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Japanese and US perspectives on the National Innovation Ecosystem

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Abstract

Coinciding with a proposal for a National Innovation Ecosystem (NIES) by the US Council on Competitiveness, Japan's Industrial Structure Council proposed a major shift from a technology policy to an innovation policy based on the ecosystem concept. While Japan and the US achieved success through mutual inspiration in the 1980s and 1990s, both countries need a new approach to sustaining their national innovation, especially in light of the new paradigm for a post-information society, which began in the early 2000s. Realizing this need led both countries to reexamine the broader applications of the ecosystem discipline to technology policy systems. This paper analyzes the parallel paths of technology policy in Japan and the US over the last three decades. We found that the development cycle in both countries is governed by four ecosystem principles: (1) sustainable development through substitution, (2) self-propagation through co-evolution, (3) organizational inertia and inspired learning from competitors, and (4) heterogeneous synergy.

Keywords: Technology policy; Innovation policy; National Innovation Ecosystem; Ecosystem; Co-evolution

1. Introduction

In December 2004, the Council on Competitiveness proposed a framework for innovation, the National Innovation Ecosystem (NIES), as part of the final report of the National Innovation Initiative (NII).[1] The report, *Innovate America: Thriving in a World of Challenge and Change* [1], released at the National Innovation Summit held in Washington, DC, pointed out that a dramatic change in the US approach to innovation would be required in order to sustain its long-term competitive advantage. The report proposed the NIES as part of the US challenge to establish a global leadership position in innovation.

The report stimulated discussions of how to enhance US international competitiveness, with various proposals from industry, professional academies, and Congress, including "Losing the Competitive Advantage" by the American Electronics Association [2], "Rising Above the Gathering Storm" by several

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[1]NII was launched by the Council in October 2003 to bring together over 500 leaders from industry, academia, government, and the non-profit sector.

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professional academies [3], "Innovation Agenda: A Commitment to Competitiveness to Keep America #1" by Democrats in the House of Representatives [4], a Congressional bill entitled "National Innovation Act" [5] and another entitled "Protecting America's Competitive Edge Act" [6]. Based on these proposals, President Bush announced the American Competitiveness Initiative in his 2006 State of the Union address [7]. The initiative defined science and technology as twin foundations of economic growth, and it allocated $5.9 billion for FY 2007 for investments in research and development and to improve education and encourage entrepreneurship. Subsequently, various bills to further strengthen competitiveness were submitted.

At about the same time as the NII report, the Industrial Structure Council in Japan proposed a major shift, from a technology-oriented policy to an innovation-oriented policy based on the ecosystem concept [8]. The Council stressed the necessity of the ecosystem as the foundation of continuous innovation. The proposal appeared in the third Science and Technology Basic Plan published March 31, 2006 [9], which prioritizes key science and technology policies until FY 2010. The Plan's goal is "Innovator Japan"—to realize a vigorous economy and competitive industries through continuing innovation.

To support the achievement of this goal, the Council for Science and Technology Policy announced a Comprehensive Strategy for Creating Innovation on July 14, 2006 [10], which is intended to improve efficiency and innovative research and development. Subsequently, the Council on Economic and Fiscal Policy (CEFP) proposed the Outline of Strategy for Economic Growth on July 26, 2006 [11], which aimed at realizing the Japanese Model of Economic Growth. The CEFP's strategy includes strengthening global competitiveness, improving productivity through information technology and innovation in the service industries, revitalizing regional small- and medium-size enterprises, creating demand through structural reform, and developing infrastructures for five fundamental areas: human resources, manufacturing, finance, technology, and management.

The US strategy for competitiveness has been discussed at length by many sources. The *Young Report* [12] in 1985 was followed by additional recommendations for industrial policy, including the *New Young Report* in 1987 [13], *Made in America* in 1989 [14] and *Innovate America* in 2004 [1]. The release of *Innovate America* re-ignited discussions about US global competitiveness, which eventually led to proposals such as the Task Force on the Future of American Innovation [15], a report by the US Government Accounting Office [16], and others [2–7].

Japan also focused on greater competitiveness. Several institutions, including the Industrial Structure Council [8,17], the National Commission on Strategy for Industrial Technology [18], and the Japan Society for Science Policy and Research Management [19], have made recommendations for enhancing Japan's global competitiveness. Discussions in both countries highlighted the fact that innovation is not a linear process but has multi-faceted and continual interactions. Innovation is a complex and dynamic phenomenon in which all stakeholders and institutions are interconnected, which is one facet of an ecosystem. In that context, optimizing a nation's global innovation performance depends on ecosystem principles. In order to strengthen their global competitiveness, Japan and the US have optimized their innovation performance not only internally but also externally within the innovation ecosystem.

Many studies have demonstrated the application of ecosystem principles to society. Odum pioneered the holistic concept of the ecosystem [20], showing the interconnectedness of nature and the effects of industrial, urban, and agricultural activities in ecosystems. Marten stressed that co-existence, co-adaptation, and co-evolution are emergent properties of an ecosystem [21]. He defined co-existence as "existing together," co-adaptation as "fitting together," and co-evolution as "changing together." According to Marten, co-existence and co-adaptation are not as dynamic as the typical sustainable ecosystem. Co-evolution plays an essential role in sustaining an ecosystem in an evolutionary way. Moore [22] set up an analogy for competition drawn from the study of biology and social systems. He suggested that a company can be seen not as a member of a single industry but as part of a business ecosystem that covers a variety of industries. Companies in a business ecosystem co-evolve around a new innovation, working cooperatively and competitively to support new products and satisfy customer needs. Wiens [23] indicated that ecological patterns and processes are scale-dependent. He argued that the degree of scale dependency differs for different ecological systems, and relationships between spatial and temporal scales of variation may be well-behaved and orderly within a domain of scale but differ from one domain to another. Industrial ecology provides a systematic view of the interactions between industrial and ecological systems, as Watanabe [24–26] demonstrated for Japan's industrial policies. Similar research is underway, led by the US [27].

This paper applies the industrial ecology approach to demonstrating that the US is now losing its competitive advantage due to a mismatch between its institutional systems and a post-information society, despite its conspicuous accomplishments in the new economy of the 1990s. Meanwhile, Japan's institutional systems are enjoying a comparative advantage.

2. Cycles of mutual inspiration between Japan and the US

An attempt by Japan to apply ecosystem principles to technology policy systems was initiated in the early 1970s. Aimed at analyzing and evaluating the complex relationships between the surrounding environment and human activities centered around industry, Japan's Ministry of International Trade and Industry (MITI)[2] introduced the concept of ''industrial ecology'' in the early 1970s [24,25]. A similar activity occurred in the US in the early 1990s, initiated by the National Academy of Engineering [3]. The basic principle of industrial ecology suggests that, under certain constraints, substitution among available production factors is acceptable in a closed system in order to achieve sustainable development. Based on this, Japan achieved notable energy efficiency improvements in the 1980s, which can be attributed to energy technology substitutions [28,29].

Application of the analogy of ecosystem principles to technology policy systems created a cycle of mutual inspiration between Japan and the US, with both countries succeeding in a variety of ways through the 1970–1990s, including postulating the concept of industrial ecology in the early 1970s.

Inspired by a 1950s system proposed by the UK's Engineering Research Association (ERA), MITI attempted to introduce a similar system that would increase the international competitiveness of Japan's industrial technologies. In 1961, the Japanese government enacted the Law of Engineering Research Association, which triggered an R&D collaboration between government, university, and industry. The ERA system has adapted well to Japan's institutional systems. One unique institutional development in the 1980s was an R&D consortia, which balances cooperation and competition among the participants and leverages industry's vigorous R&D, leading to a mechanism that activates inter-firm technology spillovers.

Encouraged by Japan's successes [30], the US enacted the National Cooperative Research Act in 1984, which encouraged R&D collaboration and later leveraged collaboration between university and industry. After the economic stagnation of the 1980s, the US achieved significant economic growth in the 1990s even while Japan experienced a ''lost decade'' due to economic stagnation in that country. This created a foundation for the IT-driven economy of the 1990s, and the US's successful recovery can be attributed to the substitution of IT for traditional manufacturing technologies, leading to new functionality developments that required a shift from a manufacturing—technology, growth-oriented trajectory in an industrial society to an IT-driven, new functionality—development trajectory in an information society that emerged at the beginning of the 1990s.

In order to overcome the lost decade of the 1990s and stagnant GDP growth, Japan made great efforts to learn and absorb advanced technologies and systems from its competitors. These efforts included learning and absorbing from US initiatives that linked university and industry and stimulated the revitalization of the role of universities in Japan in the early 2000s.

Since the IT bubble burst in 2001, the US is again confronted with a ''new reality'' [1,31] similar to the one it confronted in the 1980s [32]. By contrast, Japan's competitiveness has been recovered from the dramatic decline of the 1990s. This role reversal indicates a new paradigm in a post-information society of the early 2000s, one that shifts from a functionality-oriented to a solution-oriented trajectory that is seamless, and includes the participation of all players and institutions, which is similar to an evolving ecosystem. Japan and the US are at the edge of this shift and both have gained profound insights into the nature of innovation inspired by the ecosystem. That led both countries to the announcement of their

[2]MITI was renamed METI (Ministry of Economy, Trade and Industry) in 2001, following reorganization of Japan's central government.

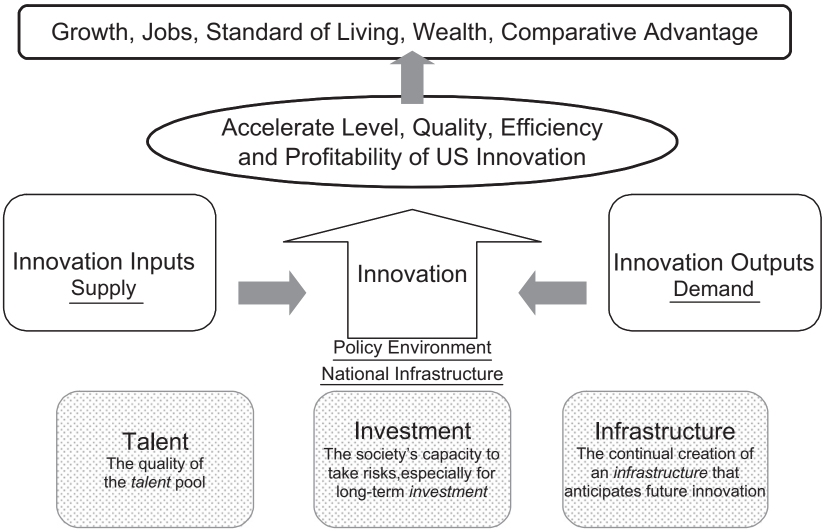


Fig. 1. Scheme of a national innovation ecosystem. *Source*: Ref. [31], adapted by the authors.

respective national frameworks of innovation mentioned earlier: the National Innovation Ecosystem (US), and the ecosystem innovation policy (Japan). Fig. 1 illustrates the NIES, and highlights several noteworthy postulates:

- Innovation is much more than technology; many other complementary resources and services are essential for market success.
- Like human health, no single attribute is adequate to capture the dynamics and multiple features of innovation.
- Innovation success and diffusion is ultimately determined by demand, not just by technical inputs and product features.
- Firms exist beyond technology push and market pull, embracing both sides of the equation by collaborating with customers, partnering with external sources of innovation, integrating resources into new business models, and focusing on global market opportunities.
- Non-linear dynamics characterize the innovation value chain at the national and firm levels.

3. Co-evolutionary cycles governed by ecosystem principles

The reversal of competitive dominance between Japan and the US corresponds to the paradigm shift from an industrial society in the 1980s to an information society in the 1990s. A similar change will also occur in a post-information society. Based on the NIES concept, this change suggests that the co-evolutionary cycle between Japan and the US is governed by four principles of ecosystems:

(a) Sustainable development through substitution.
(b) Self-propagation through co-evolution.
(c) Organizational inertia and inspired learning from competitors.
(d) Heterogeneous synergy.

Each of these principles has appeared over the last three decades: (1) in an industrial society of the 1980s; (2) in an information society of the 1990s; (3) in the paradigm shifts from an industrial society to an information society, and then an information society to a post-information society; and (4) in a post-information society of the 2000s.

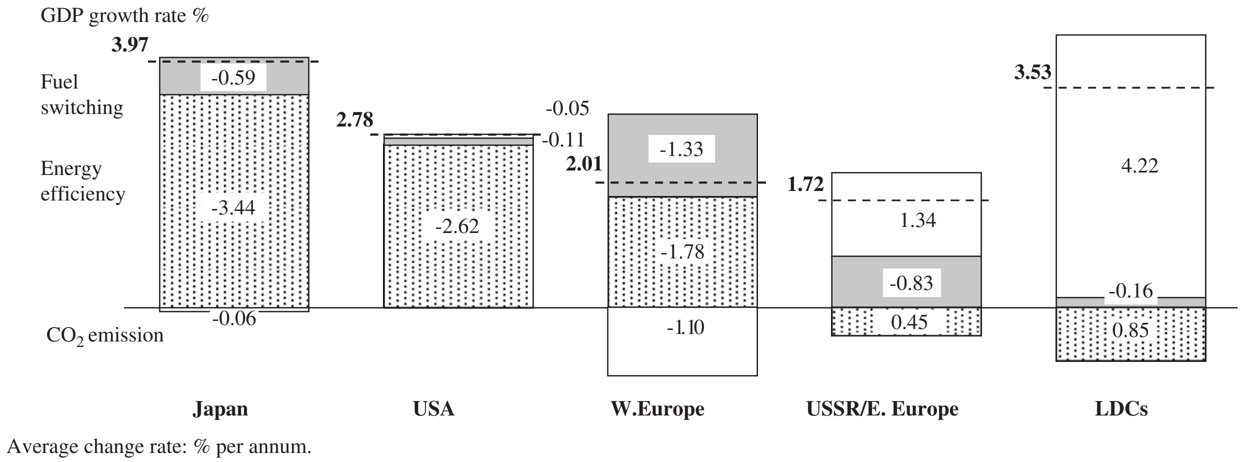


Fig. 2. Comparison of development in major countries/regions (1979–1988). *Source*: Ref. [29], adapted by the authors. Average change rate: % per annum.

3.1. Sustainable development through substitution

Japan's successful economic growth as an industrial society is the result of industry efforts to substitute technology for constrained production factors (such as labor and energy). This is one function of an ecosystem, where one species slows down and another speeds up to compensate, in order to maintain homeostasis (checks and balances that dampen oscillations) [33,34]. Japan substituted technology for energy, using capital to overcome energy constraints; energy technology using capital for energy efficiency improvements, or non-energy technology with capital for production increases. Capital/technology was also substituted for labor to induce capital and R&D investment for further economic growth.

Japan succeeded in this technology substitution, particularly in the energy field after the first energy crisis in 1973, thereby enabling it to shift from energy-dependence mode to a ‘‘greener’’ mode in order to achieve dramatic energy efficiency improvement [28,29]. Japan recorded the highest economic growth (3.97% per year) with a 0.06% decline in CO_2 emissions in the 10 years following the second energy crisis in 1979 (see Fig. 2). This was possible due to conspicuous energy efficiency improvements (3.44% per year). During the same period, the US attained 2.78% economic growth, and CO_2 emissions increased by 0.05%, although its energy efficiency improvement remained at 2.62%.

3.2. Self-propagation through co-evolution

At the beginning of the 1990s, competitiveness dominance was shifting from Japan to the US Japan's competitiveness continued to decline thereafter, and in 2002 the IMD ranked Japan as 30th in the world [35]. The reason for Japan's dramatic decline in competitiveness can be attributed to a poor choice for its growth trajectory. As shown in Appendix A, this represents a paradigm shift from high economic growth at the end of 1980s to economic maturity. In contrast, the US shifted its growth trajectory from growth-oriented development (in which economic growth leverages further growth) to a new functionality development-initiated trajectory (which maintains sustainable growth based on developing new functionality). During this time, Japan continued to cling to the traditional growth-oriented trajectory, largely because of inertia owing to its successes during periods of high economic growth while following a traditional trajectory [34].

As a consequence of this poor choice, the contributions of technological improvements to economic growth—or TFP (total factor productivity) growth to GDP growth—declined dramatically in the 1990s. As Fig. 3 shows, in the 1980s Japan's TFP growth rate is significantly higher than that of the US, with 2.8% per year and 0.9% per year from 1985 to 1990. This changed dramatically in the 1990s, falling to negative 0.3% per year and 0.9% per year in the first half of the 1990s, and 0.2% per year and 1.5% per year in the second half of the 1990s.

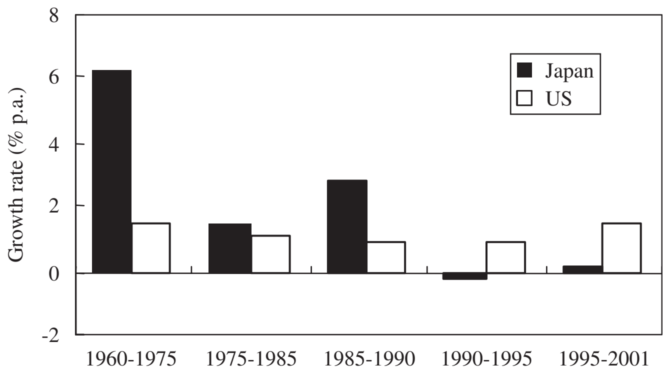


Fig. 3. Trends in TFP growth rate in Japan and the US (1960–2001). *Sources*: 1960–1975: [36]; 1975–2001: [37].

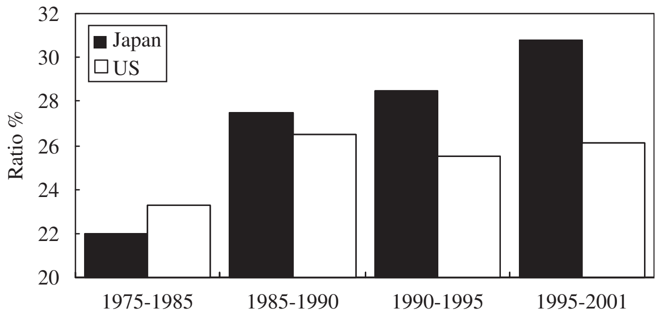


Fig. 4. Trends in R&D intensity in Japan and the US (1975–2001). R&D intensity = ratio of R&D investment to GDP. *Source*: Ref. [38].

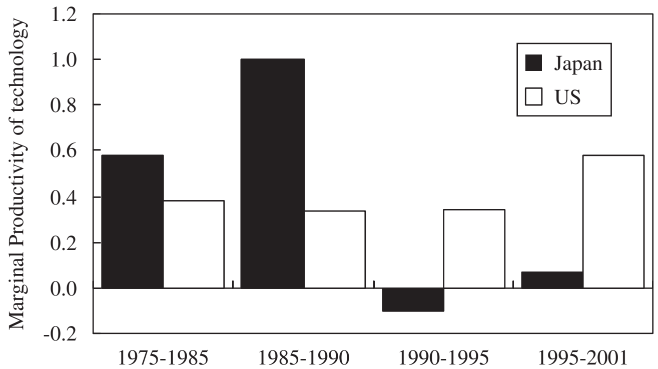


Fig. 5. Trends in marginal productivity of technology (MPT) in Japan and the US (1960–2001). Marginal productivity of technology = ratio of growth rate of TFP to R&D intensity. *Sources*: Refs. [37,38].

TFP growth rate is measured by multiplying the product of R&D intensity (the ratio of R&D investment to GDP) and marginal productivity of technology (MPT). As Fig. 4 shows, Japan maintains a high level of R&D intensity. Therefore, the dramatic decline in Japan's TFP growth rate in the face of such high R&D intensity can be attributed to the dramatic decrease in MPT, as shown in Fig. 5. This is evidence that Japan has become a nation of "poor output despite large input" with respect to its technology productivity. In fact, Japan's MPT was overtaken by the US in the 1990s.

Such a conspicuous difference in MPT between Japan and the US can be attributed to the adaptability of marginal productivity of manufacturing technology during the shift to an information society. Manufacturing industries in the US and Japan presented clear contrasts in the elasticity of MPT to the shift to an information society. Contrary to increased US efforts to improve its adaptability, Japan fell into a declining trend in the 1990s. The US success can be attributed to successfully replacing manufacturing technologies with IT in order to switch from growth-oriented development trajectory to new functionality development-initiated trajectory [39,40].

3.3. Organizational inertia and learning inspired by competitors

When the US substituted IT for manufacturing technologies in the 1990s, it resulted in organizational inertia. The trend in Japan toward inspired learning from competitors contrasted sharply with the US inertia, and as a result, Japan overtook the US in competitive advantage.

For some time, the US has been dealing with problems in its the science and mathematics educational system. The OECD Program for International Student Assessment measured the performance of 15-year-old students in industrialized countries in 2000 (27 countries) and 2003 (29 countries). This assessment revealed that in science literacy, the US dropped from 14th in 2000 to 19th in 2003, and from 18th to 24th in mathematics literacy. In contrast, Japan ranked first in 2000 and fourth in 2003 in science literacy, and second in 2000 and second in 2003 in mathematics literacy [41,42].

In addition, the US has seen a deterioration in its basic system for higher education. The number of Chinese, South Korean, and Taiwanese students who choose to pursue their Ph.D. courses at US universities has declined since the late 1990s. In contrast, the number of students who chose to pursue Ph.D. courses in their own countries nearly doubled from 1994 to 1998 [43].

A joint report by the National Academy of Science and National Academy of Engineering, entitled "Rising above the Gathering Storm: Energizing and Employing America for a Brighter Economic Future" [3] gave the following warnings, followed by proposals for programs and bills for the training and education of talented people:

- The committee is deeply concerned that the scientific and technical building blocks of the US's economic leadership are eroding at a time when many other nations are gathering strength.
- The highest priority should be assigned to increasing the talent pool by vastly improving K-12 (kindergarten through 12th grade) mathematics and science education.
- A means is needed to quickly, legally, and safely admit to the US relatively small numbers of talented people who possess the skills needed to make major contributions to the US's future competitiveness and well-being.

Contrary to US concerns, Japan made every effort to learn from the US's accomplishments in the 1990s. This learning-by-experience revitalized leading Japanese high-technology firms during the 1990s. Fig. 6 shows

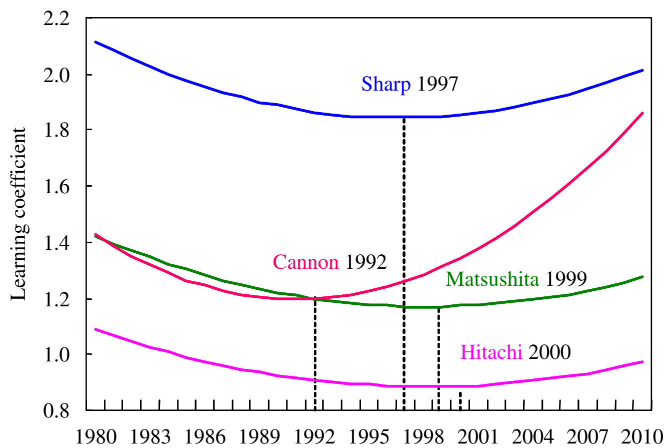


Fig. 6. Learning coefficients of the Japanese 4 Representative High-tech Firms (1980–2003). 1980–2003 = estimate; 2004–2010 = prediction based on trends in 1980–2003. *Source*: Ref. [45], adapted by the authors.

Table 1
Growth rate, Japanese and US manufacturing industries during three periods (1980–2004)

Industrial society (1980–1990)	Information society (1991–2000)	Post-information society (2001–2004)
−1.1% p.a. Higher growth rate in Japan	5.3% p.a. Higher growth rate in the US	−1.0% p.a. Higher growth rate in Japan recovered

Table 2
Growth rate, Japanese and US corporate R&D investment during three periods (1980–2004)

Industrial society (1980–1990)	Information society (1991–2000)	Post-information society (2001–2004)
−5.2% p.a. Higher investment in Japan	4.2% p.a. Higher investment in the US	−9.8% p.a. Higher investment in Japan recovered

an analysis of trends in learning coefficients in the four leading electric machinery firms: Canon, Sharp, Matsushita, and Hitachi.

The learning coefficients for Canon and Sharp demonstrated a significant increase beginning in 1992 and again in 1997. While the coefficients for Matsushita and Hitachi also increased at the turn of the century after many years of decline, those increases were not significant. It suggests that Japanese high-technology firms learn from and assimilate the experiences of US IT institutions during the shift from an information society in the 1990s to a post-information society in the 2000s [44]. Their efforts differ, however, reflecting each firm's strategy, resulting in different inflection years and rates of increase in the learning coefficient, as the figure shows.

3.4. Heterogeneous synergy

Japan's learning efforts, stimulated by US economic accomplishments in the new economy, bore fruit in a notable recovery of the manufacturing industry in recent years. Four signs indicate the possibility of another reversal of competitive position between Japan and the US.

3.4.1. Manufacturing industry production

Simple regression analyses (see Appendices B–D) show the correlation between relative growth rate and relative production level in Japanese and US manufacturing industries in three periods: an industrial society (1980–1990), an information society (1991–2000), and a post-information society (2001–2004). The correlations are identified as −1.1% per year, 5.3% per year, and −1.0% per year, respectively (summarized in Table 1) [44]. This analysis demonstrates that Japan experienced higher growth in a post-information society.

3.4.2. Corporate R&D investment

Using the same regression analysis, the growth rate between Japanese and US corporate R&D investment during the same three periods can be identified as −5.2% per year in an industrial society, 4.2% per year in an information society, and −9.8% per year in a post-information society (summarized in Table 2). This analysis demonstrates that Japan achieved higher growth again in a post-information society.

3.4.3. Ratio of shareholders' equity in manufacturing industry

The same regression analysis shows that the growth rate between Japanese and US equity to total assets was 0.53% from the first quarter of 1996 to the fourth quarter of 1997, −0.28% from the first quarter of 1998 to the second quarter of 2001, and −0.31% from the third quarter of 2001 to the first quarter of 2005 (summarized in Table 3). This analysis also demonstrates that Japan recovered higher investment again in a post-information society.

Table 3
Growth rate between Japanese and US shareholders' equity ratios in manufacturing industry during three periods (1996–2005)

Information society		Post-information society
Q1 1996–Q4 1997	Q1 1998–Q2 2001	Q3 2001–Q1 2005
−0.53% (equivalent of 2.1% p.a.)	−0.28% (equivalent of −1.1% p.a.)	−0.31% (equivalent of −1.3% p.a.)
Higher investment in Japan	Higher investment in the US	Higher investment in Japan recovered

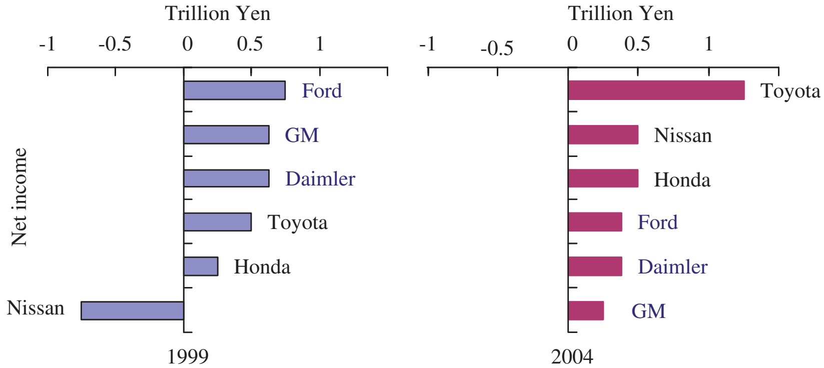


Fig. 7. Comparison of value based on net income of six leading automotive firms (1999 and 2004). *Source*: Nihon Keizai Shimbun, April 15, 2005.

3.4.4. Net income in automotive firms

While US firms increased in size through M&As in the 1990s, a comparison of the six leading automotive firms shows that their net incomes dramatically decreased in 2004, resulting in ranking changes among Japanese firms such as Toyota, Nissan, and Honda [44] (see Fig. 7). Toyota and GM financial results contrasted sharply in 2005. While Toyota posted a record consolidated net income of ¥1.4 trillion (a 17.2% increase compared to 2004), GM incurred a consolidated net loss of ¥1.2 trillion (compared to ¥0.3 trillion in 2004). For the last several years, GM has focused on restructuring its operations to improve performance, which resulted in a massive reorganization of the automotive industry, and a three-way alliance among GM, Renault, and Nissan.

All these signs suggest that the US demonstrated higher competitiveness by posting the highest growth rate during an information society period of the 1990s. However, in certain fields the US lost its dominant position, and beginning in the 2000s, it lagged behind Japan in a post-information society as Japan posted a higher growth rate. While the US benefited from the IT-driven economy, it suffered from a decline in competitiveness after the Asian financial crisis in 1997, and this decline was accelerated by the bursting of the IT bubble in 2000. This supports the fact that other competitors of the US, including India and China, are beginning to catch up after learning from the example of the US as well as through US investments and outsourcing.

In contrast, Japan has become revitalized in a post-information society by integrating its comparative advantages in manufacturing technology with IT learned from the US while enduring the lost decade of the 1990s. However, the recent revitalization of Japan's manufacturing industry is not industry-wide, which has led to polarization in profitability among high-technology firms. The operating income to sales (OIS) of four leading firms (discussed earlier) has changed in two different trajectories. Fig. 8 shows OIS trends in Japan's 10 leading electric machinery firms over the period 1987–2005. We note that Canon and Sharp increased their average OIS steadily over all three periods examined. Comparing the average OIS in the 2000s with that of the 1980s, Canon doubled its OIS and Sharp increased it by 50%. In contrast, Matsushita decreased its average OIS by 41% in the 1990s and 86% in the 2000s, and Hitachi reduced its average OIS by 48% in the 1990s and 66% in the 2000s.

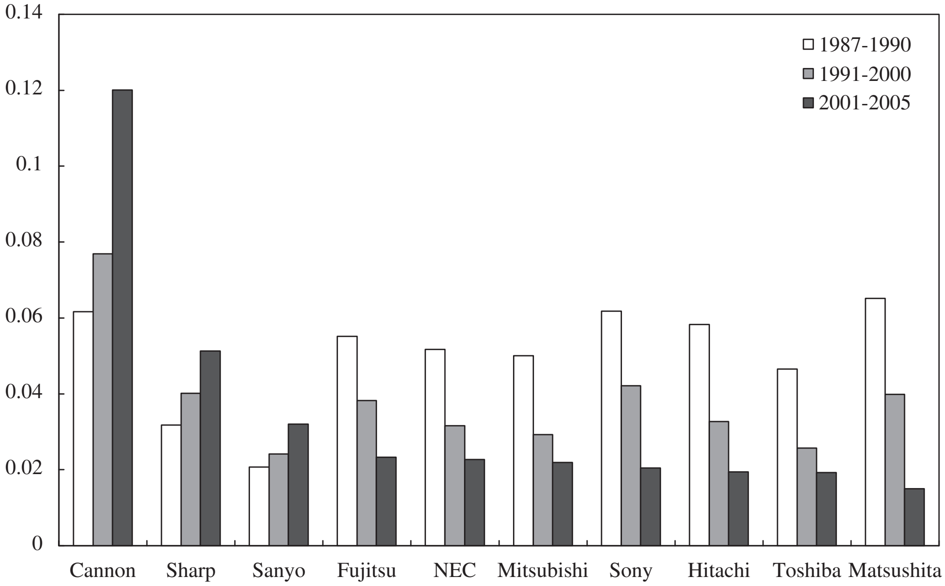


Fig. 8. Operating income to sales (OIS) of Japan's 10 leading electric machinery firms (1987–2005). *Source*: Nikkei Financial Data.

4. Approaches to innovation

Based on a noticeable polarization in their profitability, we found that Japanese high-technology firms can be divided into two groups:

(a) *Group A*: Firms endeavoring to introduce global learning.
(b) *Group B*: Firms clinging to old behaviors based on Japan's traditional institutions.

The two groups take contrasting approaches to innovation. While Group A is keen to develop their own core technology and also introduce global learning driven by xenophobia, Group B disregards learning from competitors and clings to the Not-Invented-Here syndrome.

Polarization into Group A and Group B based on profitability suggests that the co-evolution between external acquisition and internal acquisition of potential resources for innovation could be the key to success in a post-information society. External acquisitions will increase spillover effects from in-house technology stock, which will provide for further internal cumulative learning. It also forces outside learning because of strong competition. Both external and internal acquisitions accelerate learning from outside experience, which contributes to further external acquisition. The synergies between in-house technology stock and external resources make external acquisition effective for identifying what to learn from competitors. This in turn leads to a realization of co-evolution between innovation and institutional systems, moving toward seamless participation by all players and institutions.

Such a co-evolution between external and internal acquisition leads to polarization of Japanese high-technology firms. According to co-evolution, firms in Group A increase their profits to strengthen their competitiveness in the global economy. On the other hand, firms in Group B still cling to internal acquisitions. They rely on their own technology to make profits, and depend on learning from the inside, not the outside.

These hypothetical examples share a similar recognition: sources of technology are distributed both inside and outside using the concept of distributed innovation proposed by Haour [46]. Distributed innovation offers firms two primary benefits: (1) firms can raise revenue by using channels such as licensing and selling innovation projects; and (2) firms can tap into external technical know-how and combine it seamlessly with their internal capabilities to develop "high impact" products and services. They are less constrained by their internal technical capabilities (or lack thereof), and they gain agility and effectiveness.

Given the foregoing, continued polarization of Japanese high-technology firms is expected to have a major impact on Japan's institutions and will likely maintain their stereotypical business behavior. In order to mitigate the impact of this behavior, explanations of the new co-evolutionary dynamism between innovation and institutional systems in a post-information society is required. Both groups need to generate synergies toward seamless participation by all players and institutions, moving toward a ubiquitous economy in a post-information society.

5. Conclusion

Prompted by the National Innovation Ecosystem proposed simultaneously by both Japan and the US during the transition from an information society to a post-information society, we analyzed the significance of co-evolutionary dynamism in an ecosystem.

Our research found a mutually inspiring development cycle between Japan and the US, which resulted in higher competitiveness. Consequently, there was a comparative advantage alternately achieved by both countries corresponding to paradigm shifts from an industrial society in the 1980s, to an information society in the 1990s, to a post-information society in the early 2000s. In this context, a comparative empirical analysis of development trajectories in both countries in each paradigm was performed by applying the co-evolutionary dynamism involved in an ecosystem.

The analysis conducted in this paper revealed that the competitive positions of Japan and the US reversed repeatedly corresponding to the paradigm shifts from an industrial society to an information society to a post-information society. A mutually inspiring co-evolutionary development cycle between Japan and the US functioned well in leveraging innovative efforts to win the competitive race between both countries, leading to a shift of competitive advantage from Japan to the US in the 1990s.

These changes are governed by the four principles of ecosystems, as follows:

(a) Japan's conspicuous economic achievement in an industrial society in the 1980s can be attributed to its success in incorporating ecosystem principles in its industrial policy by means of *sustainable development through substitution*, i.e., technology substitution for constrained production factors, primarily energy after the energy crises.
(b) The US recovery of its dominant competitive position over Japan in an information society in the 1990s can be attributed to the US's timely switch from a growth-oriented development trajectory to a new functionality development-initiated trajectory by means of IT substitution for manufacturing technology, which is derived from *self-propagation through co-evolution*.
(c) Corresponding to the paradigm shift to a post-information society in the early 2000s, the US is again confronting a new reality due to the emergence of catch-up competitors such as India and China, as well as a move in Japan toward new innovation. This confrontation can be attributed to *organizational inertia*, which in turn inspired Japan's *learning from competitors* in the 1980s.
(d) Such movement in Japan sheds light on the polarization of Japanese high-technology firms into two groups: (i) firms launching into global participation with high profits, and (ii) firms maintaining their stereotypical behavior based on traditional Japanese institutions that insist on pursuing an NIH syndrome. This polarization suggests *heterogeneous synergy* toward seamless participation by all players and institutions.

These findings suggest the following policy implications:

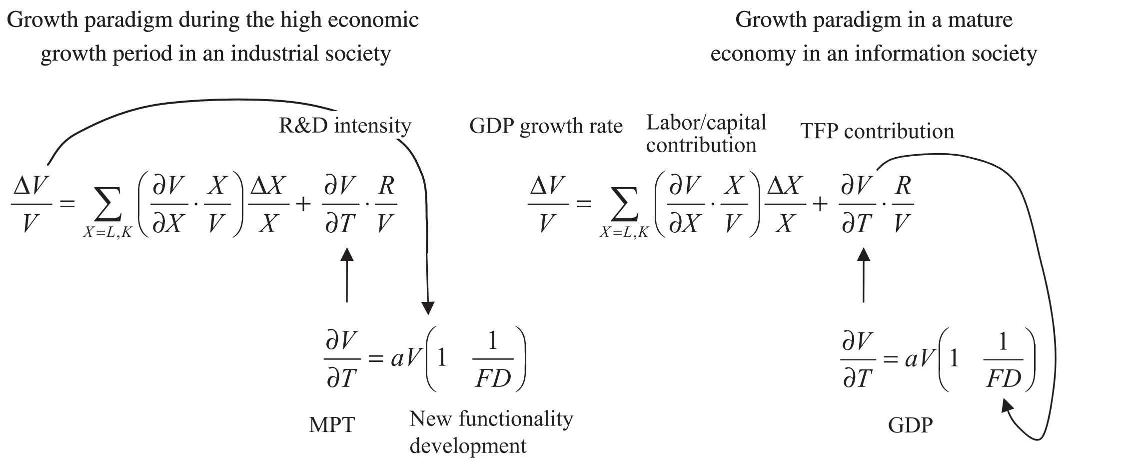
- A technology policy should generate innovation with a view to constructing co-evolution among heterogeneous players with different degrees of competitive advantage. Each player is required to recognize and develop its core competence through learning inspired by other players. That would make great contributions to co-evolutionary heterogeneous synergy.
- Given the efficiency of systems for constructing the above co-evolution, the agility, adaptability, and alliance among heterogeneous players should be maintained and enhanced. That would enable players to complement their innovation activities with each other and appropriately respond to global changes.

- To activate co-evolution among heterogeneous players, Japan should transform its traditional stereotypical institution into a diverse institution with flexible socioeconomic systems, collaboration, and integration between various players. This is crucial to ensuring that potential innovation resources are effectively explored and utilized.

Given that Japan has been revitalizing its economy since the early 2000s, its inherent strengths should produce a mutually inspiring development cycle between Japan and the US. The dominant competitive position has shifted repeatedly between Japan and the US, corresponding to the cycle analyzed in this paper. However, Japan changed its institutional systems during the race and realized the co-evolution between the emergence of innovation and the advancement of institutional systems. This recognition was postulated by Fujio Mitarai, President of the Japan Business Federation and former Chairman and CEO of Canon Inc.: "Finance and development should be global while human affairs should be local." This postulate suggests that Japan has balanced its management style with international standards, which is what Vogel [47] stressed, pointing out that Japan has never emulated the American model. After scrutinizing their options, government officials and industry leaders chose to modify or reinforce preexisting institutions rather than abandon them. Thus, Japan has chosen what it should learn (or not learn) in order to co-evolve its own institutional systems. Such choice is a key factor for co-evolution between innovation and institutional systems, including the National Innovation Ecosystem.

Further work could focus on clarifying the new dynamism between innovation and institutional systems in a post-information society, which would contribute to better measuring innovation. The US Department of Commerce announced the establishment of the Measuring Innovation in the 21st Century Economy Advisory Committee in August 2006. The Committee will propose new or improved methods to measure innovation in the economy, which will help explain how innovation occurs in different sectors of the economy, how it is diffused across the economy, and how it impacts on economic growth and productivity. In order to establish an accurate method for assessing and evaluating innovation, the National Innovation Ecosystem will enable more profound insight into co-evolution during the innovation development cycle, generated by activities of heterogeneous players and the advancement of institutional systems.

Appendix A. Growth trajectory options in Japan and the US corresponding to a mature economy



Japan's choice
(Growth-oriented development trajectory)

U.S.'s choice
(New functionality development-initiated trajectory)

where V, GDP; X, labor, capital; T, technology stock; R, R&D investment; MPT, marginal productivity of technology; FD, new functionality development; TFP, total factor productivity; a, coefficient of technology diffusion.

Appendix B. Correlation between relative growth rate and relative production level in Japanese and US manufacturing industries (1980–2004)

$$\ln \frac{Y_{\mathrm{US}}}{Y_{\mathrm{JP}}} = a + g_1 D_1 t + g_2 D_2 t + g_3 D_3 t + bD_2 + cD,$$

where Y_{US}: US manufacturing industry production; Y_{JP}: Japanese manufacturing industry production; a, b and c: scale factors; g_1, g_2 and g_3: balance of the average growth rate between Japan and the US's manufacturing industry in the period of an industrial society, an information society, and a post-information society, respectively; D_1, D_2 and D_3: coefficient dummy variables corresponding to the three periods; D: dummy variable (1987 = 1, other years are 0); t: time trend.[3]

a	g_1	g_2	g_3	b	c	adj. R^2	DW
21.449 (4.15)	−0.011 (−4.13)	0.053 (17.63)	−0.010 (−4.06)	−127.233 (−16.05)	0.063 (2.15)	0.974	1.70

Appendix C. Correlation between relative growth rate and relative level in Japanese and US corporate R&D investment (1980–2004)

$$\ln \frac{Y_{\mathrm{US}}}{Y_{\mathrm{JP}}} = a + g_1 D_1 t + g_2 D_2 t + g_3 D_3 t + bD_2 + cD_3,$$

where Y_{US}: US corporate R&D investment; Y_{JP}: Japanese corporate R&D investment; a, b and c: scale factors; g_1, g_2 and g_3: balance of the average growth rate between Japan and the US's corporate R&D investment in the period of an industrial society, an information society, and a post-information society, respectively; D_1, D_2 and D_3: coefficient dummy variables corresponding to the three periods, and t: time trend.

a	g_1	g_2	g_3	b	c	adj. R^2	DW
103.37 (15.71)	−0.052 (−15.67)	0.042 (10.96)	−0.098 (−6.32)	−186.85 (−18.54)	93.52 (2.94)	0.948	1.89

Appendix D. Correlation between relative growth rate and relative level in Japanese and US Shareholders' equity ratios in the manufacturing industry (1996–2005)

$$\ln \frac{\mathrm{SHE}_{\mathrm{US}}}{\mathrm{SHE}_{\mathrm{JP}}} = a + g_1 D_1 t + g_2 D_2 t + g_3 D_3 t,$$

where $\mathrm{SHE}_{\mathrm{US}}$: US shareholders' equity ratio in manufacturing industry; Y_{JP}: Japanese shareholders' equity ratio in manufacturing industry; a: scale factor; g_1, g_2 and g_3: balance of the average growth rate between

[3]Given the average growth rate in Japan and the US are g_{US} and g_{JP}, respectively,

$$Y_{\mathrm{US}_t} = Y_{\mathrm{US}_0}(1 + g_{\mathrm{US}})^t \approx Y_{\mathrm{US}_0} e^{g_{\mathrm{US}} t},$$

where Y_{US_t} and Y_{US_0}: production level at time t and initial stage, respectively.
Taking logarithm, $\ln Y_{\mathrm{US}_t} = \ln Y_{\mathrm{US}_0} + g_{\mathrm{US}} t$.
Similarly, $\ln Y_{\mathrm{JP}_t} = \ln Y_{\mathrm{JP}_0} + g_{\mathrm{JP}} t$.
Taking balance,

$$\ln Y_{\mathrm{US}_t} - \ln Y_{\mathrm{JP}_t} = \ln Y_{\mathrm{US}_t}/Y_{\mathrm{JP}_t} = \left(\ln Y_{\mathrm{US}_0} - \ln Y_{\mathrm{JP}_0}\right) + (g_{\mathrm{US}} - g_{\mathrm{JP}})t \equiv a + gt,$$

where $a = \ln Y_{\mathrm{US}_0} - \ln Y_{\mathrm{JP}_0}$, $g = g_{\mathrm{US}} - g_{\mathrm{JP}}$.

Japan and the US's corporate R&D investment in the period of an industrial society, an information society, and a post-information society, respectively; D_1, D_2 and D_3: coefficient dummy variables corresponding to the three periods, and t: time trend.

a	g_1	g_2	g_3	adj. R^2	DW
0.0716 (5.71)	0.0053 (2.10)	−0.0028 (−3.52)	−0.0031 (−6.94)	0.898	1.57

References

[1] Council on Competitiveness. Innovate America: thriving in a world of challenge and change. Washington, DC: Council on Competitiveness; 2004.
[2] American Electronics Association. Losing the competitive advantage: the challenge for science and technology in the United States. Washington, DC: American Electronics Association; 2005.
[3] Committee on Prospering in the Global Economy of the 21st Century: an agenda for American Science and Technology, National Academy of Sciences, National Academy of Engineering, Institute of Medicine. Rising above the gathering storm: energizing and employing America for a brighter economic future. Washington, DC: National Academies Press; 2005.
[4] House Democrats. Innovation agenda: a commitment to competitiveness to keep America #1. Washington, DC: House Democrats; 2005.
[5] Website of Council on Competitiveness. 〈http://innovateamerica.org/pdf/National_Innovation_Act_2005.pdf〉.
[6] Website of Council on Competitiveness. 〈http://innovateamerica.org/pdf/PACE2Pager_section_by_section.pdf〉.
[7] Office of Science and Technology Policy. American competitiveness initiative: leading the world in innovation. Washington, DC: Domestic Policy Council, Office of Science and Technology Policy; 2006.
[8] Industrial Structure Council. Science and technology policy inducing technological innovation. Tokyo: Industrial Structure Council, METI; 2005.
[9] Government of Japan. Science and technology basic plan. Tokyo; 2006.
[10] Council for Science and Technology Policy. Comprehensive strategy for creating innovation. Tokyo: Council for Science and Technology Policy; 2006.
[11] Council on Economic and Fiscal Policy. Outline of strategy for economic growth. Tokyo: Council on Economic and Fiscal Policy; 2006.
[12] President's Commission on Industrial Competitiveness. Global competition: the new reality. Washington, DC: President's Commission on Industrial Competitiveness; 1985.
[13] Council on Competitiveness. America's competitive crisis: confronting the new reality. Washington, DC: Council on Competitiveness; 1987.
[14] Dertouzos ML, Lester RK, Solow RM, MIT Commission. Made in America: regaining the productive edge. Cambridge: MIT Press; 1999.
[15] Task force on the future of American innovation. See: 〈http://www.futureofinnovation.org/〉.
[16] United States Government Accounting Office. 21st century challenges: reexamining the base of the federal government. Washington, DC: US GAO; 2005.
[17] Industrial Structure Council. Trade and industry policies in the 1970s. Tokyo: METI Industrial Structure Council; 1971.
[18] National Commission on Strategy for Industrial Technology. The strategy for industrial technology. Tokyo: METI National Commission on Strategy for Industrial Technology; 2000.
[19] Japan Society for Science Policy and Research Management. A nascent resurgence of technological competitiveness: a temporary event or a shift to structural reform? Tokyo: Japan Society for Science Policy and Research Management; 2004.
[20] Odum EP. Ecology. New York: Harcourt; 1975.
[21] Marten GG. Human ecology. London: Earthscan Publications; 2001.
[22] Moore JF. Predators and prey: a new ecology of competition. Harvard Business Rev 1993;71(3):75–86.
[23] Wiens JA. Spatial scaling in ecology. Funct Ecol 1989;3(4):385–97.
[24] Watanabe C. Industry-ecology: introduction of ecology into industrial policy. Tokyo: MITI; 1972.
[25] Watanabe C. Industrial ecology and Japan's industrial policy. In: Richards D, Fullerton B, editors. Industrial ecology. Washington, DC: National Academy Press; 1994. p. 12–9.
[26] Watanabe C. Industrial ecology and technology policy: Japanese experience. In: Ayres RU, Ayres LM, editors. A handbook of industrial ecology. Cheltenham/Northampton: Edward Elgar; 2002. p. 232–45.
[27] Erkman S. Industrial ecology: a historical view. J Cleaner Prod 1997;5(1–2):1–10.
[28] Watanabe C. Mitigating global warming by substituting technology for energy. Energy Policy 1995;23(4/5):447–61.
[29] Watanabe C. Systems option for sustainable development: effect and limit of MITI's efforts to substitute technology for energy. Res Policy 1999;28(7):719–49.
[30] National Research Council. R&D consortia and US-Japan collaboration. Washington, DC: National Academy Press; 1990.

[31] 21st Century Innovation Working Group, Council on Competitiveness. Innovation, the new reality for national prosperity. Washington, DC: Council on Competitiveness; 2004.
[32] Council on Competitiveness. America's competitive crisis: confronting the new reality. Washington, DC: Council on Competitiveness; 1987.
[33] Watanabe C. Trends in the substitution of production factors to technology. Research Policy 1992;21(6):481–505.
[34] Watanabe C. The feedback loop between technology and economic development: an examination of Japanese industry. Technol Forecast Social Change 1995;49(2):127–45.
[35] IMD. The world competitiveness yearbook 2002. Zurich: IMD; 2002.
[36] Englander AS, Evenson R, Hanazaki M. R&D, innovation and the total factor productivity slowdown. OECD Econ Stud 1988;11:7–41.
[37] European Commission. European competitiveness report 2001. Luxembourg: Office for Official Publications of the European Communities; 2001.
[38] Ministry of Education, Culture, Sports, Science and Technology (MEXT). White paper on science and technology in Japan. Tokyo: MEXT; annual issues.
[39] Kondo R, Watanabe C. The virtuous cycle between institutional elasticity, IT advancement and sustainable growth: can Japan survive in an information society? Technol Soc 2003;25(3):319–35.
[40] Watanabe C, Kondo R. Institutional elasticity towards IT waves for Japan's survival: the significant role of an IT testbed. Technovation 2003;23(4):307–20.
[41] OECD. Knowledge and skills for life: first results from PISA 2000. Paris: OECD; 2000.
[42] OECD. Learning for tomorrow's world—first results from PISA 2003. Paris: OECD; 2003.
[43] National Science Foundation. Science and engineering indicators 2002. Virginia: National Science Foundation; 2002.
[44] Watanabe C, Fukuda K. National innovation ecosystems: the similarity and disparity of Japan-US technology policy systems toward a service oriented economy. J Services Res 2006;6(1):159–86.
[45] Watanabe C, Moriyama K, Fukuda K. Empirical analysis of change in entrepreneurial features corresponding to the transformation of the characterization of technology. In: Proceedings for the 7th IIASA-TITech meeting. Luxemburg, Austria; 2005. p. 309–49.
[46] Haour G. Resolving the innovation paradox: enhancing growth in technology companies. Basingstoke: Palgrave Macmillan; 2004.
[47] Vogel SK. Japan remodeled: how government and industry are reforming Japanese capitalism. New York: Cornell University Press; 2006.

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