainable development in BRICs by means of effective utilization of potential resources.

This paper attempts to demonstrate the foregoing hypothetical expectations by means of an empirical analysis comparing co-evolutionary structures in 40 countries and also ICT's triggering role in the four BRIC countries.

1. Introduction

1.1. Noteworthy observations

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 of 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 [1]. Furthermore, BRICs have abundant natural resources. China accomplished a conspicuous economic growth of 9.8% p.a. over the period 1980–2003, followed by India and Brazil with 5.8% and 2.4% p.a., respectively [2]. In addition, Russia started its high economic growth in 1998 and is now at a level similar to India. Comparing 2.7% p.a. of G7's average annual growth since 1980 [2], the BRICs' current economic growth has demonstrated their conspicuous potential.

The vast potential of the BRICs' economic growth can be attributed to their affluent natural resources and land, coupled with a large and cheap labor market and a high rate of foreign direct investment. The BRIC's combined crude oil production in

* Corresponding author. Tel.: +81 3 5734 2248; fax: +81 3 5734 2252.
E-mail address: watanabe.c.aa@m.titech.ac.jp (C. Watanabe).

0160-791X/$ – see front matter © 2008 Elsevier Ltd. All rights reserved.
doi:10.1016/j.techsoc.2008.10.013

2004 amounted to 20.6% of the world's production [3]. Both China and India have huge populations of over 1 billion, enabling the potential for job growth in manufacturing, software services, and call centers. While Brazil and Russia have smaller populations of 182 million and 144 million, respectively, both countries endeavor to develop their energy and raw materials driven industries [4]. Moreover, the large foreign direct investment in the BRICs has provided them with the necessary financing for economic development. In 2004, the amount of foreign direct investment in the BRICs was 15% of the total foreign direct investment in the world, and 41% of that of all developing countries combined [5].

However, the experiences of developed countries and NIEs (Newly Industrializing Economies) demonstrate that sustainable economic development depends on technology innovation that activates and synchronizes the potential of natural, financial, and human resources with economic growth [6,7]. Similarly, BRICs' sustainable economic development is subject to technology innovation, whereby they can effectively utilize their potential resources of all kinds.

While BRICs have demonstrated a total factor productivity (TFP) growth rate higher than that of other countries—including industrialized countries such as the USA and Japan—their TFP contribution to GDP growth rate still remains at a lower level [8–13]. This implies that while the BRICs make use of potential technology development, they still remain dependent on the impetus of rapid economic growth and not on substantial innovation which would enable effective synchronization of their potential resources with sustainable development.

If the rise and fall of the Japanese economy over the last half century can be attributed to the co-evolution and subsequent disengagement between innovation and institutional systems [6,14], BRICs' substantial innovation can also be attributed to their co-evolutionary dynamism.

Notable prospects for this expectation can be seen in BRICs' conspicuous advancement in information and communication technology (ICT) [15–17]. Corresponding to a paradigm shift from an industrial to an information society in the 1990s and with the unique features of ICT as a self-propagating dynamism reacting to the impetus of economic growth [6,14], BRICs have demonstrated the world's highest advancement in development and utilization of ICT in computers, the Internet, and mobile phones [16,17]. With the impetus of economic growth, such rapid advancement, in turn, drives the co-evolution of their institutional systems [18,19].

This increase suggests that the advancement of ICT in BRICs could trigger the co-evolution between their innovation and institutional systems, which is essential for their sustainable development by means of effective utilization of their potential resources.

1.2. Hypotheses

The forgoing observations provided us with the following hypothetical views with respect to the BRICs' future sustainability in their development by means of their potential resources:

(i) BRICs' sustainable development depends on the effective utilization of their potential resources including human and natural resources by means of technological advancement.
(ii) Such technological advancement is subject to the co-evolutionary dynamism between innovation and institutional systems.
(iii) The development of ICT plays a triggering role for this co-evolution.

1.3. Existing works

The term of BRICs was first used in a Goldman Sachs' report [20], which argued that the economies of the BRICs are rapidly developing and will eclipse most of the current richest countries of the world by the year 2050. Goldman Sachs released a follow-up report in 2004 focusing on the impact of the growth of these four economies on global markets [21].

Stimulated by these reports, many researchers have studied the important role of BRICs in the world economy and global policy and the potential development of BRICs [22–27]. For example, Thornton predicted that "BRICs are expected to play an increasingly important role in the global economy in the coming decades, and these four countries have come to symbolize the exciting challenges and opportunities presented by dynamic emerging markets" [23].

While these studies highlighted the optimistic views on BRICs' development, some researchers have pointed out critical tasks that could obstruct their optimistic view. Georgieva highlighted the specific risks and challenges in each BRIC country and pointed out that their sustainability of high growth will depend on several crucial factors including sound and stable macroeconomic and development policies, development of strong and capable institutions, human development, and increasing degree of openness [24]. Similarly, Jensen suggested some growth factors for the BRICs such as institutional framework, openness, TFP, capital, population growth, and education level [26].

These studies pointed out the significance of technology advancement for BRICs' sustainable development. However, no empirical analysis has been conducted on the contribution of substantial technological innovation to BRICs' economic growth by means of effective utilization of their potential resources.

To date, many studies have attempted to elucidate the dynamism inducing the surge of new innovation. Innovation, assimilation, and utilization of technology chiefly depend on the economy, society, culture, habit, system, and public policies of a country. This comprehensive system may be defined as "institutions." North [28] postulated that "The humanly devised constraints structure human interaction. They are made up of formal constraints (e.g. rules, laws, and constitutions), informal constraints (e.g. norms of behavior, conventions, and self-imposed codes of conduct) and their enforcement characteristics." Ruttan [29] suggested that "Institutions are the social rules that facilitate coordination among people by helping them form expectations for dealing with each other" and also "They reflect the conventions that have evolved in different societies regarding the behavior of individuals and groups." Thus, institutions play a prominent role in industrial progress and it is essential to examine the institutional environments for characterizing industrial dynamics and advantages.

Meanwhile, a number of works have conducted theoretical and empirical analyses on institutional systems [29–37]. Binswanger's pioneer work [33] paid special attention to the role of institutional systems in inducing innovation. Marten [34] stressed that co-adaptation and co-evolution are emergent properties of an ecosystem. He stated that while co-adaptation is fitting together, co-evolution is changing together to play an essential role in sustaining an ecosystem. Janes [35] and Flood [36] pointed out that while complex institutions reject co-evolution with innovation, they might accelerate self-propagating development once they overcome a certain threshold. In an ICT driven global economy, which is quite similar to an evolutional ecosystem, co-evolution between innovation and institutions is essential for a nation's sustainable development. Watanabe [37] has also conducted intensive work on the behavior of institutional systems and postulated that institutional systems are defined by a three-dimensional system that consists of (i) national strategy and socio-economic system, (ii) entrepreneurial organization and culture, and (iii) historical perspectives.

Given that the co-evolutionary dynamism between innovation and institutional systems is a decisive part of an innovation driven economy, sustainability of BRICs' development is subject to this co-evolution. However, no one has undertaken the analysis in this dimension.

As core technology in an information society, ICT is a driving force transforming the traditional socio-economic structure by permeating people's daily life, organizational activities, and society as a whole [38–41]. Furthermore, the unique nature of ICT is formed dynamically through the interaction with institutional systems [38,39]. Watanabe and Kondo [14,19] demonstrated that the nature of ICT could be developed in a self-propagating way through its interaction with institutions. Given the conspicuous impetus in BRICs' development, there is a strong possibility for them to maximize the benefit of ICT by leveraging its self-propagating nature.

However, despite the increasing number of studies on BRICs' development and growth, to date, no attempt has been made to identify the possible co-evolution between their institutional systems and innovation, essential for their sustainable development by making effective utilization of their potential resources.

1.4. Focus of the analysis

Based on the preceding reviews, this paper attempts to demonstrate the aforementioned three hypotheses with special focus on the following dimensions: first, the potential of BRICs' technology to utilize their potential resources for sustainable development is analyzed by computing their TFP. Second, considering manufacturing technology, ICT and software as innovation, a comparative empirical analysis is conducted of the co-evolutionary dynamism between innovation and institutional systems in 40 countries with special attention to the four BRIC countries. Finally, the triggering role of ICT to the co-evolutionary dynamism in the BRICs is examined. The ICT is represented here by the personal computer (PC), the Internet (IN), and the mobile phone (MP).

1.5. Structure of the paper

Section 1 has presented the introduction, and Section 2 presents the analytical framework. Section 3 analyzes the potential of technological development in the BRICs. The co-evolutionary dynamism between innovation and institutional systems is demonstrated in Section 4. Section 5 identifies the role of ICT in triggering this co-evolution. Finally, Section 6 briefly summarizes the findings, policy implications and the points of future works.

2. Analytical framework

As reviewed in the preceding section, given the BRICs' strong impetus in development in addition to their conspicuous development and utilization of ICT, their sustainable development can be envisaged. This can be done by triggering a co-evolution between innovation and institutional systems through the further advancement of ICT, thereby enabling effective utilization of their potential resources. This dynamism is illustrated in Fig. 1.

In line with this dynamism, the following four dimensions essential for BRICs' sustainable development are analyzed:

(i) Potential of technological advancement,
(ii) Institutional systems,
(iii) Co-evolutionary dynamism between innovation and institutional systems, and
(iv) Triggering role of ICT.

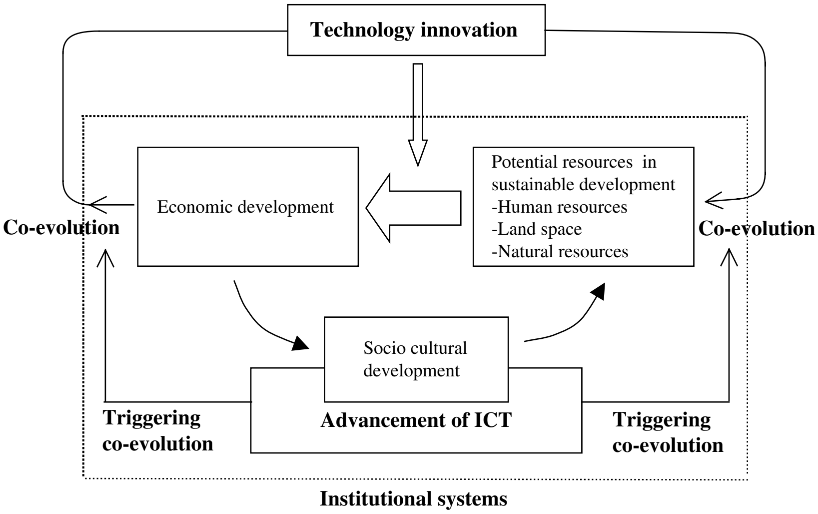

Fig. 1. Scheme of BRICs sustainable development.

2.1. Measurement of the potential of technological advancement

Effective utilization of BRICs' potential resources for sustainable development depends not only on the traditional production factors such as labor and capital, but also substantially on the technological advancement measured by TFP.

BRICs' GDP can be depicted by traditional Cobb–Douglas type production function incorporating labor, capital, and technology represented by TFP.

In line with the Wilson approach [20], which depicts the technological progress rate in catching-up countries as a function of the catching-up speed with that of the USA (see Appendix 1), technological progress in BRICs can be considered part of a process of catch-up with the most developed economies. The speed of convergence is assumed to depend on their economic level as demonstrated by GDP per capita, with the assumption that as the developing economies get closer to the GDP per capita levels of the developed economies, their TFP growth rate gradually decreases. Thereby, their TFP increase ratio can be computed.

2.2. Constitution of institutional systems

Institutional systems (IS) are identified by the following three dimensions (Fig. 2):

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

Therefore, institutional systems (IS) can be depicted as a function of three dimensions *X*, *Y* and *Z*. In addition, each respective dimension can also be depicted as a function of components of its dimension as demonstrated in Fig. 2.

On the basis of the foregoing structure of institutional systems, using principal component analysis (PCA) for the three dimensions respectively, institutional systems can be depicted by means of the governing principal components (see Appendix 2-1).

2.3. 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 principal components of the institutional systems in 40 countries (BRICs, OECD, 6 Asian newly industrializing and developing countries). Manufacturing technology (MT), ICT, and software (SW) are taken for innovation (see Appendix 2-2). Characteristics of co-evolutionary dynamism in BRICs are highlighted by comparison with Japan and the USA.

2.4. Measurement of the triggering role of ICT

In-depth analysis is focused on the triggering role of ICT to the co-evolutionary dynamism between innovation and institutionary systems taking PCs, Internet, as well as mobile phone as representing ICT. Aiming at identifying the

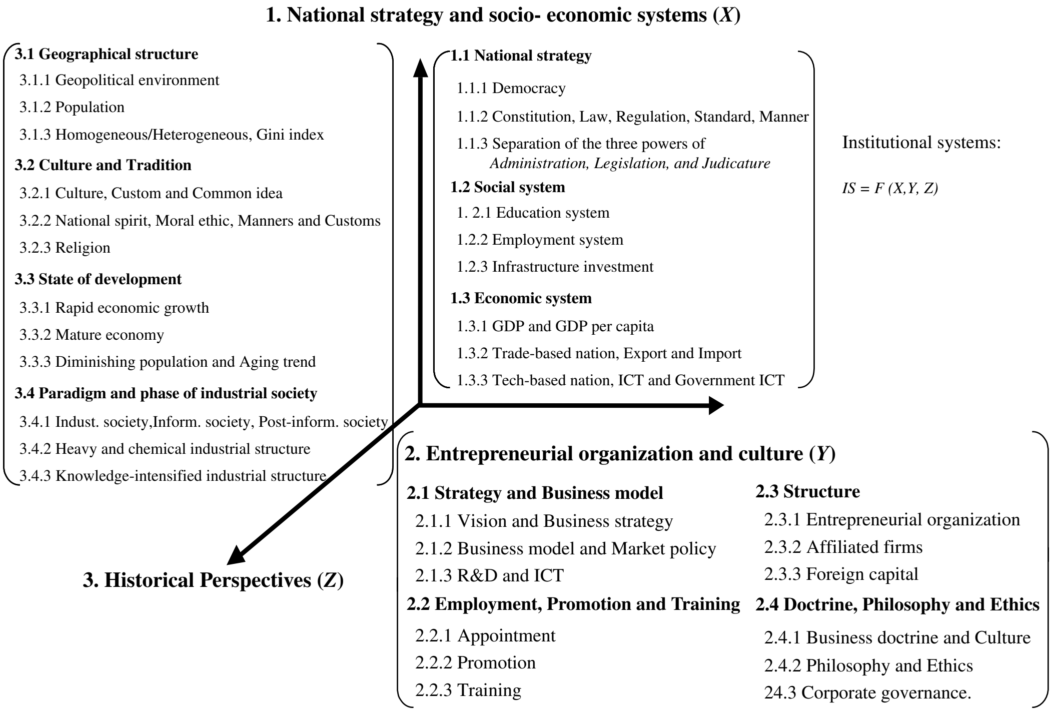

Fig. 2. Constitution of three dimensions of institutional systems. Source: Watanabe [37].

conspicuous development potential of ICT in BRICs, first, comparative analyses of ICT development trajectories between Japan, the USA and BRICs were conducted by using logistic growth model.

Second, the triggering role of ICT was demonstrated by identifying the co-evolutionary dynamism between institutional systems and PC, Internet (IN) as well as mobile phone (MP) by taking principal components regression analysis (see Appendix 2-3).

3. Potential of technological advancement in the BRICs

The potential of technological advancement in the BRICs can be identified by measuring TFP in the production function. While the TFP of developed countries has been measured by many studies, there are still difficulties in measuring TFP in BRICs due primarily to the shortage of reliable statistics particularly of the operating rate of the capital stock and substantial working hours of the labor force.

On the basis of the existing works on this measurement, Table 1 compares estimates of TFP growth rate and its contribution to GDP growth rate in major countries.

Table 1
Estimates of TFP growth rate and its contribution to GDP growth rate in major countries.

Country	Period	GDP growth, rate (% p.a.) (1)	TFP growth, rate (% p.a.) (2)	Contribution, ratio of TFP (%) (2/1)	Sources
Brazil[a]	1990–1995	3.5	1.1	31	Fajnzylber and Lederman [8]
Russia	2002	2.9	1.2	41	IMF [42]
India	1995–1999	6.6	2.2	33	Lee and Khatri [10]
China	2002	9.1	3.6	40	Wu [11]
Japan	2001–2004	2.2	1.2	55	OECD [12], MIC [19]
USA	2000–2004	2.5	1.6	66	OECD [12], IMF [42]
OECD	2000–2005	2.0	0.9	43	OECD [12]
Indonesia	1990–1994	8.5	2.2	26	Lee and Khatri [10]
Philippines	1995–1999	5.0	1.1	22	Lee and Khatri [10]
Thailand	1990–1999	5.7	1.7	30	Lee and Khatri [10]
Taiwan	1995–1999	6.5	2.3	35	Lee and Khatri [10]
Korea	1995–1999	5.9	3.0	51	Lee and Khatri [10]

[a] The average values of 18 Latin American Countries are taken for Brazil.

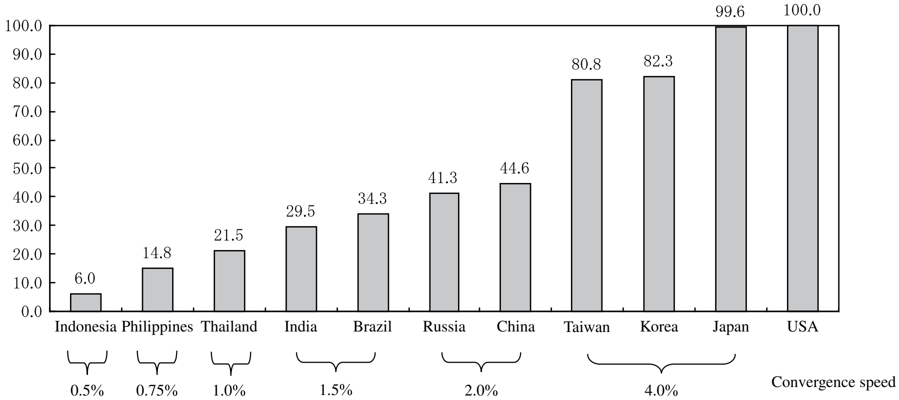

Fig. 3. Classification of convergence speed in selected countries by means of the average of infrastructure and total expenditure on R&D (Index: USA = 100). Original source: IMD [4].

Although we should be careful of the comparison because of the differences between the sources and subsequent difference of the period examined, Table 1 suggests that TFP growth rates in some BRIC countries demonstrate among the highest level. However, their contribution ratios are much smaller than those in industrialized countries like Japan and the USA.

High levels of TFP growth rate in BRICs can largely be attributed to rapid economic growth and not necessarily synchronized with substantial technological advancement that would enable BRIC's effective utilization of their potential resources.

These reviews recall the Wilson approach [20] in identifying TFP growth in catching-up countries which indicate that TFP growth in these countries depends on the impetus to catch-up with the most advanced economies and also the convergence speed governed by the "potential technological strength" of the nation.

With this understanding, Fig. 3 compares the convergence speed in selected countries taking the average value of infrastructure and total expenditure for R&D, which represent the "potential technological strength" of the nation. The infrastructure demonstrates the basic condition and environment required to catch-up with technological advancements, and is composed of infrastructures for health and environment, science and technology, and education. Total expenditure for R&D represents the input in technology development in a catching-up country. Based on these values, levels of convergence speed are classified into six clusters as demonstrated in Fig. 3.

Fig. 3 suggests that the convergence speed of Indonesia is the lowest at 0.5%, which corresponds to the lowest average score of infrastructure and total expenditure on R&D. Indonesia is followed by the Philippines and Thailand with convergence speeds of 0.75% and 1.0%, respectively. Four BRIC countries are divided into two groups: 1.5% for India and Brazil and 2.0% for Russia and China depending on their average score of infrastructure and total expenditure for R&D. Similarly, Japan and two Asian advanced economies, Taiwan and Korea, are in a group of the highest 4.0% convergence speed.

Utilizing the result of the convergence speed estimation, Table 2 compares the estimates of TFP growth rate and its contribution to GDP growth rate in BRICs, Japan, the USA, and other Asian economies in the latest year 2004.[1] Table 2 suggests that TFP contributions to GDP growth in industrialized countries such as the USA and Japan are at a high ratio demonstrating substantial technology advancement. Korea also demonstrates a high level of TFP contribution followed by Taiwan. Their high economic performances can be attributed to rapid progress in electronic technology and ICT. While BRICs have demonstrated higher levels of TFP growth rate than other countries examined, including industrialized countries as the USA and Japan, their TFP contribution rate to GDP growth rate still remains at a lower level than that of these countries. The BRICs average TFP contribution to GDP is 46%, and the remaining 54% still depended on traditional labor and capital input in 2004.

These findings suggest that while BRICs incorporate potential technological innovation, they still depend chiefly on rapid economic growth. Considering the ample potential resources such as natural, financial, and human resources in BRICs, their sustainable development depends on the effective utilization of these resources by means of substantial technology innovation.

4. Co-evolutionary dynamism between innovation and institutional systems

On the basis of the constitution of three dimensions of institutional systems as demonstrated in Fig. 2, using principal component analysis (PCA) for the three dimensions respectively, structure of institutional systems in 40 countries is identified as shown in Fig. 4 (see details in Appendix 3).

[1] Note that while Table 2 indicates the state of the latest year 2004, Table 1 demonstrates the average in certain period in the 1990s or the 2000s.

Table 2
TFP growth rate and its contribution to GDP growth rate in selected countries (2004).

Countries	GDP per capita	Convergence, speed γ (%)	TFP growth rate (%)	GDP growth rate (%)	Contribution, ratio of TFP (%)
Brazil	7969	1.5	2.7	5.7	47
Russia	9832	2.0	3.0	7.2	42
India	3013	1.5	4.1	7.8	53
China	5430	2.0	4.2	10.1	42
Japan	28 670	4.0	1.5	2.7	54
USA	38 360	–	2.6	3.9	67
Indonesia	3505	0.5	1.5	5.0	30
Philippines	4438	0.75	1.9	6.2	31
Thailand	7675	1.0	1.9	6.3	30
Taiwan	24 676	4.0	2.1	4.5[a]	47
Korea	20 777[b]	4.0	2.7	4.7	57

Original sources: $\Delta V/V$: real GDP growth in 2004 (IMF [42]); V/P: GDP (PPP) per capita in 2004 [4].
[a] Three years average data of real GDP growth in 2003–2005 is used (IMF [42]).
[b] GDP (PPP) per capita in 2004 (IMF [42]) is used for Korea.

Fig. 4 demonstrates the constitution of the main principal components (PCs) of each respective three dimensions with major proxies demonstrating the significant loading of variables.

Aiming at examining the co-evolutionary dynamism between institutional systems and innovation, utilizing the results of the principal component analyses, principal components' regressions were conducted among the principal components of institutional systems and MT, ICT as well as software in 40 countries. Using backward eliminating method (BEM) with 5% significant level criteria,[2] the principal components that have significant influences on MT, ICT, as well as software were identified (see details of the results of the analyses in Appendix 4). MT, ICT, and software are represented by *Production Process Sophistication* [15], *Network Readiness Index* [15], and *Potential of Software Development* [4,43], respectively. The *Potential of Software Development* is computed by utilizing the ratio of the number of publications concerning software and GDP PPP per capita.

4.1. Manufacturing technology

The regression result for MT demonstrates statistically significant (see Eq. (A4-1) in Appendix 4), 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 workforce* (PC_{22}) and *elasticity of heterogeneous nations* (PC_{32}) is significant governing institutional factors in the development of MT in the 40 countries examined. Contributions of these factors to MT in BRICs are summarized in Table 3. Japan and the USA are also included for comparison.

Table 3 demonstrates clear contrast between BRICs and Japan/USA with respect to negative or positive impacts of PC_{21} and PC_{11} on their MT development. While these institutional factors induced MT in Japan and the 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, Figs. 5 and 6 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.

Fig. 5 suggests that India and Brazil developed better than China and Russia in terms of PC_{21}. Factors such as *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, an area that requires growth. On the other hand, such factors as *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 issues in Russia which require development.

Similarly, Fig. 6 suggests that China's development surpassed the other three BRIC countries in terms of *quality of traditional development base* (PC_{11}). However, in China such factors as *skilled labor*, *GDP per capita*, and *quality of the educational system* require further development. India must improve its *total expenditure on R&D*, *trade to GDP ratio*, *GDP per capita*, as well as *overall infrastructure quality*. For Russia, the areas in need of development are *risk of political instability* and *need for economic and social reforms* are. Brazil's focus might best be on the *quality of the educational system* and *overall infrastructure quality*.

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

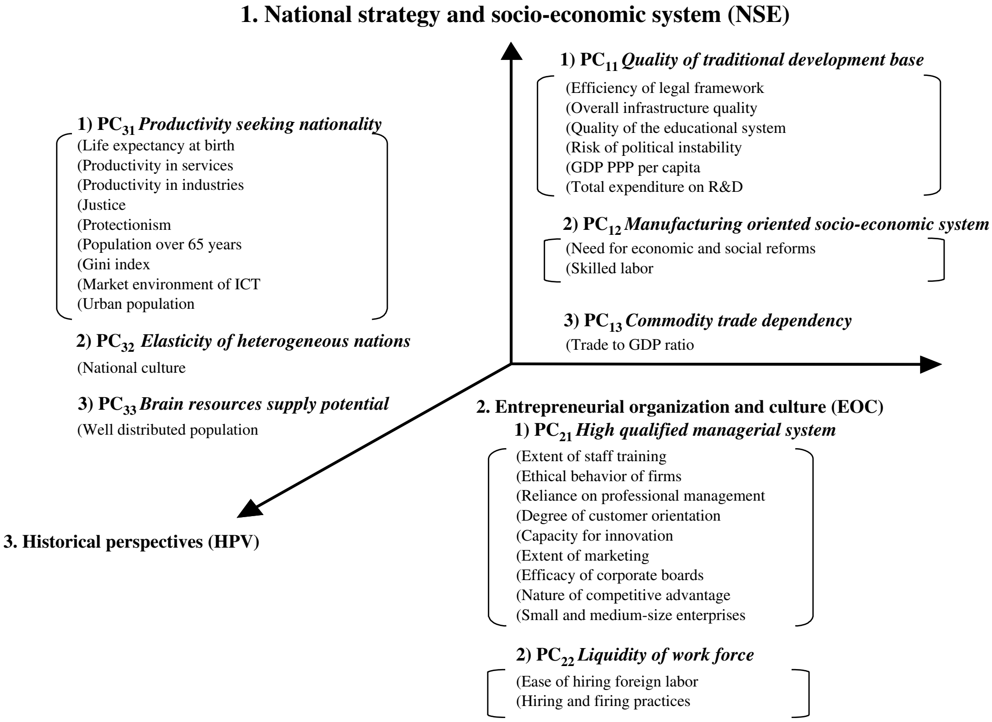

Fig. 4. Structure of institutional systems in 40 countries (2004).

4.2. Information and communication technology (ICT)

The regression result for ICT is statistically significant (see Eq. (A4-2) in Appendix 4), and indicates that MT, software, and institutional factors contribute to the development of ICT. In addition to MT and software, *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 for ICT. Table 4 summarizes contributions of these factors to ICT in BRICs, Japan, and the USA.

Table 4 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 Fig. 6). Furthermore, contrary to the strong inducement of PC_{13} in Japan and the USA, this inducement is weak in the BRICs and even impedes China. Similar to MT, PC_{11}, consisting of *efficiency of legal framework, overall infrastructure quality, quality of the educational system, risk of political instability, and GDP per capita* and *total expenditure on R&D*, impedes the 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 disparity, and development of urbanization contribute to the advancement of ICT. These two countries have the world's highest diffusion velocity in PCs, the Internet, and mobile phones. Unlike India and China, scores of PC_{32} in the 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, Fig. 7 analyzes the constitution of PC_{32} in the four BRIC countries by comparing scores of 12 variables constituting this component.

Table 3
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

Original sources: the Global Competitiveness Report 05–06 [15], World Competitiveness Yearbook 2005 [4], The Global Information Technology Report 04–05 (WEF, 2005) [16], World Development Indicators 2005 [44], Human Development Report 2005 [45], and World Telecommunication Indicators 2004 [17].

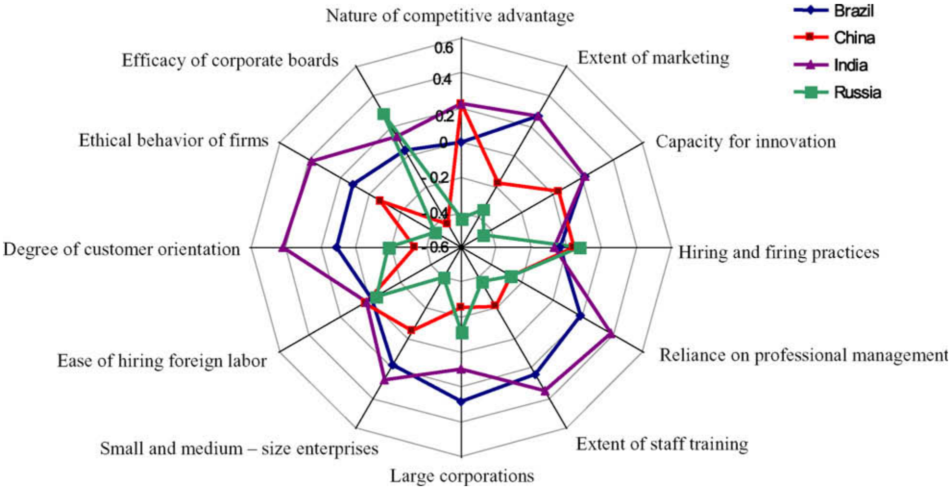

Fig. 5. Contribution of high qualified managerial system (PC_{21}) in the BRICs (2004). Original sources: the Global Competitiveness Report 05–06 [15], and World Competitiveness Yearbook 2005 [4].

Fig. 7 demonstrates that such factors as *market environment of ICT, population over 65 years, justice, protectionism* and *national culture* are all extremely points of weakness in Russia. Factors requiring enhancement for Brazil are related to economic growth, construction of market environment, as well as population and urbanization.

4.3. Software (SW)

The regression result for software is also statistically significant (see Eq. (A4-3) in Appendix 4), 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 development in the BRICs, Japan, and the USA are summarized in Table 5.

Table 5 demonstrates that while the USA is positive in all factors, it is the opposite for Japan. Among the six countries compared, China has the highest value for the potential of software development, thus demonstrating its rapid development of software, which can be attributed to the high impact of PC_{32} and PC_{22}. India demonstrates the highest contribution of PC_{12}

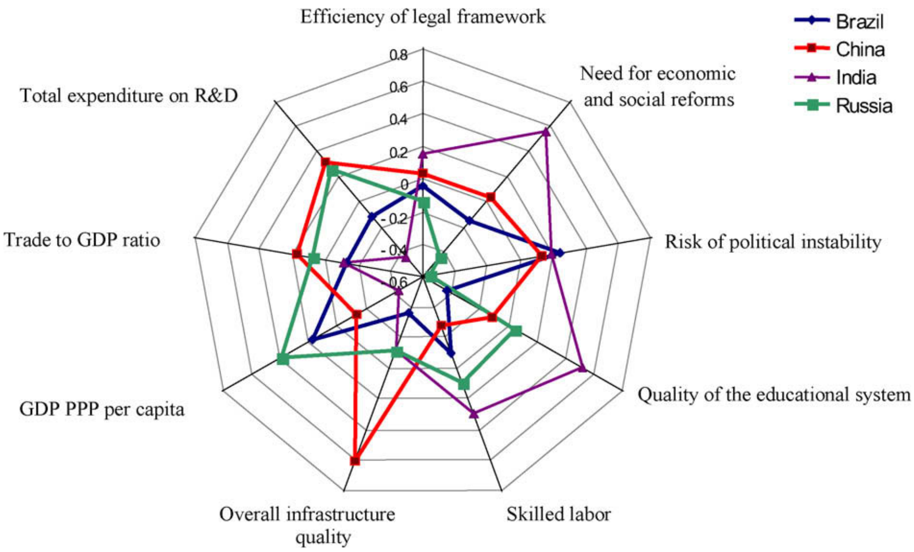

Fig. 6. Contribution of quality of traditional development base (PC_{11}) in the BRICs (2004). Original sources: the Global Competitiveness Report 05–06 [15], and World Competitiveness Yearbook 2005 [4].

Table 4
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

Original sources: the Global Competitiveness Report 05–06 [15], World Competitiveness Yearbook 2005 [4], The Global Information Technology Report 04–05 [16], World Development Indicators 2005 [44], Human Development Report 2005 [45], and World Telecommunication Indicators 2004 [17].

and significant positive impact of PC_{32} (see Fig. 7). These two factors 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 foregoing analysis demonstrates that (i) The advantage of ICT talent's training and the talent supply market contribute to the development of the software industry in China and India; and (ii) characteristics that include a "high-quality workforce," "cheap pay" and an "English sphere" in the software industry give India its competitive edge in the world.

In light of the contrasting impacts of PC_{22} on software in BRICs, Fig. 8 analyzes the constitution of PC_{22} in the four BRIC countries by comparing scores of 12 variables constituting this component.

Fig. 8 suggests that China has advantages in *ease of hiring foreign labor* and *hiring and firing practices*, but is vulnerable in *efficacy of corporate boards*, *nature of competitive advantage*, and *ethical behavior of firms*. Meanwhile, India is also cited for *ease of hiring foreign labor*, but is weak at *hiring and firing practices, in* contrast to China. Russia has the most conspicuous advantage in *hiring and firing practices* but is weak in *ease of hiring foreign labor* compared with other BRIC countries. Contrary to the characteristics of these three BRIC countries, no conspicuous factor can be identified in Brazil. It seems that all of them require further development, particularly within *hiring and firing practices* and *ease of hiring foreign labor*.

4.4. Co-evolutionary dynamism between MT, IT, software and institutional systems

Based on the foregoing analyses, it can be identified that there is a correlation between institutional systems and MT, ICT, and software. Such a correlation leads to constructing a co-evolutionary dynamism between MT, ICT, software, and institutional systems as demonstrated in Fig. 9.

This demonstrates that a strong connection between innovation—represented by MT, ICT, as well as software—and institutional systems functioned well in the 40 countries and led to the construction of a co-evolutionary dynamism as illustrated in Fig. 10.

Fig. 10 demonstrates that institutional systems play an important role in cultivating emerging innovation, and given the foregoing interaction reacts positively, leading to a virtuous cycle. In this case, emerged innovation contributes to a change in

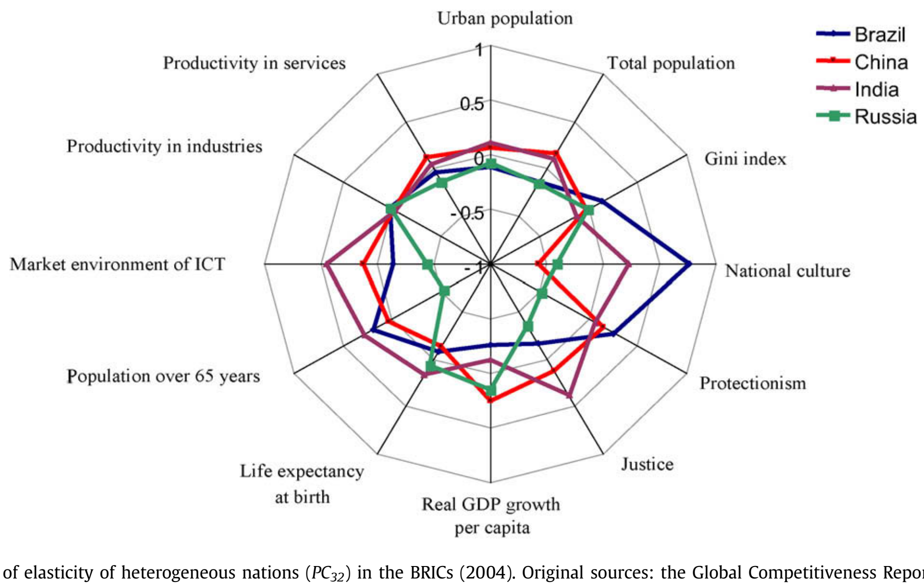

Fig. 7. Contribution of elasticity of heterogeneous nations (PC_{32}) in the BRICs (2004). Original sources: the Global Competitiveness Report 05–06 [15], World Competitiveness Yearbook 2005 [4], The Global Information Technology Report 04–05 [16], World Development Indicators 2005 [44], and Human Development Report 2005 [45].

Table 5
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

Original sources: the Global Competitiveness Report 05–06 [15], World Competitiveness Yearbook 2005 [4], The Global Information Technology Report 04–05 [16], World Development Indicators 2005 [44], Human Development Report 2005 [45], World Telecommunication Indicators 2004 [17], and SCI (Web of Science, 2005) [43].

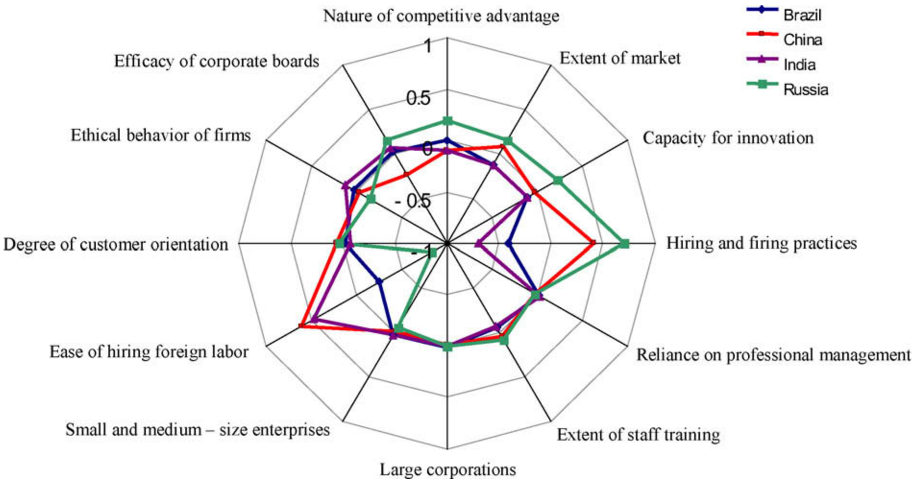

Fig. 8. Contribution of liquidity of workforce (*PC_{22}*) in the BRICs (2004). Original sources: the Global Competitiveness Report 05–06 [15], World Competitiveness Yearbook 2005 [4].

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. Thus, a strong dynamic between innovation and institution would be urgent for BRICs to effectively contribute to their sustainable development.

5. The role of ICT in triggering co-evolution

On the basis of the preceding analyses, the role that BRICs ICT may play in triggering the co-evolution between innovation and institutional systems is examined. This co-evolution leverages BRICs innovation driven economy and enables BRICs sustainable development by making effective utilization of potential resources. On the basis of logistic growth model,[3] which depicts the ICT development trajectory, developing trajectories of PC, Internet (IN) and mobile phone (MP) as the core technologies of ICT, are estimated. The results of the estimates are summarized in Tables 6–8.

Tables 6–8 indicate that the diffusion velocities (coefficient "*a*" in the Tables) of all BRICs' ICT, PC, Internet, and MP, are much higher than those in the USA and Japan in spite of the current lower adaptation, which suggests the huge potential of further ICT development and dissemination in the four BRIC countries.

To examine the triggering role of ICT advancement in the co-evolution between institutional systems and innovation in the BRICs, principal components regressions were conducted in 40 countries. Using backward eliminating method (BEM) with 5% significant level criteria, the principal components that have significant influences on PC, IN, and MP are identified (see details of the results of the analyses in Appendix 5).

5.1. PC

The regression results for PC were statistically significant (see Eq. (A5-1) in Appendix 5), and indicate that Internet, MP, and institutional factors contribute to the development of PC. In addition, *quality of traditional development base* (PC_{11}), *highly qualified managerial system* (PC_{21}), *liquidity of workforce* (PC_{22}), *productivity seeking nationality* (PC_{31}), *elasticity of*

[3] $f(t) = K/1 + e^{-(at+b)}$, where $f(t)$: number of adopters; a: diffusion velocity; b: the initial value; K: carrying capacity (ceiling of the adoption of innovative goods); and t: time trend.

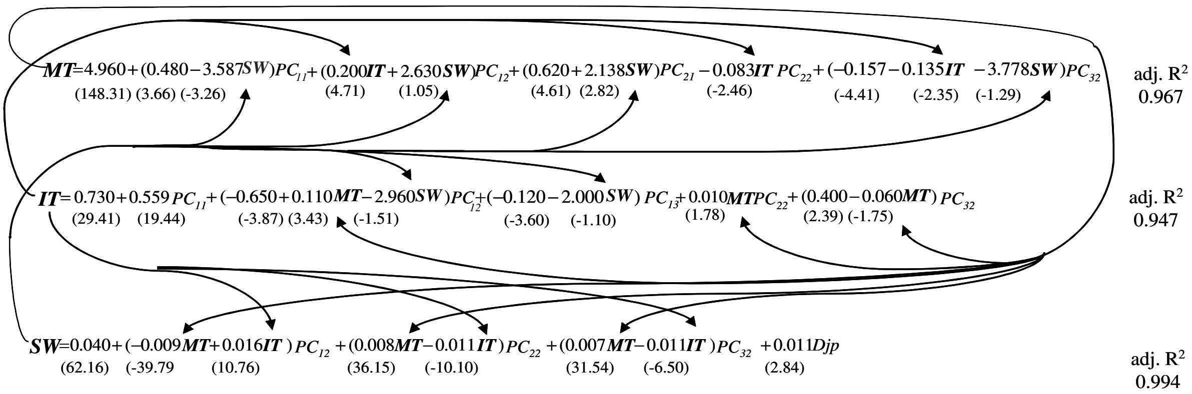

Fig. 9. Contributing effects between institutional factors, MT, ICT and software. [a]In this Figure, IT represents ICT. [b]Figures in parentheses indicate *t*-values.

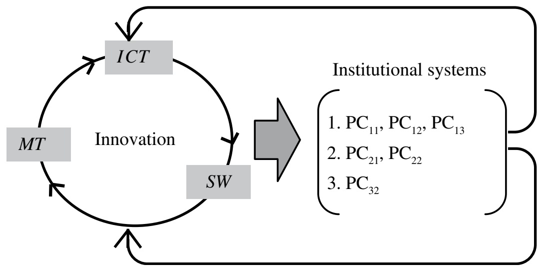

Fig. 10. Co-evolutionary dynamism between innovation and institutional systems.

Table 6
Comparison of developing trajectories of PC between BRICs, Japan and the USA.

	K	A	b	adj. R^2
Brazil	56 173 (4.93)	0.27 (20.70)	−4.75 (−37.52)	0.998
Russia	42 818 (3.71)	0.29 (11.02)	−4.55 (−30.47)	0.994
India	74 325 (6.83)	0.31 (31.90)	−5.12 (−57.21)	0.999
China	89 190 (5.58)	0.42 (9.24)	−5.83 (−18.50)	0.992
Japan	119 511 (3.32)	0.22 (6.93)	−3.14 (−15.86)	0.983
USA	493 469 (2.56)	0.13 (4.14)	−2.30 (−3.80)	0.969

Figures in parentheses indicate *t*-values, all statistically significant at the 1% level.
Original sources: the Global Information Technology Report 04–05 (WEF, 2005) [16], World Telecommunication Indicators 2004 [17].

Table 7
Comparison of developing trajectories of internet between BRICs, Japan and the USA.

	K	A	b	adj. R^2
Brazil	29 986 (11.67)	0.63 (12.59)	−8.43 (−16.99)	0.996
Russia	27 884 (6.58)	0.60 (8.97)	−8.91 (−12.76)	0.992
India	109 460 (5.41)	0.87 (4.97)	−10.99 (−6.03)	0.979
China	108 782 (28.79)	0.85 (19.03)	−10.90 (21.88)	0.998
Japan	67 997 (62.88)	0.59 (27.03)	−7.26 (−30.53)	0.999
USA	188 867 (32.73)	0.50 (16.38)	0.50 (16.38)	0.996

Figures in parentheses indicate *t*-values, all statistically significant at the 1% level.
Original sources: the Global Information Technology Report 04–05 (WEF, 2005) [16], World Telecommunication Indicators 2004 [17].

Table 8
Comparison of developing trajectories of mobile phone between BRICs, Japan and the USA.

	K	A	b	adj. R^2
Brazil	731 (3.22)	0.41 (8.01)	−6.66 (−19.51)	0.990
Russia	1045 (8.84)	0.88 (54.43)	−13.51 (−142.40)	0.999
India	843 (27.84)	0.70 (13.61)	−10.59 (−15.05)	0.995
China	1479 (7.23)	0.82 (8.01)	−16.32 (−9.33)	0.989
Japan	685 (50.34)	0.59 (18.04)	−10.48 (−19.27)	0.996
USA	759 (33.14)	0.34 (31.97)	−6.05 (−46.74)	0.999

Figures in parentheses indicate *t*-values, all statistically significant at the 1% level.
Original sources: the Global Information Technology Report 04–05 (WEF, 2005) [16], World Telecommunication Indicators 2004 [17].

Table 9
Contribution of institutionary system to PC in 6 countries (2004).

	lnPC	Const.	PC_{11}	PC_{21}	PC_{22}	PC_{31}	PC_{32}	PC_{33}
Brazil	4.407	5.490	−1.134	−1.604	−0.670	2.618	−0.413	0.119
Russia	4.736	5.490	−1.330	−2.564	0.103	2.872	0.543	−0.378
India	2.310	5.490	−0.889	−4.021	−0.866	11.527	−3.872	−5.060
China	3.249	5.490	−1.271	−4.907	0.425	5.524	−1.373	−0.641
Japan	6.355	5.490	−0.194	0.697	−0.139	0.532	0.570	−0.600
USA	6.449	5.490	−0.276	1.696	0.059	0.494	−0.198	−0.817

Original sources: the Global Competitiveness Report 05–06 [15], World Competitiveness Yearbook 2005 [4], The Global Information Technology Report 04–05 (WEF, 2005) [16], World Development Indicators 2005 [44], Human Development Report 2005 [45], World Telecommunication Indicators 2004 [17].

heterogeneous nations (PC_{32}) and *brain resources supply potential* (PC_{33}) are significant governing institutional factors to the development of PC. Contributions of these factors to PC in the BRICs, Japan and the USA are summarized in Table 9.

Table 9 demonstrates a clear contrast between BRICs and Japan/USA with respect to negative or positive impacts of PC_{21} on their development of PC (see Fig. 5). While this institutional factor induced high diffusion of PC in Japan and the USA, it impeded the diffusion of PC in the BRICs. The most significant contributing institutional factor for the BRICs is PC_{31}. Scores of this component in the BRIC countries are much higher than those in the USA and Japan and contribute to BRICs rapid growth rate of PC. Among them, India demonstrates the top, followed by China, Russia and Brazil.

In light of the significant impacts of PC_{31} on PC in the BRICs, Fig. 11 analyzes the constitution of PC_{31} by comparing scores of 12 variables constituting this component.

Fig. 11 suggests that India's high score can be attributed to the high values of *justice*, *income imparity (Gini Index)* and *market environment of ICT* while current states of *productivity in industrie*s, *life expectancy at birth* and *urban population* have impeded an increased score. The most significant institutional factor to the development of PC in China is *life expectancy at birth* followed by *protectionism, justice* and *market environment of ICT*, while a low level of *productivity in service* and large *population* have impeded the increase in PC. Russia has advantages in *productivity in service*, *productivity in industries* and *population*, while requiring further enhancement of its *protectionism, justice, life expectancy* and *economic growth*. The factors of *urbanization*, *productivity in industries, economic growth* and *protectionism* have contributed to the score of PC_{31} in Brazil, while the balance of *income*, low degree of *justice* and *younger population* impeded the increase of the score.

5.2. Internet

The regression result for the Internet demonstrates statistically significant (see Eq. (A5-2) in Appendix 5), and indicates that PC, MP, and institutional factors contribute to the development of Internet. In addition, *highly qualified managerial system* (PC_{21}), *productivity seeking nationality* (PC_{31}), *elasticity of heterogeneous nations* (PC_{32}) and *brain resources supply potential* (PC_{33}) are significant governing institutional factors to the development of Internet. Contributions of these factors to Internet in the BRICs, Japan and the USA are summarized in Table 10.

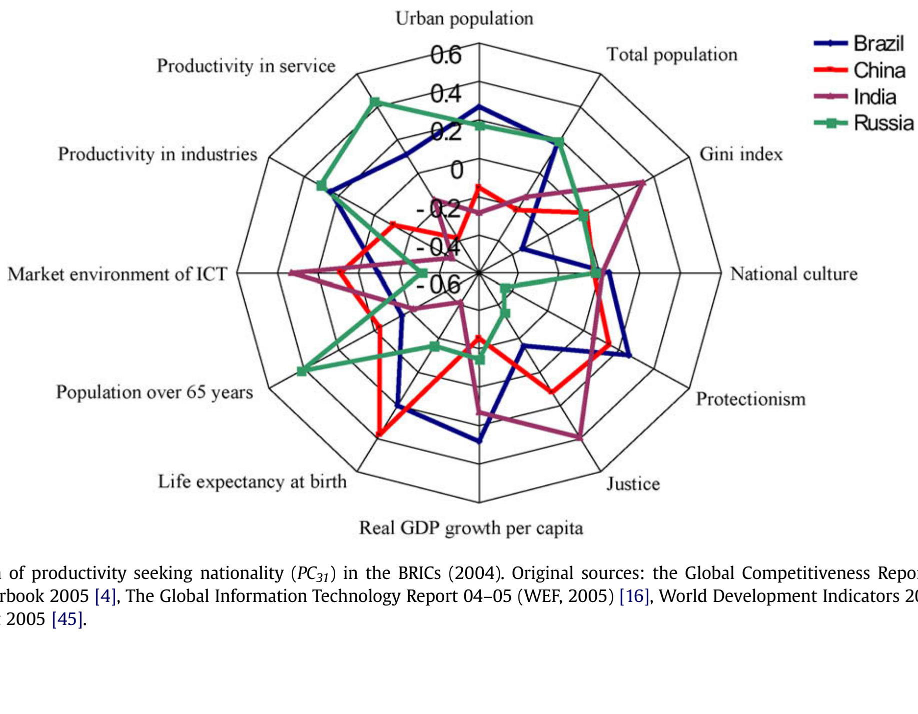

Fig. 11. Contribution of productivity seeking nationality (PC_{31}) in the BRICs (2004). Original sources: the Global Competitiveness Report 05–06 [15], World Competitiveness Yearbook 2005 [4], The Global Information Technology Report 04–05 (WEF, 2005) [16], World Development Indicators 2005 [44], and Human Development Report 2005 [45].

Table 10
Contribution of institutional system to internet in 6 countries (2004).

	lnIN	Const.	PC_{21}	PC_{31}	PC_{32}	PC_{33}
Brazil	8.273	5.726	−1.448	3.803	0.052	0.141
Russia	7.001	5.726	−2.239	3.994	−0.396	−0.084
India	5.152	5.726	−3.792	8.871	−2.822	−2.830
China	7.394	5.726	−4.507	6.136	−0.268	0.307
Japan	3.453	5.726	0.571	−1.333	−0.991	−0.519
USA	4.584	5.726	1.429	−1.582	0.259	−1.247

Original sources: the Global Competitiveness Report 05–06 [15], World Competitiveness Yearbook 2005 [4], The Global Information Technology Report 04–05 (WEF, 2005) [16], World Development Indicators 2005 [44], Human Development Report 2005 [45], World Telecommunication Indicators 2004 [17].

Table 11
Contribution of institutional system to mobile phone in 6 countries (2004).

	lnMP	Const.	PC_{31}	PC_{33}
Brazil	5.727	6.754	−1.027	0.243
Russia	5.454	6.754	−1.300	0.076
India	4.487	6.754	−2.267	−0.367
China	5.046	6.754	−1.707	−0.349
Japan	6.912	6.754	0.159	−0.104
USA	6.948	6.754	0.194	−0.129

Original sources: the Global Competitiveness Report 05–06 [15], World Competitiveness Yearbook 2005 [4], the Global Information Technology Report 04–05 (WEF, 2005) [16], World Development Indicators 2005 [45], Human Development Report 2005 (UN, 2006) [46], and World Telecommunication Indicators 2004 [17].

Table 10 demonstrates a similar contributing effect of institutional factors to Internet as to that of PC. Both the USA and Japan have high positive scores of *highly qualified managerial system* (PC_{21}) which contribute to diffusion of Internet, while the weakness of PC_{21} is significantly impeding the Internet diffusion in the BRICs (see Fig. 5). The most significant contributing institutional factor to Internet for the BRICs is *productivity seeking nationality* (PC_{31}), the scores of PC_{31} in the BRICs are all significantly positive (India is the highest, followed by China, Russia and Brazil) while that of the USA and Japan are negative (see Fig. 11).

5.3. Mobile phone

The regression result for MP also demonstrates statistically significant (see Eq. (A5-3) in Appendix 5), and indicates that Internet and institutional factors contribute to the development of MP. In addition, PC_{31} and PC_{33} are significant to the development of MP. Further to the preceding analysis, contributions of governing institutional factors to MP in the BRICs, Japan and the USA are summarized in Table 11.

The positive scores of *productivity seeking nationality* (PC_{31}) in the USA and Japan in Table 11 demonstrate that PC_{31} has contributed the diffusion of MP in ICT advanced countries, while the weakness of *productivity seeking social system* is a significant impediment for the diffusion of MP in the BRICs (see Fig. 9). The scores of PC_{33} suggest that the problem of the big overall *population* and the *income* imbalance has negative impacts on diffusion of MP.

6. Conclusion

In light of the conspicuous economic growth demonstrated by the BRIC countries in the early 21st century depending on their geographic advantages, this paper analyzed the possibility of their sustainable development and identified the necessary conditions to be satisfied.

With the understanding that advancement of technology induced by a co-evolution between innovation and institutional systems is crucial for the BRICs' sustainable development, empirical analyses of the development trajectories in 40 countries centered around the BRIC countries were conducted and demonstrated the following hypothetical views:

(i) BRICs sustainable development depends on the effective utilization of their potential resources by technology advancement,
(ii) This advancement is subject to the co-evolutionary dynamism between innovation and institutional systems, and
(iii) Further advancement of ICT plays a triggering role for this co-evolution.

Noteworthy findings include:

(i) While BRICs have currently demonstrated a higher TFP growth rate than other countries, its TFP growth depends simply on the impetus of rapid economic growth not on the substantial innovation, enabling effective synchronization of potential resources and sustainable development.

(ii) The major factor impeding BRICs' substantial technology innovation can be attributed to low MT levels.
(iii) BRICs have constructed a strong interacting relationship between innovation including MT, ICT, software and their institutional systems, and therefore, advancement of MT depends on the way of interaction between ICT, software, and institutional systems. However certain institutional factors impede this interaction and lead to a virtuous cycle that creates a co-evolution between innovation and institutional systems.
(iv) Strong impediment factors in the 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.
(v) 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 the USA, the conspicuous growth rates of ICT market environment, labor source and human resource supply in China and India suggest their potential for rapid development.
(vi) Given the strong interaction between MT, ICT, software, and institutional systems, further advancement of ICT and software 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 sustainable development.

These findings lead to the following policy implications to support the BRICs sustainable development:

(i) Every effort should focus on the effective utilization of abundant natural resources, land area, and population to encourage sustainable development.
(ii) Technology advancement efforts should focus on the accomplishment of this development through the improvement of the productivities of resources, land area and labor.
(iii) Given that the co-evolution between innovation and institutional systems is essential for substantial innovation enabling the above accomplishment, institutional impediments of such a co-evolution should be eliminated.
(iv) In this context, structural improvement of management systems including enterprise management, education and training of employee, market strategy and customer satisfaction systems should be endeavored.
(v) Potential comparative advantages in ICT and software should be fully utilized for this improvement. ICTs use as a trigger to leverage co-evolution between innovation and institutional systems should be accelerated.

Future research should focus on the in-depth empirical analysis of the similarity and disparity of institutional innovation between the BRIC countries. Identification of comparative advantages and disadvantages on the innovation in each respective country and effects of global co-evolution within the BRICs as well as with other countries would be another important subject to be investigated at high priority.

Appendix 1. Wilson approach in measuring technological progress rate in catching-up countries

$$\frac{A_t}{A_{t-1}} = \beta - \gamma \ln\frac{(V/P)_i}{(V/P)_{US}}$$

where A_t: level of technological progress at time t; V: GDP; P: population; $(V/P)_i$: GDP per capita in catching-up economy i; $(V/P)_{US}$: GDP per capita in the USA; β: long-term TFP growth rate in the USA; and γ: convergence speed for catching-up economy.

Appendix 2. Principal component analysis in analyzing the co-evolution between innovation and institutional systems

2-1. Principal components of the institutional systems

$X = X(\mathrm{PC}x_1, \mathrm{PC}x_2, \mathrm{PC}x_3,\ldots,\mathrm{PC}x_n)$, $Y = Y(\mathrm{PC}y_1, \mathrm{PC}y_2, \mathrm{PC}y_3,\ldots,\mathrm{PC}y_n)$, $Z = Z(\mathrm{PC}z_1, \mathrm{PC}z_2, \mathrm{PC}z_3,\ldots,\mathrm{PC}z_n)$, where $\mathrm{PC}x_i$, $\mathrm{PC}y_i$, and $\mathrm{PC}z_i$ $(i = 1 \sim n)$ are principal components of three dimensions in IS, respectively.

2-2. Principal components regression between institution and innovation

Regression models: $\mathrm{MT} = F(\mathrm{PC}_{\alpha\beta}, \mathrm{ICT}, \mathrm{SW})$, $\mathrm{ICT} = F(\mathrm{PC}_{\alpha\beta}, \mathrm{MT}, \mathrm{SW})$, $\mathrm{SW} = F(\mathrm{PC}_{\alpha\beta}, \mathrm{MT}, \mathrm{ICT})$, where $\mathrm{PC}_{\alpha\beta}$: governing principal components of institutional systems; α $(=x, y, z)$: three dimensions of institutional systems; and β $(=1 \sim n)$: number of principal components in three dimensions.

2-3. Principal components regression on the co-evolution between institution and ICT

Regression models: $\mathrm{PC} = F(\mathrm{PC}_{\alpha\beta}, \mathrm{MP}, \mathrm{IN})$, $\mathrm{IN} = F(\mathrm{PC}_{\alpha\beta}, \mathrm{PC}, \mathrm{MP})$, $\mathrm{MP} = F(\mathrm{PC}_{\alpha\beta}, \mathrm{PC}, \mathrm{IN})$,, where $\mathrm{PC}_{\alpha\beta}$: governing principal components of institutional systems; α $(=x, y, z)$: three dimensions of institutional systems; and β $(=1 \sim n)$: number of principal components in three dimensions.

Appendix 3. Principal component analysis of three dimensions of institutional system in 40 countries

(1) Based on the structure of institutional systems as Fig. 2, proxies representing 33 institutional factors were constructed as tabulated in the right hand side of follows:

Proxies of selected factors

□ National strategy and socio-economic system

1.1 National strategy 1.1.1 Democracy 1.1.2 Constitution, Law, Regulation, Standard, Manner 1.1.3 Separation of the three powers of *Administration, Legislation*, and *Judicature*	1.1.1 Efficiency of legal framework 1.1.2 Need for economic and social reforms 1.1.3 Risk of political instability
1.2 Social system 1. 2.1 Education system 1.2.2 Employment system 1.2.3 Infrastructure investment	1.2.1 Quality of the educational system 1.2.2 Skilled labor 1.2.3 Overall infrastructure quality
1.3 Economic system 1.3.1 GDP and GDP per capita 1.3.2 Trade-based nation, Export and Import 1.3.3 Tech-based nation, ICT and Government ICT	1.3.1 GDP PPP per capita 1.3.2 Trade to GDP ratio 1.3.3 Total expenditure on R&D

□ Entrepreneurial organization and culture

2.1 Strategy and Business model 2.1.1 Vision and Business strategy 2.1.2 Business model and Market policy 2.1.3 R&D and ICT	2.1.1 Nature of competitive advantage 2.1.2 Extent of marketing 2.1.3 Capacity for innovation
2.2 Employment, Promotion and Training 2.2.1 Appointment 2.2.2 Promotion 2.2.3 Training	2.2.1 Hiring and firing practices 2.2.2 Reliance on professional management 2.2.3 Extent of staff training
2.3 Structure 2.3.1 Entrepreneurial organization 2.3.2Affiliated firms 2.3.3 Foreign capital	2.3.1 Large corporations 2.3.2 Small and medium-size enterprises 2.3.3 Ease of hiring foreign labor
2.4 Doctrine, Philosophy and Ethics 2.4.1 Business doctrine and Culture 2.4.2 Philosophy and Ethics 2.4.3 Corporate governance	2.4.1 Degree of customer orientation 2.4.2 Ethical behavior of firms 2.4.3 Efficacy of corporate boards

□ Historical perspectives

3.1 Geographical structure 3.1.1 Geopolitical environment 3.1.2 Population 3.1.3 Homo/Hetero, Gini index	3.1.1 Urban population 3.1.2 Total population 3.1.3 Gini index
3.2 Culture and Tradition 3.2.1 Culture, Custom and Common idea 3.2.2 National spirit, Moral ethic, Manners and Customs 3.2.3 Religion	3.2.1 National culture 3.2.2 Protectionism 3.3.3 Justice
3.3 State of development 3.3.1 Rapid economic growth 3.3.2 Mature economy 3.3.3 Diminishing population and Aging trend	3.3.1 Real GDP growth per capita 3.3.2 Life expectancy at birth 3.3.3 Population over 65 years
3.4 Paradigm and phase of industrial society 3.4.1 Indult. society, Inform. society, Post-inform. society 3.4.2 Heavy and chemical industrial structure 3.4.3 Knowledge-intensified industrial structure	3.4.1 Market environment of ICT 3.4.2 Productivity in industries 3.4.3 Productivity in services

(2) The main process and result of principal component analysis for three dimensions

(i) National Strategy and Socio-economic System (NSE)

Table A1
Descriptive statistics of principal components on NSE.

Components	Eigen value	Variance proportion (%)	Cumulative variance proportion (%)
PC_1	4.754	52.825	52.825
PC_2	1.292	14.350	67.175
PC_3	1.047	11.629	78.804
PC_4	0.633	7.029	85.833
PC_5	0.407	4.523	90.356
PC_6	0.402	4.467	94.824
PC_7	0.248	2.758	97.582
PC_8	0.127	1.412	98.993
PC_9	0.091	1.007	100.000

Table A2
Standardized weight and loading of variables in selected PCs on NSE.

	Standardized weight of variables in selected PCs			Loading of variables		
	PC_1	PC_2	PC_3	PC_1	PC_2	PC_3
Efficiency of legal framework	0.423	−0.134	0.041	0.923	−0.152	0.042
Need for economic and social reforms	0.125	0.729	0.016	0.272	0.829	0.016
Risk of political instability	0.377	−0.157	0.090	0.822	−0.179	0.092
Quality of the educational system	0.389	0.198	0.044	0.849	0.225	0.045
Skilled labor	0.246	0.479	−0.317	0.537	0.544	−0.324
Overall infrastructure quality	0.417	−0.188	−0.011	0.910	−0.214	−0.011
GDP PPP per capita	0.358	−0.289	0.107	0.780	−0.328	0.109
Trade to GDP ratio	0.146	0.192	0.839	0.318	0.218	0.858
Total expenditure on R&D	0.357	−0.046	−0.415	0.779	−0.052	−0.425

(ii) Entrepreneurial Organization and Culture (EOC)

Table A3
Descriptive statistics of principal components on EOC.

Components	Eigen value	Variance proportion (%)	Cumulative variance proportion (%)
PC_1	7.696	64.135	64.135
PC_2	1.229	10.239	74.373
PC_3	0.920	7.663	82.037
PC_4	0.811	6.757	88.794
PC_5	0.398	3.318	92.111
PC_6	0.342	2.850	94. 961
PC_7	0.242	2.014	96.975
PC_8	0.133	1.112	98.086
PC_9	0.078	0.653	98.739
PC_{10}	0.060	0.503	99.242
PC_{11}	0.060	0.496	99.738
PC_{12}	0.031	0.262	100.000

Table A4
Standardized weight and loading of variables in selected PCs on EOC.

	Standardized weight of variables in selected PCs		Loading of variables	
	PC_1	PC_2	PC_1	PC_2
Nature of competitive advantage	0.311	−0.134	0.862	−0.149
Extent of marketing	0.314	−0.140	0.872	−0.155
Capacity for innovation	0.315	−0.157	0.875	−0.174
Hiring and firing practices	0.065	0.662	0.179	0.734
Reliance on professional management	0.336	0.023	0.931	0.025
Extent of staff training	0.345	−0.074	0.957	−0.082
Large corporations	0.234	−0.006	0.650	−0.007
Small and medium-size enterprises	0.300	0.044	0.833	0.049
Ease of hiring foreign labor	0.031	0.667	0.087	0.739
Degree of customer orientation	0.331	−0.058	0.919	−0.064
Ethical behavior of firms	0.341	0.012	0.945	0.131
Efficacy of corporate boards	0.312	−0.171	0.866	−0.190

(iii) Historical Perspectives (HPV).

Table A5
Descriptive statistics of principal components on HPV.

Components	Eigen value	Variance proportion (%)	Cumulative variance proportion (%)
PC_1	6.135	51.127	51.127
PC_2	1.714	14.287	65.414
PC_3	1.113	7.395	74.692
PC_4	0.691	5.757	80.449
PC_5	0.597	4.978	85.427
PC_6	0.476	3.965	89.393
PC_7	0.398	3.320	92.713
PC_8	0.280	2.335	95.047
PC_9	0.222	1.851	96.898
PC_{10}	0.145	1.212	98.110
PC_{11}	0.143	1.194	99.305
PC_{12}	0.083	0.695	100.000

Table A6
Standardized weight and loading of variables in selected PCs on HPV.

	Standardized weight of variables in selected PC			Loading of variables		
	PC_1	PC_2	PC_3	PC_1	PC_2	PC_3
Urban population	0.263	−0.107	−0.421	0.652	−0.140	−0.444
Total population	−0.215	0.164	0.637	−0.533	0.215	0.672
Gini index	−0.280	0.108	−0.364	−0.693	0.141	−0.384
National culture	0.034	0.612	−0.357	0.085	0.801	−0.377
Protectionism	0.313	0.328	−0.093	0.776	0.429	−0.098
Justice	0.329	0.325	0.187	0.816	0.425	0.197
Real GDP growth per capita	−0.249	0.237	0.076	−0.616	0.310	0.080
Life expectancy at birth	0.359	−0.136	−0.045	0.890	−0.178	−0.047
Population over 65 years	0.289	−0.364	0.141	0.716	−0.476	0.149
Market environment ICT	0.273	0.379	0.276	0.676	0.496	0.291
Productivity in industries	0.350	0.033	0.101	0.867	0.043	0.107
Productivity in services	0.356	−0.109	0.025	0.882	−0.143	0.026

Appendix 4. Principal components regressions between the principal components of institutional systems and MT, ICT as well as software in 40 countries

$$\begin{aligned} MT = {} & \underset{(148.31)}{4.960} + \Big(\underset{(3.66)}{0.480} - \underset{(-3.26)}{3.587}\,SW\Big)\underset{(4.71)}{PC_{11}} + \Big(\underset{(1.05)^{**}}{0.200}\,ICT + \underset{(4.61)}{2.630}\,SW\Big)\underset{(2.82)}{PC_{12}} + \Big(\underset{(-2.46)}{0.620} + 2.138\,SW\Big)PC_{21} - 0.083\,ICT\,PC_{22} \\ & + \Big(\underset{(-4.41)}{-0.157} - \underset{(-2.35)}{0.125}\,ICT - \underset{(-1.29)^{*}}{3.778}\,SW\Big)PC_{32}, \quad adj.\ R^2 0.967 \end{aligned} \tag{A4-1}$$

*Significant at the 10% level; **significant at the 15% level.

$$\begin{aligned} ICT = {} & \underset{(29.41)}{0.730} + \underset{(19.44)}{0.559}\,PC_{11} + \Big(\underset{(-3.87)\quad(3.43)}{-0.650} + \underset{(-1.51)^{*}}{0.110}\,MT - \underset{(-3.60)}{2.960}\,SW\Big)\underset{(-1.10)^{**}}{PC_{12}} + (-0.120 - 2.000\,SW)PC_{13} \\ & + \underset{(1.78)}{0.010}\,MT\,\underset{(2.39)}{PC_{22}} + \Big(0.400 - \underset{(-1.75)}{0.060}\,MT)\,PC_{32}, \quad adj.\ R^2 0.947 \end{aligned} \tag{A4-2}$$

*Significant at the 10% level; **significant at the 15% level.

$$\begin{aligned} SW = {} & \underset{(62.16)}{0.040} + \Big(\underset{(-39.79)}{-0.009}\,MT + \underset{(10.76)}{0.016}\,ICT\Big)\underset{(36.15)}{PC_{12}} + \Big(\underset{(-10.10)}{0.008}\,MT - \underset{(31.54)}{0.011}\,ICT\Big)\underset{(-6.50)}{PC_{22}} + \Big(\underset{(2.84)}{0.007}\,MT - 0.011ICT\Big)PC_{32} \\ & + 0.011D_{jp}, \quad adj.\ R^2 0.994 \end{aligned} \tag{A4-3}$$

Appendix 5. Principal components regressions between the principal components of institutional systems and PC, internet as well as MP in 40 countries

$$\begin{aligned}\ln \mathrm{PC} = {} & \underset{(67.63)}{5.49} + \Big(\underset{(2.94)}{3.87} - \underset{(3.04)}{0.65} \ln \mathrm{IN}\Big)\mathrm{PC}_{11} + \Big(\underset{(3.95)}{14.21} - \underset{(3.86)}{2.05} \ln \mathrm{MP}\Big)\mathrm{PC}_{21} + \Big(\underset{(2.99)}{2.03} - \underset{(2.69)}{0.30} \ln \mathrm{IN}\Big)\mathrm{PC}_{22} \\ & + \Big(\underset{(4.30)}{-14.06} + \underset{(4.43)}{1.25} \ln \mathrm{IN} + \underset{(2.72)}{1.07} \ln \mathrm{MP}\Big)\mathrm{PC}_{31} + \Big(\underset{(4.70)}{-6.62} + \underset{(4.48)}{0.95} \ln \mathrm{MP}\Big)\mathrm{PC}_{32} \\ & + \Big(\underset{(4.08)}{-4.60} - \underset{(4.32)}{0.89} \ln \mathrm{IN} + \underset{(4.61)}{1.48} \ln \mathrm{MP}\Big)\mathrm{PC}_{33}, \quad \text{adj. } R^2 0.932\end{aligned} \tag{A5-1}$$

$$\begin{aligned}\ln \mathrm{IN} = {} & \underset{(61.36)}{5.73} + \Big(\underset{(3.16)}{13.57} - \underset{(3.07)}{1.97} \ln \mathrm{MP}\Big)\mathrm{PC}_{21} + \Big(\underset{(2.51)}{-8.18} + \underset{(2.26)}{0.92} \ln MP\Big)\mathrm{PC}_{31} + \Big(\underset{(3.68)}{-6.5} + \underset{(3.58)}{1.12} \ln \mathrm{MP}\Big)\mathrm{PC}_{32} \\ & + \Big(\underset{(3.03)}{-3.8} + \underset{(3.89)}{1.24} \ln \mathrm{MP} - 0.80 \ln PC\Big)\underset{(4.32)}{}\mathrm{PC}_{33}, \quad \text{adj. } R^2 0.880\end{aligned} \tag{A5-2}$$

$$\ln \mathrm{MP} = \underset{(87.54)}{6.75} + \Big(\underset{(3.50)}{2.06} - 0.28 \ln \mathrm{IN}\Big)\underset{(5.19)}{} \mathrm{PC}_{31} - \underset{(1.93)}{0.12\ \mathrm{PC}_{33}}, \quad \text{adj. } R^2 0.790 \tag{A5-3}$$

References

[1] International Monetary Fund (IMF). World Economic Outlook Database. Washington (DC): IMF; April 2006.
[2] International Monetary Fund (IMF). World Economic Outlook Database. Washington (DC): IMF; April 2004.
[3] British Petroleum (BP). Statistical Review of World Energy. Available from: http://www.bp.com/; 2005.
[4] International Institute for Management Development (IMD). World Competitiveness Yearbook 2005. Lausanne, Switzerland: IMD; 2005.
[5] United Nations Conference on Trade and Development (UNCTAD). World Investment Report 2005. Switzerland: UNCTAD; 2006.
[6] 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):319–35.
[7] Dahlman C, Ross-Larson B, Westphal L. Managing technological development: lessons from the newly industrializing countries. World Development 1987;15(6):759–75.
[8] Fajnzylber P, Lederman D. Economic reforms and total factor productivity growth in Latin America and the Caribbean (1950–95). World Bank: Policy Research Working Paper; 1999.
[9] International Monetary Fund (IMF). Russian Federation: 2006 Article IV Consultation. Washington (DC): IMF; 2006.
[10] Lee H, Khatri Y. Information technology and productivity growth in Asia. IMP: IMF Working Paper; 2003.
[11] Wu X. Measurement and analysis of total factor productivity in every province of our country. Operations Research and Management Science 2006; 15(5):149–53.
[12] Organization for Economic Co-operation and Development (OECD). Database 2006. Available from: http://www.oecd.org/home/.
[13] Ministry of Internal Affairs and Communication (MIC). Japan Statistical Yearbook 2004. Tokyo: Statistical Research and Training Institute, MIC; 2004.
[14] Watanabe C, Kondo R. Institutional elasticity towards IT waves for Japan's survival: the significant role of an IT Testbet. Technovation 2004;23(4): 307–20.
[15] World Economic Forum (WEF). The Global Competitiveness Report 2005–2006. WEF; 2005.
[16] World Economic Forum (WEF). The Global Information Technology Report 2004–2005. WEF; 2004.
[17] International Telecommunication Union (ITU). World Telecommunication Indicators 2004. Switzerland: ITU; 2005.
[18] Watanabe C, Kondo R, Ouchi N, Wei H. Formation of IT Features through Interaction with Institutional System – Empirical Evidence of Unique Epidemic Behavior. Technovation 2003;23(3):205–19.
[19] Watanabe C, Kondo R, Ouchi N, Wei H, Griffy-Brown C. Institutional elasticity as a significant driver of IT functionality development. Technological Forecasting and Social Change 2004;71(7):723–50.
[20] Wilson D, Puruthaman R. Dreaming with BRICs: the Path to 2050. Goldman sachs: Global Economics Paper, No. 99; 2003.
[21] Available from: http://www.rediff.com/money/2004/nov/10guest1.htm.
[22] O'Neill J, Wilson D, Purushothaman R, Stupnytska A. How solid are the BRICs? Goldman Sachs: Global Economics Paper, No. 134; 2005.
[23] Thornton Grant. International Business Report 2007, Emerging markets. Available from: www.gti.org.
[24] Georgieva K. BRIC Countries in Comparative Perspective. World Bank; 2006.
[25] Harr T. BRIC the major issues. Danske Bank; 2006.
[26] Jensen T, Larsen J. The BRIC Countries, Danmarks National Bank: Monetary Review 4th Quarter; 2004.
[27] Mizuho Research Institute. The possibility and problem for the sustainable growth in BRICs. Toyo Keizai Shinposha; 2006.
[28] North DC. Economic performance through time. American Economic Review 1994;84(3):359–68.
[29] Ruttan VW. Technology, growth, and development – an induced innovation perspective. New York: Oxford University Press; 2001.
[30] North DC. Institutions, institutional change, and economic performance. Cambridge: Cambridge University Press; 1990.
[31] Knight J. Institutions and social conflict. Cambridge: Cambridge University Press; 1992.
[32] Milner HV. Interests, institutions and information: domestic politics and international relations. Princeton: Princeton University Press; 1997.
[33] Binswanger H, Ruttan V. Induced innovation: technology, institutions, and development. Baltimore: John Hopkins University Press; 1978.
[34] Marten G. Human ecology – basic concepts for sustainable development. London: Earthscan Publishers Ltd.; 2001.
[35] Janes FR. Interactive management: framework, practice and complexity. Critical issues in systems theory and practice. New York and London: Plenum Press; 1995.
[36] Flood RL. Complexity: a definition by construction of a conceptual framework. Systems Research 1987;4:177–85.
[37] Watanabe C. Science of the institutional management of technology. Tokyo: The Japan Society for Science Policy and Research Management; 2004.
[38] Cairncross F. The death of distance. Boston: Harvard Business School Press; 1997.
[39] Us Doc. Digital economy 2000. Washington (DC): DOC; 2000.

[40] Ministry of Post and Telecommunications (MPT), Japan. White Paper 2000 on Communications in Japan. Tokyo: MPT; 2000.
[41] Telecommunications Council, Japan. The info-communications vision for the 21st century. Tokyo: Telecommunications Council for the Minister of Posts and Telecommunications; 2000.
[42] International Monetary Fund (IMF). IMF World Economic and Financial Surveys 2007. Washington (DC): IMF; 2007.
[43] Science Citation Index (SCI). Web of Science. Available from: http://scientific.thomson.com/products/wos/.
[44] World Bank. World Development Indicators 2005. World Bank; 2006.
[45] United Nation (UN). Human Development Report 2005. UN; 2006.

Xuening Yao is currently pursuing her Ph.D. degree at the Department of Industrial Engineering and Management, Tokyo Institute of Technology. She graduated from Hebei Normal University with a Bachelor's Degree in Physics in 1993 and received her Master Degree of Philosophy of Science and Technology from Harbin Institute of Technology in 1996. She is a former lecturer at College of Economics and Management, Hebei University of Science and Technology. Her research interests include technology innovation and institution innovation.

Chihiro Watanabe gradated from Tokyo University with a Bachelor's degree in engineering (Urban Panning) in 1968, and received his Ph.D. (Arts and Sciences) in 1992 also from Tokyo University. He joined the Ministry of International Trade and Industry in 1968 and is the former Deputy Director-General of Technology Development. He is currently Professor in the Department of industrial Engineering and Management at Tokyo Institute of Technology, and is also Senior Advisor to the Director on Technology at the International Institute for Applied Systems Analysis. Professor Watanabe's expertise includes techno-economic systems, technology innovation and diffusion, technology management.

Ying Li is currently studying under the supervision of Professor Chihiro Watanabe at the Department of Industrial Engineering and Management of the Graduate School of Decision Science and Technology at Tokyo Institute of Technology with Master of Engineering Degree in 2007. She graduated from Wuhan Institute of Chemical Technology with Bachelor of Engineering degree in 2001. Her main research interests include Technology Innovation and Institutional Systems.