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Systems Approaches for the Industrial Development of a Developing Country

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The development of an industrial system is a complex and dynamic process. In developing countries, industrial development is even more complicated because it involves the interactions of domestic firms and multinational corporations (MNCs), the role of the government, and the development of technology. Both MNCs and the government play the role of providing the resources and the environment for the development of industrial systems. This study discusses the viewpoints of ecological systems and system dynamics to summarize the analysis of the development of Taiwan's automobile, semiconductor, and national defense industries. In addition, an evolutionary perspective is used to examine the development of the information technology and semiconductor industries. The results show that different systems viewpoint provides different insights into industrial development. Therefore, more diverse systems approaches are needed to further our understanding of the development of industrial systems.

KEY WORDS: systems approaches; ecological systems; system dynamics; evolution; industrial development; developing country.

1. INTRODUCTION

The development of an industrial system is a very complex and dynamic process. Developing industrial systems involve cultural, political, economic, and social factors, as well as aspects of science and technology policy (Lemola, 2002). Industrial development in developing countries seems to be more complicated because it also involves the interaction of domestic firms and multinational corporations (MNCs) (Ghemawat, 2001; Prahalad and Hammond, 2002), the role of the government (Haley and Low, 1998; Mathews and Cho, 1999), and technological development, which includes technology transfer, technological learning, and innovation (Berardes and Albuquerque, 2003; Guerin, 2001; Lin, 2003; Mahmood and Singh, 2003).

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The "flying-geese" model depicts a pattern of interaction for domestic firms and MNCs involved in industrial development. The model explains the industry's process of transferring low value-added technology from the developed countries to the developing ones (Kojima, 2000). For example, Japan transferred its television set production technology to Korea and Taiwan, and later to Malaysia and Thailand. In addition, foreign direct investment (FDI) is another interaction model for industrial and technological development (Liu and Wang, 2003; Ramamurti and Doh, 2004). Cooperation of MNCs and domestic firms of developing countries is yet another possible model for industrial development (Chang, 2003; Sakakibara and Cho, 2002).

A developing country's government generally plays an important role in industrial development. In the early stages of development an industrial system often lacks necessary resources such as professionals, know-how, and capital. The government may therefore choose to play a protective or facilitating role. The government usually makes some protective policies to assure the survival of domestic firms. Additionally, the government may launch R&D institutions to assist industrial development (Passos *et al*., 2004; Shyu and Chiu, 2002). However, domestic firms in a developing country ultimately have to face international competition (Wang and Pollard, 2002). The government's role is thus limited, particularly in the later stages of industrial development.

National Innovative System (NIS) is a general model for technology development and knowledge innovation that deals with the interactions among the government, enterprise, and academia (Ennals, 2004; Hayashi, 2003; Levin, 2004; Nelson, 1993). The "Triple Helix" system of integration is frequently found in developed countries. While there are many developing countries employing this system to upgrade their research and development capabilities (Intarakumnerd *et al*., 2002; Lu and Lazonick, 2001; Parayil and Sreekumar, 2004), this approach may have some serious shortcomings because these countries' technological development is learning- rather than innovation-oriented (Viotti, 2002). For example, academia in Taiwan has long engaged in basic research, which is limited in its assistance to industrial development; the development of the industry's R&D systems, therefore, has relied on the cooperation of government-supported R&D institutions and domestic firms (Jan and Chen, in press).

Interaction among domestic firms, MNCs, and the government affects the industrial development of developing countries. Since the government and MNCs play the dual role of providing the resources and the environment for industrial and technological development, the interaction of these roles should be considered in the industrial development. This paper attempts to examine the relationship of the domestic firms, the government, and the MNCs by regarding the industry as a system, and reexamines its objectives, environment, resources, and components, according to Churchman's systems approach to world problems (Churchman, 1968; Fuenmayor, 2001). This paper further applies the perspective of ecological

systems (Ackoff and Gharajedaghi, 1996) to the analysis of industrial systems, and uses a system dynamics model to examine their development. In addition, an evolutionary perspective (Miller, 1978) is employed to explore the industrial development. In this study, the example of the development of Taiwan's industrial system is used to explore the ways in which industrial development in developing countries can be analyzed through the use of the systems approaches.

2. SYSTEMS THINKING TO INDUSTRIAL DEVELOPMENT

The identification of systems objectives is the starting point of systems thinking (Churchman, 1968); therefore, to understand the development of industrial systems, it is necessary to reexamine those systems' real objectives. A system's objectives are not "out there." Instead, they can be identified by either rethinking or criticizing. To identify the objectives, it is also essential to determine the environment and boundaries of the system. Since it is difficult to understand the whole (Flood, 1999), establishment of the boundaries is itself an important process in systems thinking. The identification of a system's boundaries means distinguishing its environment and resources; however, for an industrial system, the identification of the boundary seems more difficult in this case because both the government and the MNCs play the dual role of provider of the resources and the environment for these systems.

In fulfilling this role, the government may provide the industrial system with a favorable environment and initial resources to develop the industry. For instance, it can formulate protective policies to safeguard the development of the industrial system, and it can also establish R&D institutions to support the R&D activities of the system. However, the government's industrial policies tend to be dynamic because it has overall objectives with regard to the whole country's industrial and economic development. Generally the government offers more resources during the early stages of the selected industry. In Taiwan, for example, once the government decided to regard the semiconductor industry as a strategic industry, it set up a science park to develop the industry and supported an R&D institution to foster the technological development of the integrated circuit (IC) industry. Then, through a spin-off from this R&D institute, human resources and technology as well as equipment were transferred from the institute in order to set up some domestic industrial firms. Many internationally prominent semiconductor firms, such as the Taiwan Semiconductor Manufacturing Company Ltd. (TSMC), a leading firm in the foundry industry, have been established in such a manner. However, as the firms gained stability, the government would shift resources to newer industries such as the biomedical or the thin field transistor liquid crystal display (TFT-LCD) industries. Although the government plays an essential role in the development of industrial systems at the start, its policies will change because the government has general policies with regard to the industry and technological

development as a whole. Therefore, for a particular industry, government support in the form of protective policies and resources changes across different stages of the system's development.

MNCs also play the dual role of the provider of resources and the environment. In the early stages of an industry's development, they may provide human resources, capital, and technology to assist the domestic firms in building up their initial know-how and productivity. However, the main objective of the MNCs is to search for potential new markets in the developing country in order to improve their profit in the global economy (Arnold and Quelch, 1998). Therefore, its relationship with the domestic firms is as competitive as it is cooperative. MNCs prefer to concentrate their resources on the development of high-value-added technology and tend to transfer low-value-added technology and outsource the product lines to developing countries. The flying-geese model explains this cooperative relationship. The practice of licensing non-core know-how to original equipment manufacturer (OEM) companies is quite common among the MNCs. Through international division of labor, it can achieve a win–win result. Therefore, in developing countries, those invested in the development of industrial systems must take the MNCs' intentions and goals into consideration. When the domestic firms have accumulated knowledge and improved their competence through long-term technological research and education, conflicts tend to appear between the firms and the MNCs. In this case, the MNCs may attempt to limit the domestic firms' development. In fact, the development of Taiwan's automobile industry has been inhibited tremendously with regard to the capacity for overall automotive design by its MNC technological partners (Jan and Hsiao, 2004).

Ackoff analyzes the progress of contemporary enterprises and proposes three models for systems: mechanical systems, organic systems, and social systems (Ackoff, 1994). Later, an ecological system was added to create a four-system model (Ackoff and Gharajedaghi, 1996). In ecological systems, the system as a whole has no purpose, but its components have their own goals. From the industrial researcher's viewpoint, it seems that the industrial system in a developing country is an ecological system, because it has no overall purpose but its components, including the domestic firms, and the government and the MNCs in their role as resource providers, have their own purposes. However, the role of the environment in industrial development should also be considered. If we regard industrial systems as ecological systems, the dual-role dilemma can be resolved.

3. INDUSTRIAL SYSTEMS AS ECOLOGICAL SYSTEMS

Obviously, the most significant component of an industrial system in a developing country is its domestic firms. The goal of these firms is to make the maximum possible profit through the accumulation of human resources, capital, know-how, productivity, and technology. The government's main participation

in the industrial system takes the form of government-funded R&D institutions. Their main goal is to support the R&D activities in order to initiate or facilitate the technological development of the industrial system. The MNCs are involved through their corporations' divisions located within the developing country, which provide necessary capital and know-how to their domestic partners to assist the development of the industrial system. This manner of identifying the major components of the system, however, cannot resolve the problem of the dual role of the government and the MNCs. Therefore, if we want to regard the development of an industrial system as an ecological system, the identification of the system's components requires further analysis.

An ecological system is capable of maintaining itself as a whole while its components pursue their own purposes (Ackoff and Gharajedaghi, 1996). In fact, most companies today are involved in an ecological system, a loose networks of suppliers, distributors, outsourcers, technology providers, and so on (Iansiti and Levien, 2004). As in a biological ecosystem, a company may share its fate with other components within the system, and a smart company can develop strategies that will benefit every other component of the ecosystem. If we consider an industrial system as an ecological system, it is possible to see that every component of the system may adopt policies that will benefit other components and help maintain the system as a whole.

3.1. Key Players

To resolve the dual role of the government and MNCs, we can regard the components of the industrial system as key players, identifying the purposes of the key players by their main policies. Table I lists the policies of the major players of dual roles within industrial systems. In general, an industrial system includes at least three typical key players: domestic firms, the government, and the MNCs. For different industries, there will be other major players exerting certain influences on the development of the industrial system. The policies of each player may, in fact, vary during the development of the system. Protective policies may be set up by the government during the early stages of development, but these policies are usually modified or abandoned during the later stages. From a key player's point of view, it appears that the development of the industrial system is the result of the dynamic interaction of the varying policies of each of the key players. Although the industrial system itself has no goal, each player has its own purposes. Furthermore, the policies of players of dual roles include policies that arise from both of their roles, as providers of resources and environment.

3.2. Industrial System Development

In an ecological system, the system's behavior cannot be understood through traditional planning and control processes (Morgan, 1982), but through an analysis

Table I. Policies of the Key Dual-Role Players in Industrial Systems

Government	MNCs
Environmental Role	
Make laws and regulations beneficial to the development of industrial systems	Maintain core competitiveness
Provide excellent infrastructure (the building of science-based parks)	Tend not to offer high value-added know-how
	Profit-oriented
	Prevent domestic firms from becoming competitors
Resource Provider Role	
Government supported R&D institutions	Offer necessary human resources, resources, and know-how in the early stages
Policies as rewards, reduction of tax rate, etc.	Inclined to provide low value-added or outdated know-how
Cultivate the workforce required by the industry systems	Cultivate partnership
Cultivate competitive domestic firms	

of the results of the interaction among the policies of the key players. For each key player in an industrial system, different policies are formulated according to its own objectives, which make up its participation in and contribution to the system's development. In the present case, system dynamics (SD) is an appropriate methodology to study the development of industrial systems. SD allows a researcher to describe the system's structure in order to explain the system's behaviors (Coyle, 1996; Forrester, 1961), and this methodology has been widely applied to industrial development (Berends and Romme, 2001; Corben *et al*., 1999; Dangerfield and Roberts, 2000; Ford, 1997; Liehr *et al*., 2001; Oliva and Sterman, 2001; Pardue *et al*., 1999). Analyzing each key player's policies makes it possible to construct information–decision–action loops that allow us to understand the system's structure and behavior. SD has been used to analyze the development of Taiwan's automobile, semiconductor, and national defense industries (Chen and Jan, in press; Jan and Hsiao, 2004; Jan and Jan, 2000). The key players and their major polices are shown in Table II.

In the earlier stages of the development of Taiwan's automobile industry, the government played a pivotal role in formulating protective regulations against the importing of related technology. In playing this role, the government helped domestic firms accumulate preliminary capabilities in manufacturing and design. However, in a situation in which the domestic firms attempt to expand their production and R&D capabilities, they may come into conflict with the objectives of their foreign partners. Instead of being partners, then, they become competitors, and cooperative strategies turn into conflicts between the partners' objectives. In

Table II. Key Players and Policies of Some Taiwanese Industrial Systems

Key players	Major policies
Auto industry	
Domestic firms	Manufacturing & design capacity
Government	Protection regulations
Foreign technological partners	Provide low-end technology, but do not support whole-car design
Consumers	See auto as luxury
Semiconductor industry	
Domestic firms	Manufacturing & service capacity
Government-supported R&D institute (Industrial Technology Research Institute, ITRI)	Spin-offs from ITRI
Government	Infrastructure (science parks)
International partners	Provide technology
Defense industry	
Government-support R&D institute (Chung-Shan Institute of Science and technology, CSIST)	Weapons systems R&D
Government	Long-term resource support
Weapons system providers	Provide systems depending on the R&D capacity of CSIST

one such case, two domestic automobile firms attempted to engage in the overall design of whole cars. However, their foreign technological partners did not support such activities and, in order to fight the domestic firms' desires, they threatened that they would no longer introduce new automobiles and technology. Since Taiwanese consumers regard automobiles as a luxury good, if there were no new model the market would dry up. Therefore, the domestic automobile firms finally gave up the project of designing whole cars. They shifted back to cooperating with their MNC partners, and the firms retained their share in the domestic market. To date, they have not been allowed the capability to design whole cars. Simulation results indicate that the government played a very important role in the early stages. Later, the system's behavior became a result of the interaction of the policies of the domestic firms, technological partners, and domestic consumers (Jan and Hsiao, 2004).

The semiconductor industry is one that requires a large volume of manpower, capital, and intensive know-how. Fostering the accumulation of enough human resources, capital, know-how, and productivity has been key to the development of the semiconductor industry systems. Because the Taiwanese government regards the semiconductor industry as a strategic industry, in the earliest period the government established many regulations to attract resources to the industry, and built the science-based industrial park to promote the development of the high-tech industry. Government-supported R&D institutes (e.g. Industrial Technology Research Institute, ITRI) had also played a major role of generating spin-offs

for many of the domestic firms. The firms then began to successfully accumulate enough manpower and funded resources from the domestic market. Now, some domestic firms have become international firms, and they have attracted other MNCs as their partners, building up the world's fourth largest semiconductor industry.

Taiwan acquires weapons mainly from foreign purchases and domestic R&D. These two methods of weapons systems acquisition are closely related. At one point, Taiwan's weapon acquisition policy shifted from foreign purchases to domestic R&D. The R&D budget was raised to 50% of the total weapons budget in 1992. Many key technologies were accumulated. Since acquiring certain technologies allowed the government to purchase weapons systems from foreign countries at lower prices, the government resumed its policy to foreign purchases later. As a result, the R&D budget decreased to below 30% in 1998. This move caused the R&D institutions to lose manpower and to slow in their accumulation of technologies over a prolonged period, which had a tremendous impact on domestic R&D and weapons production. Simulation results show that if the R&D budget had remained 50% of the total after 1992, then the R&D capacity would have been maintained from 1991 to 2010. Therefore, maintaining a balance between domestic R&D and foreign purchases in the acquisition of weapons is the best option for Taiwan (Jan and Jan, 2000).

4. INDUSTRIAL DEVELOPMENT AS AN EVOLUTIONARY PROCESS

In developing countries, the government usually plays an essential role in industrial development. However, certain successful industries do not require much assistance from the government, especially those that focus on the international market. An example is Taiwan's information technology (IT) industry, whose productivity value was once ranked third in the world. The well-developed IT industry relied on the successful interaction of domestic firms and the leading global MNCs. In addition, although the semiconductor industry had relied on the government to acquire preliminary human resources, capital, know-how, and technology in earlier stages, later on this industry also depended on the successful interaction between the domestic firms within the local and international environment to accumulate capital, human resources, productivity, and know-how. The development of these two industrial systems can be viewed as an evolutionary process, the continuous and effective interaction of the industrial systems and their environment. They were successful in adapting to the environment and persisted in building up their competitive advantages on their own. The general direction of evolution is toward greater complexity of the system (Miller, 1978, p. 76). The domestic firms in these two industries have successfully increased their variety and their core competences in order to survive and develop in the global economy

(Jan and Chen, 2004; Chen and Jan, 2005). The evolutionary perspective has, in fact, been widely applied to the study of industrial development for both developed countries and developing ones (Dobrev *et al*., 2003; Lau, 2003; Muller, 2002; Xie and White, 2004; Zuniga-Vicente *et al*., 2004).

The development of Taiwan's IT industry has been linked closely to the development of the leading global MNCs (Jan and Chen, 2004). In 1980, IBM employed the open-architecture strategy to become the leading PC manufacturer. This strategy ushered in opportunities for the development of Taiwan's IT industry. With household electric appliances and video games as the foundations of the industry, Taiwan transformed itself into a monitor OEM country. In 1986, Compaq took the lead in launching the 32-bit PC, challenging IBM's leading position. Likewise, OEM became a powerful competitive weapon. During this period, Taiwan greatly expanded its OEM capacity, and then the capacity for original design manufacturer (ODM) was established. In the early 1990s the launching of Microsoft's Windows systems and the take off of Intel's CPU efficiency led to the rise of the low-price PC. With its excellent capacities in OEM and low cost overseas factories, Taiwan soared to prominence as one of the best international outsourcing partners. In the mid-1990s, with the rise of the Internet, Dell threatened Compaq's position, and Taiwan built up its global logistic systems, beginning to influence the mainstream MNCs' in global strategic decisions. In the development of Taiwan's IT industry, the government did not play a key role. Evolution was the major driving force that impelled the domestic firms in the industry to develop their core competence during their interaction with the leading MNCs in the development of the global IT industry.

In the early stages of the development of Taiwan's semiconductor industry, government assistance established its original domestic firms through spin-offs from government-supported R&D institutes, supplying preliminary human resources, capital, and technology. However, its development in later stages owed largely to the interaction of the firms in the domestic and international environment (Chen and Jan, 2005). The firms developed a successful model through a trial-and-error learning process. For example, some firms attempted to produce a 486 CPU but finally were unable. Conversely, some other firms tried to develop their manufacturing capacity toward foundries and had tremendous success. As a result, many domestic firms in Taiwan shifted to foundries and created a profitable market. Because of their success in niche markets, Taiwan's firms adopted unique strategies such as share dividends to attract a huge volume of capital and human resources in the domestic environment. The long-term accumulation of the necessary resources and their achievement of manufacturing competence allowed them to interact successfully with more of the MNCs to foster a cooperative relationship, which caused Taiwan's semiconductor industry to gain an essential position in the global industry.

5. DISCUSSION

Industrial development in developing countries is a very complicated and dynamic process. Explaining such phenomena with a ready-made principle or theory is extremely difficult. For example, the flying-geese model and the national innovation system facilitate our understanding of industrial development. Ecological systems and evolutionary perspectives also facilitate our understanding of industrial development. Furthermore, in developing countries, although there are many similarities, there are also many variables, such as infrastructure, environment, culture, and economic, political, and social situations that are particular to each country. Each country has its own development strategies applicable to its situation. For example, Korea's industrial development is different from that of Taiwan. Previously, many large corporations existed in Korea. These enormous corporations had sufficient manpower and capital to engage in the development of new businesses; therefore, their development could be conducted through conventional planning process. The business structure of Taiwan, on the other hand, is mainly composed of small- and medium-sized businesses. Therefore, in the early stages, the development of many industrial systems relied on the government's support. In particular, strategic industries represented the sectors to which the government allocated more resources to help their development. Conversely, large Korean corporations were capable of initiating the semiconductor industry on their own; the Korean government supported the industry's development by helping them obtain more financial support from government-controlled banks (Chen and Jan, 2005).

Furthermore, the interaction between industrial systems can also affect the industrial development. For example, the order in which different industry systems develop may profoundly affect the development of the industry. The development of the semiconductor industry in Taiwan and Korea accumulated human resources that were familiar with the production process and had key semiconductor manufacturing process know-how. With these ready resources, the development of TFT-LCD industry became more feasible. This fact explains why among developing countries the TFT-LCD industry is concentrated in Taiwan and Korea.

In the development of industrial systems, many phenomena still persist that are worthy of further examination. For example, the "avoiding non-survival" strategy mentioned by Morgan (1983) has appeared frequently in the industrial development of developing countries. In Taiwan, domestic firms discovered that adopting a strategy of not competing with the MNCs made it easier for them to survive. For example, the foundry industry has been one of the most successful industries in Taiwan because it built up a niche market by avoiding direct competition with integrated device manufacturers (IDM). In the IC design industry, VIA Technology once reached a position from which it could threaten Intel's leading position in the chip market; however, such a boom did not last long. The IT firms adapted to its environment by implementing strategies of cooperating with the

leading MNCs in the industry, avoiding competition in the high-value-added area. These examples reflect strategies of avoiding nonsurvival. When developing countries transform into newly industrialized countries, however, many relationships between domestic firms and MNCs will change and competition will be unavoidable. At present, Taiwan has focused on widely building R&D centers. There seem to be an endless number of ways of creating niche markets and adjusting the developmental strategy in order to adapt to its environment.

In summary, the development of industrial systems in developing countries is a complicated and dynamic process. This study has examined the development of many representative industries based on ecological systems, system dynamics, and evolution, using the history of industrial development in Taiwan as an example. Results of this study demonstrate that with different systems approaches, valuable insights can be made that will help us further understand industrial development.

REFERENCES

Ackoff, R. L. (1994). Systems thinking and thinking systems. *Syst. Dyn. Rev.* **10**(2–3), 175–188.

Ackoff, R. L., and Gharajedaghi, J. (1996). Reflections on systems and their models. *Syst. Res.* **13**(1), 13–23.

Arnold, D. J., and Quelch, J. A. (1998). New strategies in emerging markets. *Sloan Manage. Rev.* **40**(1), 7–20.

Berardes, A. T., and Albuquerque, E. D. (2003). Cross-over, thresholds and interactions, between science and technology: Lessons for less-developed countries. *Res. Pol.* **32**(5), 865–885.

Berends, P. A. J., and Romme, A. G. L. (2001). Cyclicality of capital-intensive industries: A system dynamics simulation study of the paper industry. *OMEGA-Int. J. Manage. Sci.* **29**(6), 543–552.

Chang, Y. C. (2003). Benefits of co-operation on innovative performance: Evidence from integrated circuits and biotechnology firms in the UK and Taiwan. *R & D Manage.* **33**(4), 425–437.

Chen, J. H., and Jan, T. S. (2005). A variety-increasing view to the development of the semiconductor industry in Taiwan. *Technol. Forecasting Soc. Change* **72**(7), 850–865.

Chen, J. H., and Jan, T. S. (in press). A system dynamics model of the semiconductor industry development in Taiwan. *J. Operat. Res. Soc.* to appear in DOI: 10.1057/palgrave.jors.2601958.

Churchman, C. W. (1968). *The Systems Approach*, Delta, New York.

Corben, D., Stevenson, R., and Wolstenholme, E. F. (1999). Holistic oil field value management: using system dynamics for 'intermediate level' and 'value-based' modeling in the oil industry. *J. Operat. Res. Soc.* **50**(4), 383–391.

Coyle, R. G. (1996). *System Dynamics Modelin—A Practical Approach*, Chapman & Hall, London.

Dangerfield, B. C., and Roberts, C. A. (2000). A strategic evaluation of capacity retirements in the steel industry. *J. Operat. Res. Soc.* **51**(1), 53–60.

Dobrev, S. D., Kim, T. Y., and Carroll, G. R. (2003). Shifting gears, shifting niches: Organizational inertia and change in the evolution of the US automobile industry, 1885–1991. *Org. Sci.* **14**(3), 264–282.

Ennals, R. (2004). Europe as a knowledge society: Integrating universities, corporations, and government. *Syst. Pract. Action Res.* **17**(3), 237–248.

Flood, R. L. (1999). Knowing of the unknowable. *Syst. Pract. Action Res.* **12**(3), 247–256.

Ford, A. (1997). System dynamics and the electric power industry. *Syst. Dyn. Rev.* **13**(1), 57–85.

Forrester, J. W. (1961). *Industrial Dynamics*, MIT Press, Cambridge.

Fuenmayor, R. (2001). The oblivion of Churchman's plea for a systems approach to world problems. I. The inseparability of systems thinking and world issues in the modern epoch. *Syst. Pract. Action Res.* **14**(1), 11–28.

Ghemawat, P. (2001). Distance still matters—The hard reality of global expansion. *Harvard Business Rev.* **79**(8), 137–147.

Guerin, T. F. (2001). Transferring environmental technologies to China: Resent developments and constraints. *Technol. Forecasting Soc. Change* **67**(1), 55–75.

Haley, U. C. V., and Low, L. (1998). Crafted culture: Governmental sculpting of modern Singapore and effects on business environments. *J. Org. Change Manage.* **11**(6), 530–553.

Hayashi, T. (2003). Effect of R&D programmes on the formation of university–industry–government networks: Comparative analysis of Japanese R&D programmes. *Res. Pol.* **32**(8), 1421–1442.

Iansiti, M., and Levien, R. (2004). Strategy as ecology. *Harvard Business Rev.* **82**(3), 68–78.

Intarakumnerd, P., Chairatana, P. A., and Tangchitpiboon, T. (2002). National innovation system in less successful developing countries: The case of Thailand. *Res. Pol.* **31**(8–9), 1445–1457.

Jan, T. S., and Chen, H. H. (2004). Evolution of the information technology industry in Taiwan, *Unpublished Working paper.*

Jan, T. S., and Chen, Y. (in press). The R&D system for industrial development in Taiwan. *Technol. Forecasting Soc. Change*, to appear in DOI: 10.1016/j.techfore.2005.01.005.

Jan, T. S., and Hsiao, C. T. (2004). A four-role model of the automotive industry development in developing countries: A case in Taiwan. *J. Operat. Res. Soc.*, **55**(11), 1145–1155.

Jan, T. S., and Jan, C. G. (2000). Development of weapon systems in developing countries: A case study of long range strategies in Taiwan. *J. Operat. Res. Soc.* **51**(9), 1041–1050.

Kojima, K. (2000). The 'flying geese' model of Asian economic development: Origin, theoretical extensions, and regional policy implications. *J. Asian Econ.* **11**(4), 375–401.

Lau, H. F. (2003). Industry evolution and internationalization processes of firms from a newly industrialized economy. *J. Business Res. Pol.* **56**(10), 847–852.

Lemola, T. (2002). Convergence of national science and technology policies: The case of Finland. *Res. Pol.* **31**(8/9), 1481–1490.

Levin, M. (2004). Cross-boundary learning systems—Integrating universities, corporations, and governmental institutions in knowledge generating systems. *Syst. Pract. Action Res.* **17**(3), 151–159.

Liehr, M., Größler, A., and Milling, P. M. (2001). Cycles in the sky: Understanding and managing business cycles in the airline market. *Syst. Dyn. Rev.* **17**(4), 311–332.

Lin, B. W. (2003). Technology transfer as technological learning: A source of competitive advantage for firms with limited R&D resources. *R&D Manage.* **33**(3), 327–341.

Liu, X. H., and Wang, C. G. (2003). Does foreign direct investment facilitate technological progress? Evidence from Chinese industries. *Res. Pol.* **32**(6), 945–953.

Lu, Q. W., and Lazonick, W. (2001). The organization of innovation in a transitional economy: Business and government in Chinese electronic publishing. *Res. Pol.* **30**(1), 55–77.

Mahmood, I. P., and Singh, J. (2003). Technological dynamism in Asia. *Res. Pol.* **32**(6), 1031–1054.

Mathews, J. A., and Cho, D. S. (1999). *Tiger Technology: The Creation of Semiconductor Industry in East Asia*, Cambridge University Press, Cambridge.

Miller, C. (1978). *Living Systems*, Mcgraw-Hill, New York.

Morgan, G. (1982). Cybernetics and organization theory: Epistemology or technique? *Hum. Relat.* **35**(7), 521–537.

Morgan, G. (1983). Rethinking corporate strategy: A cybernetic perspective. *Hum. Relat.* **36**(4), 345–360.

Muller, C. (2002). The evolution of the biotechnology industry in Germany. *Trend Biotechnol.* **20**(7), 287–290.

Nelson, R. R. (1993). *National Innovation Systems: A Comparative Analysis*, Oxford University Press, Oxford.

Oliva, R., and Sterman, J. D. (2001). Cutting corners and working overtime: Quality erosion in the service industry. *Manage Sci*. **47**(7), 894–914.

Parayil, G., and Sreekumar, T. T. (2004). Industrial development and the dynamics of innovation in Hong Kong. *Int. J. Technol. Manage.* **27**(4), 369–392.

Pardue, J. H., Clark, T. D., Jr., and Winch, G. W. (1999). Modeling short- and long-term dynamics in the commercialization of technical advances in IT producing industries. *Syst. Dyn. Rev.* **15**(1), 97–105.

Passos, C. A. S., Terra, B. R. C., Furtado, A. T., Vedovello, C., and Plonski, G. A. (2004). Improving university–industry partnership—The Brazilian experience through the scientific and technological development support program. *Int. J. Technol. Manage.* **27**(5), 475–487.

Prahalad, C. K., and Hammond, A. (2002). Serving the world's poor, profitably. *Harvard Business Rev.* **80**(9), 48–57.

Ramamurti, R., and Doh, J. P. (2004). Rethinking infrastructure investment in development countries. *J. World Business* **39**(2), 151–167.

Sakakibara, M., and Cho, D. S. (2002). Coopeative R&D in Japan and Korea: A comparison of industrial policy. *Res. Pol.* **31**(5), 673–692.

Shyu, J. Z., and Chiu, Y. C. (2002). Innovation policy for developing Taiwan's competitive advantages. *R&D Manage.* **32**(4), 369–374.

Viotti, E. B. (2002). National learning systems—A new approach on echnological change in late industrializing economies and evidences from the cases of Brazil and South Korea. *Technol. Forecasting Soc. Change* **69**(7), 653–680.

Wang, T., and Pollard, R. (2002). Selecting a technical strategy for high-tech enterprises in developing countries—A case study. *Int. J. Technol. Manage.* **24**(5/6), 648–655.

Xie, W., and White, S. (2004). Sequential learning in a Chinese spin-off: The case of Lenovo Group Limited. *R&D Manage.* **34**(4), 407–422.

Zuniga-Vicente, J. A., Fuente-Sabate, J. M., and Rodriguez-Puerta, J. (2004). A study of industry evolution in the face of major environmental disturbances: Group and firm strategic behaviour of Spanish banks, 1983—1997. *Br. J. Manage.* **15**(3), 219–245.