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CO-EVOLUTION AND NETWORKS ADAPTATION

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JEL - codes: Z00, -, -

Co-evolution and Networks Adaptation: What Can We Learn from Biology?

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Introduction

During the last fifteen years, the research on networks has greatly developed, reflecting the fact that "outcomes increasingly are decided by competition between networks of firms rather than competition among firms" (Achrol and Kotler, 1999: 146). However, despite the abundance of studies on networks (Grandori and Soda, 1995; Gulati, 1998), defined as "any collection of actors (N≥2) that pursue repeated, enduring exchange relations with one another and, at the same time, lack a legitimate organizational authority to arbitrate and resolve disputes that may arise during the exchange" (Podolny and Page, 1998: 58), these studies are restricted to examining static features of networks, such as density, trust, control, workflow, cohesion or power (Podolny and Page, 1998). Dynamic aspects are generally neglected (Oliver and Ebers, 1998). Even network sociology (Burt, 1982; 1992), that takes into account not the individuals but the relations between the individuals and their regularities, produces models that are "static, descriptive, algebraic, and linear deterministic" (McKelvey, 1999:

305). Even though these static techniques are a precious tool for the comprehension of networks, they cannot explain the dynamic processes, such as the adaptation of a network of firms to a changing environment.

This article examines networks from a dynamic perspective of adaptation, considering, like Human and Provan (1997) that a network allows to accomplish specific organizational objectives that none of the members could have accomplished individually. Through a strong specialization and in quest for complementarities, a network can represent an efficient response to the instability of the environment, as a system of distributed intelligence (McKelvey, 2001).

The issue of adaptation has largely been studied at the organizational level, following the seminal works of Hannan and Freeman (1984), but the analysis of adaptation at an inter-organizational level still remains confined to a process of selection, in the perspective of population ecology (Hannan and Freeman, 1977). As Kraatz suggests, "one prominent void is in the area of the role that interorganizational networks may play in adaptation" (1988: 622). The exploitation/exploration framework developed by March (1991) and refined by Levinthal and March (1993) allows us to study adaptation processes within networks (Koza and Lewin, 1998; Rothermael and Deeds, 2004). According the March, "the essence of exploitation is the refinement and extension of existing competences, technologies and paradigms", while "the essence of exploration is experimentation with new alternatives" (1991: 85). The issue we address in this article is the following: How can exploitation and exploration be developed and balanced in a network? To shed light on this issue, we shall examine internal and external network ties.

This research is anchored in network sociology (Burt, 1982, 1992; Nohria and Eccles, 1992) and in the resource-based view (Wernerfelt, 1984; Barney, 1991), but benefits from the progress of complexity theory to propose a new grid of analysis. In fact, "complexity theory explicitly addresses the question of how much interconnection is best (…) what level of interdependency is associated with the best performance" (Caroll and Burton, 2000: 320). In particular, Kauffman's multi-agent NKCS model (1993), issued from biology, allows to simulate evolution of species and to understand the adaptation mechanisms at work.

To analyze the ways networks adapt, we first present a qualitative study. Nine Japanese networks are studied through interviews conducted in several firms and local communities. We then identify mechanisms that generate adaptation, group them and analyze them from the perspective of the results of the NKCS model. The comparison of the results of this "dynamic, stochastic recursive and non linear" model (McKelvey, 1999: 305) with the results of the case studies conducted in Japan allows us to enhance the understanding of adaptation processes in networks.

The article is organized as follows. A discussion of co-evolution in a network leads to a distinction between its two constituting dimensions, internal and external (section 1). The qualitative methodology and the classification of networks studied are then introduced (section 2). Finally, the results of the cases studies are presented analytically, from the point of view of the NKCS model (section 3).

1. CO-EVOLUTION IN A NETWORK OF FIRMS

Co-evolution, in its broadest sense, refers to evolutive adaptation that takes places in several elements (genes or species) following their reciprocal influences. Co-evolution in a population stems from a conjunction of a high number of different elements and ties that unite them. As Callon et al. have shown through a study of networks, "diversity could be a richness and a need, and not necessarily the proof of a lack of strategy" (1992: 235). Ties (or interdependencies) mean that the actions of one entity have the consequences on the related entities and on the entire system. A complex behavior of a system, at the frontier of chaos, between order and disorder, emerges from the interconnection of numerous elements within a system (internal co-evolution) and between a system and its environment (external co-evolution) (McKelvey, 2001).

1.1. Internal and external co-evolution

Internal co-evolution of a network depends on the size of the network and on the intensity of ties between its member firms.

- The size of a network refers to the number and variety[1] of firms and resources engaged to develop a specific production system enabling to satisfy a client. As the resource-based view argues, firms can be considered as bundles of resources (Barney, 1991; Wernerfelt, 1984). By extension to the interorganizational level, the network uses and develops bundles of valuable, rare, inimitable and non-substitutable resources (Barney, 1991).
- The intensity of internal ties refers to interdependencies between network members and to different types of ties in which firms are embedded. The results from the literature seem contradictory on this point. According to Granovetter's (1973) perspective, weak ties allow the system to be flexible, through the exploitation of structural holes (Burt, 1992). In a second perspective, the one of embeddedness, the strength of ties enables, on the contrary, to enhance the density of information exchange (Granovetter, 1985). This ambivalence of ties is partially explored by Uzzi (1997) who shows, through a study of 23 firms in the textile industry that

[1] This measure is found in biology: variety of living beings in a community, which represents both the number of species and the number of entities (relative abundance) within species (Cunningham, Cunningham & Saigo, 2001). For example, the Hamming distance is the number of positions in two chains of the same length in which the corresponding elements are different.

organizations that dispose of both strong and weak ties through a network, are more flexible and capable to respond to the changes of the environment.

External co-evolution of a network refers to the number of clients, or more precisely systems of client-responses, of a network and the intensity of ties between them.

- A network depends not only on its internal, but also on its external resources (Pfeffer and Salancik, 1978), mainly its clients. In fact, a network deploys combinations of resources to respond to the clients' orders. Its performance depends on the power relations that it maintains with its clients (by controlling their concentration and the resources it exchanges). A weak number of clients minimizes transaction costs but reduces the capacity of a network to perceive possible changes in the environment and to adapt to them (Zajac et al., 2000).
- The intensity of external ties refers to interdependence between the clients. Like there are interactions between the members of a network, there are also interactions between its clients. If clients are competitors or partners, external co-evolution is strong. Conversely, if clients are very different one from the other, namely in terms of domains or industries to which they belong, external co-evolutionary density is weak.

The adaptation capacity of a network is therefore influenced by the two dimensions of co-evolution. The NKCS model, presented in the following section, can help us understand its dynamics.

1.2. A complex approach to co-evolution: the NKCS model

In a system that co-evolves, there is no unique tie between the actors (McKelvey, 1997), since every modification of an element has an impact on the entire system. According to complexity theory, internal interactions influence the structure, the change and the performance of a system. The trade-off between order and disorder rests on the following argument: adaptability of a system depends on the connections between its elements. Without connection, the system is simply disorganized, but if the elements are over-connected, the system immobilizes and adaptability decreases. These tensions are called "complexity catastrophes" and are related to the notion of coupling (Weick, 1976). The appropriate form and the right level of interdependencies need to be found to place the system into the state of performance and adaptability.

To formalize these elements we use a simulation model. The NKCS model (Kauffman, 1993), of the biological origin, proposes a new perspective of co-evolution within networks.

"N", size of species, refers to the number of firms and resources that constitute a network. "K", epistatic interactions within species, refers to the intensity of ties between the firms in a network. "S", number of species, refers to the number of client-responses of a network. Each network has to respond to the demands of its clients and to develop specific systems of production resources for each of them. "C", interactions between species, refers to the intensity of ties between the clients "client-responses" of a network.

Each "client-response" needs to adapt to its environment, without a centralized decision, but through accumulation of local decisions. Each firm thus changes independently, contributing to the emergence of a collective equilibrium within a network. By applying this model to the study of networks of firms, we consider that networks and animal species are populations with similar behavior and objectives. The collective entity is submitted to no strict authority but relies on coordination of its agents and their interaction through simple rules, in order to resolve complex problems. A network needs to look for external financing, develop its infrastructures and innovate. An animal community needs to look for food, construct a shelter and secure its reproduction.

Internal co-evolution of each species depends on its size (N) and on the strength of ties between its members (K). This internal co-evolution is observed in animals. While animals living in herds, members of a flock of birds or a shoal of fish are weakly differentiated (no specific role is attributed to a member), in some species, interactions are enhanced and a specific organization emerges. In a pack of wolves for example, a strict hierarchy is respected (from alpha, chief of the pack, to omega, the scapegoat), in an anthill, a termitarium or a swarm of bees, the work is divided and each member has a particular role (worker, soldier, breeding sexual, primary sexual, brood cumb,…). A parallel can be made with the Japanse hierarchical subcontracting networks. The NK model has been applied to organizational science. Levinthal (1997) shows that a high level of internal co-evolution can lead an organization to adopt very different organizational forms, depending on its initial situation and its evolution trajectory (Levinthal, 1997: 940-944) and push it to undertake strategic reorientations, that is, to change radically its resources (Levinthal, 1997: 944-946). Rivkin (2000) argues that a high level of internal co-evolution protects an organization from imitation by its competitors. Rivkin explains that "in a strategy whose pieces are numerous and tightly knit, small probabilities that each element will be replicated incorrectly cumulate to produce a high likelihood that imitators will fare poorly" (2000: 839). But Rivkin also shows that a high level of internal evolution hinders the possibilities of internal replication of a system of resources of an organization (for example in one of its subsidiaries).

Thus, at the organizational level, internal co-evolution is ambivalent. It sometimes appears as a vector of competitive advantage and protection from imitation, sometimes as an obstacle to adaptation and replication of efficient organizational routines. A moderated level of internal co-evolution enables to adapt at the “edge of chaos”, between two attractors constituting the regimes of order and disorder.

External co-evolution depends on the number of species (S) and the intensity of ties between them (C). External co-evolution of a species depends on the variety of its preys and the interactions between them. In certain species, external co-evolution is weak. The resource of a herd for instance is specific and static: gnus eat only andropognon (a herb with leaves), zebras eat the hardest stems of the high weed. On the other hand, some species diversify their alimentation sources and are therefore characterized by strong external co-evolution: trees and flours for bees; grains and even greenflies rose as livestock for ants.

While the robustness of Kauffman’s model (stability of the results of the model regarding its different parameters) has already been tested (Rivkin, 2001), its comparison to real cases is a research direction to explore. This biological metaphor of networks can create perspicacity (Morgan, 1999). The comparison of animal species and networks of firms allows us to shed light on the similar adaptation mechanisms and to develop a typology. Section 2 presents the case studies and leads to their classification, in the literal and theoretical replication logic (Eisenhardt, 1989).

2. CASE STUDIES

To understand how diversity and interdependence affect network dynamics and which combination of these variables leads to optimal adaptability, we conducted a qualitative study in industrial districts in Japan, where “co-evolutionary pockets” (McKelvey, 1999) can be observed: geographically close firms cooperate intensely in search for a competitive advantage and at the same time, share a common destiny. The choice of this setting was doubly motivated. First, within industrial districts, a multitude of networks, mostly of small co-evolving firms can be found. Small firms combine their resources and competencies to respond to their clients' demands. The functioning through networks within industrial concentrations is in fact one of the key characteristics of the Japanese industry. Second, these zones are particularly relevant for the study of adaptation processes because they are confronted to a major environmental change: industry relocation. Although industry relocation hits today all industrialized countries, Japan is probably the most affected. Since the middle of 1990s, the transfer of production systems to South-East Asia progresses exponentially and has been considerably accrued during the last five years with the explosion of industry relocation to China. The ability of networks to respond to a changing environment can therefore be evaluated in this setting. The existence of different levels of diversity and interdependence within networks suggests that a considerable variety of responses to change (in other words adaptability) may exist as well, even though networks operate within the same niche or in the same environment. Each of the variables presented earlier (size of the network, intensity of internal ties, number of clients and intensity of external ties) should have an impact on the survival modes and on adaptation of networks.

2.1. Data collection method

Japanese networks were studied through case studies. We adopted a qualitative method, based essentially on semi-structured interviews with entrepreneurs. Three criteria guided our sampling choice. First, for external validity (even though it is limited to the Japanese case), we wanted to study manufacturing networks situated in different types of industrial districts[2]. In fact, districts were first considered as a homogenous phenomenon (Becattini, 1987), but the subsequent research has shown that there are divergences between them (Paniccia, 1998) and that there are different forms of districts. It was therefore important to include in our sample networks present in all types of industrial districts. Second, we took care that the elements of comparison exist in terms of context of networks. Third, we wanted to cover to a maximum the industrial diversity. Thus, nine manufacturing networks studied belong to various industries such as metal, mechanic, automobile, electronic, textile, semiconductors or precision engineering.

Networks are dynamic, moving structures and it is difficult to define their borders (Angot and Josserand, 2003), because they are often controlled by several actors and are changing constantly (Forgsgren and Johansons, 1992). Moreover, our research deals with the networks of small firms, which are often informal and with no explicit borders. Nevertheless, our goal is not to determine the exact borders and structures of networks, like the network sociologist do[3]. We rather wish to understand their dynamic and namely how they adapt to the changes in their environment. We use two criteria to delimit the networks that we study. The first is geographical. This criterion can be questionable, since it is possible that some actors outside the geographical area in question belong to the network. However, this critique can be nuanced because Japanese manufacturing networks (and in particular small-firm ones) are essentially geographical networks (Whittaker, 1997). The second indication that helps us delimit the networks is given by the network actors.

[2] According to Japanese researchers, there are four types of industrial districts in Japan: company towns, regional districts, urban industrial zones and traditional districts.
[3] For an overview of the network sociology analyses, see Angot and Josserand (2003).

Semi-structured interviews were conducted with entrepreneurs, experienced managers and local officials. Two waves of interviews were organized. During the first one, the most important, 42 interviews were conducted over a six-month period in 2002 and 2003. During the second wave, in 2004, 15 additional interviews were performed. We wanted to interview "typical" firms, of the most represented size in the network. In hierarchical networks, only subcontracting forms were interviewed. Respondents were asked about their firms (activities, functioning), the network to which their firm belongs (structure, resources, clients). To grasp the network dynamics, we applied retrospection. We asked the actors to explain the functioning of their networks and to compare the periods "before" and "after" industry relocation. We aimed to find out whether changes took place and what they were. Entrepreneurs provided detailed accounts, period by period. In addition, local officials from the "offices of support to local industries" proposed historical accounts on industrial firms, on the cooperation and competition dynamics and on the developments during the last fifteen years. Additional techniques such as observation in firms and observation in districts were applied. Other sources of non-systematic proof were also used: informal conversations and analyses of internal documents provided by small firms and local officials. These different data sources allowed us to triangulate the information, to enrich, question and verify the data (Denzin and Lincoln, 1994).

2.2. Data analysis

Interviews were recorded, transcribed and translated from Japanese. In order to summarize the information extracted from the data, we have first undertaken a thematic coding. A list of codes was developed ex ante and then slightly modified during the coding process. Several blocks of codes were included: characteristics of the industrial district (type of firms present, location, know-how), inter-firm relations (division of labor, coordination, existence of a leader, R&D), clients (types of industries, relations with clients), changes in the network (industry relocation, relations with clients). A double coding was performed, with an inter-coder reliability ration of 91%. The data retained were classified in theme-respondent matrices. Each case study corresponds to a network. Their names refer to the industrial district or the region in which networks are located.

The data analysis was organized in two stages. First, we analyzed each case separately (intra-case analysis) in order to understand how networks work and to derive results based on the data. To do so we applied the guidelines of Miles and Huberman (1984) and we designed conceptual groupings matrices[4]. We then compared the cases.

A summary of the case analyses is presented in table 1.

	Size of the network	**Intensity of ties between firms**	**Number of clients**	**Intensity of ties between clients**
Ota-ku	6038 highly specialized small firms	Cooperation in processing and production (competence coordinators confrere networks)	Several hundreds	Meta and mechanic industries
Higashi Osaka	8000 complementary firms	Important personal ties, mutual aid, central firms coordinate cooperation activities	Several hundreds	Metal, mechanic and electronic industries
Suwa	2000 small firms	Vertical pyramid structure	One client, Seiko-Epson	No tie
Nagano	Several hundreds undifferentiated small firms	Occasional transfer of orders	A hundred	Metal, mechanic and precision engineering
Hamamatsu	Several thousands undifferentiated small firms	Tiers of subcontracting firms with no ties	One client	Independent activities
Shizuoka	Several dozens of small firms	Firms have different competencies, which determine, along with social ties, their belonging to a network.	Numerous, most important of which are Yamaha and Photonics	Motorcycle, semiconductors, electronic.

[4] Conceptual grouping matrices are a tool used to present and analyze the data in which data are grouped according to concepts to which they refer.

Musashi Murayama	A few large firms and several dozens of small firms	Pyramid with large firms and subcontractors that have few horizontal ties	One client, Nissan	Automobile industry
Hitachi	700 weakly specialized small firms	Few ties between small firms	One client, Hitachi	Telecommunication, electronic, industrial equipment
Kiryu	400 highly specialized small firms	One producer assumes the risk related to production and coordinates competencies of small firms.	A few wholesale firms	No direct contacts, independent and intermediated demands

Table 1 – Intra case analysis of nine networks

We shall now present the inter-case analysis, according to four variables that determine co-evolution of networks.

The size of the network was estimated through the number of firms and different resources that constitute each network. The number of firms was given by entrepreneurs and local officials. Resources and competencies were evaluated qualitatively, through the analysis of the discourse of respondents. A double estimation was performed to reduce the possible biases. Although it is legitimate to consider that the number of resources/competences increases with the number of firms, these two elements can sometimes diverge. For example, the Hitachi network is composed of almost two times larger number of firms than the Kiryu network (700 compared to 400), while resources in Kiryu are more numerous. The entrepreneurs' discourse illustrates these differences.

"Elsewhere, town factories are more advanced in terms of technology […] here, everybody has the same machines and produces the same things." (Hitachi)
"In Kiryu, there is everything. Among the firms that are do textile, there are those that do the coloring of the cloth, those that produce yarn and others, these are different firms." (Kiryu)

The intensity of ties between network members was determined from the analysis of interviews and themes related to the division of labor, joint R&D activities, coordination of production processes and the existence of differentiated roles within a network. Thus, in the Ota-ku network (where firms are localized according to their competences, because the reception of an order by one member supposes the implication of its neighbors for certain processing tasks), in Kiryu (where each member of a network takes part in one single operation in the process of textile production), in Higashi Osaka (where the informal groupings of firms are formed around complementary competencies) or in Shizuoka (where social ties are predominant), the intensity of ties is strong. Conversely, in five other networks, interactions are limited, like in the Nagano network where the defiance substitutes collaboration: firms car respond to orders of their clients relatively independently.

"The orders arrive to the confrere network. First, there are firms that receive the orders and they diffuse them through the network. Small firms can not act alone to respond to orders. Firms are specialized and the firm that takes the order organizes the division of work" (Ota-ku)

"We can do everything by ourselves, but when we are very busy, we ask others to do a part of work" (Hitachi).

"During many years, firms did not show their competencies to others. Why? Because they were easily imitable. (…) Here in Nagano, people were not very honest in business, so there were problems." (Nagano)

The number of clients of each network was evaluated thanks to the indications given by entrepreneurs. Ota-ku, Higashi Osaka and Nagano networks have more than 100 clients, namely for the production of metal pieces. In five other networks, like Hitachi-city (the town of Hitachi), Suwa (controlled by Seiko-Epson) or Musashi Murayama (on top of which is Nissan), the number of clients is weak (1-5). It is interesting to note that the number of clients is not directly proportional to the size of the network, but rather depends on the activities of the network. Subcontracting networks of "keiretsu" type have typically few clients, while networks that engage in other activities have more clients.

> "We work with all kinds of clients, from large firms to individuals. (…) They are probably several hundreds." (Ota-ku)
> "Our clients? Toyota, Matsushita, Seiko-Epson, Canon, Aiwa,… they are 150." (Nagano)
> "This is a company-town, the town of Hitachi, and everybody works for them" (Hitachi)

The intensity of ties between clients is grasped through the domains of activity of clients and information obtained from entrepreneurs and local officials. If clients belong to very different industries, the intensity of external ties is weak (like in a network selling traditional Japanese fabric used to make kimonos; and automobile parts). Conversely, if clients are partners, or competitors, or present in highly related industries, the intensity of their ties is strong (in the Nagano network, there are direct competitors such as Matsushita and Aiwa or Canon and Seiko-Epson).

The adaptation dynamics of different configurations will be analyzed through the NKCS model in the following section.

3. CO-EVOLUTIONARY DYNAMICS AND ADAPTATION OF NETWORKS

The classification of networks allows to distinguish four different configurations (Figure 1).

		External co-evolution	
		strong	***weak***
Internal co-evolution	***strong***	Higashi Osaka Shizuoka Ota-ku	Kiryu
	weak	Nagano	Musashi Murayama Suwa Hitachi Hamamatsu

Figure 1 – Observed network configurations

In these networks, industry relocation and technological changes push networks to adapt. Some networks develop in new markets, in Japan and abroad, others invest in research to become Original Equipment Manufacturers (OEM) and commercialize their own products. The invariants of each type of network, in terms of adaptation dynamics, will be presented in the following sections.

3.1. From internal co-evolution to exploitation: "pack" networks

The first type of network can be called the "pack" network. It is characterized by strong internal co-evolution (figure 1), which allows it to exploit its resources.

In the Kiryu network, the division of labor is enhanced: collectively, the network possesses all competencies that enable it to respond to an order in the field of textile. Among manufacturing firms, some are relatively large (between 20 and 30 employees), these are producers (makers), real coordinators, "pack chiefs", that work with specialized firms for particular tasks. Thus, the yarn is produced by the yarn firm, it is then sent by the maker to weaving, and the fabric is then sent to the maker who sends it to dyeing. This organization enables the network to respond rapidly to a client's demand. But the relative weakness of the number of clients, the wholesalers (tonya), restrains the change of these strongly linked firms. In Kiryu, wholesale firms are the main clients (or the only ones) of a network. The makers are not aware of the evolution of consumers' needs and of the distributors, they tend to respond day by day to the demand of the clients. Since firms are tied by strong ties, they are blocked in relatively stable structures, which prevent them from looking for new partnerships. The production of fabric in China has led to an important loss of work (some factories closed, and others produce less). Instead of changing the domain of their activity, makers have switched to more restrained markets, namely fashion, but have few ties with the market to be efficient in the long run.

> "China, Corea, Taiwan, production moves there more and more. It's because the workforce is not expensive. Here we do what they can not do there. (…) Things that we produce go to commercial firms like shosha or to wholesalers like tonya and they work with apparel makers. (…) we want to treat directly with apparel makers and have raw information, but it is difficule." (Kiryu)

The ambivalence of internal co-evolution is related to a trade-off between the rapidity of change and the long-term performance. In a network, strong ties accelerate adaptation but reduce long-term performance. In Kauffman's model, internal co-evolution, linked to the increase of N and K, has two effects. It first provokes an increase of the number of local optima (equilibrium configurations for which none of the members of a species can increase independently its performance). A limited number of movements on the fitness landscape is necessary to attain one of the local optima. According to Kauffman, “as K increases, the proportion of agents reaching Nash equilibria increases” (1993: 143). But, internal co-evolution leads also to a decrease of the average performance of local optima. Thus, the system progresses rapidly, but risks to get blocked in a configuration, which is far from the global optimum.

Thus, as Kauffman’s model emphasizes and as the cases of Japanese networks show, internal co-evolution of a network acts favorably on its dynamics and on its flexibility, in particular in short term. Strong ties between members enable a rapid response to an instantaneous demand of the environment, but cannot ensure permanence of the network in the long run. This finding is coherent with the results of Maillat (1996), who shows that local production systems that work on a limited territory, take advantage of knowledge that is historically built and embedded, and innovate incrementally.

The “pack networks” exploit the best their actual resources (as in wolves, where the group enables to attack larger animals and then distribute the pray). They are close to “convergent networks” in which “any actor can at any time mobilize all the network’s skills without having to get involved with costly adaptation” (Callon et al, 1992: 223). But strong internal co-evolution embeds it to a rigid production processes (wolves do not adapt their rapid chasing hunting technique to their prey), and reduces its capacity to adapt rapidly to a changing environment.

3.2. From external co-evolution to exploration: Migratory networks

The second type of network can be called “migratory network”. It is characterized by strong external co-evolution (figure 1), which allows it to explore new resources.

The Nagano network does not always manage to respond to its different clients in different industries efficiently, because the use of collective resources of the network is not optimal. Indeed, the members of the network, even though they are located in the same prefecture, are weakly tied. But the multiplication of clients and of links between different production systems that the network set up to respond to multiple orders, pushes it to reinvent itself permanently. Each change of orders of a client pushes the network members to adapt all of their resources. In the past, orders came regularly from large firms, but with industry relocation of watches and cameras, small firms were obliged to modify their fields of work and to look for new ones. After the production of watch parts, printer and cartridge parts, the reorientation towards nanotechnologies seemed rather obvious. Competencies in precision mechanics represent today a good base and some firms have already had some results and have started commercializing their own products. In the Nagano network, there are also firms that conduct research in other fields, like optical fibers and semi-conductors, or medical instruments. Some firms, like Hiraide Precision, have sent up partnerships with universities or research institutes, to guide the entire network towards new activities.

"They (Seiko) sold the Movement (brand) to Honk Kong and we started to supply the firm Hong Kong. The last orders from there came in 1991. But before that Seiko had started doing other things, like Epson printers. We tried to follow these developments. We started producing other metal parts, like for example these connectors (…) then they asked us t do new parts for mini printers, mini motors, floppy disks (…) in fact, clients asked us if we could do it, and we invested in R&D and we did it." (Nagano)

In the NKCS model, external co-evolution (C) slows down adaptation. In fact, each of the changes of a species S is affected by C neighboring species. The number of iterations needed to reach a local optimum is thus larger in average. Kauffman calls this oscillation around local optima the “coupled dancing” (1999: 243). Adaptive movements of each of the S species changes the performance of C neighboring species, provoking disequilibrium but also new possibilities for progress on the fitness landscape.

“Migratory networks” have the capacity to renew their resources in the long term. Like a flock of swallows that travel for more than 6000 miles due to seasonal change of alimentary resources, migratory networks have the capacity to define main orientations (for example through R&D operations) or to use guides (pilot firms) which direct efforts of network members.

3.3. From weak co-evolution to attrition: “herd networks”

The third type of network can be qualified as “herd network”. It is characterized by weak internal and external co-evolution (figure 1), which render the transformation difficult otherwise than by disappearance and replacement of its members.

Musashi Murayama, Suwa, Hitachi or Hamamatsu are examples of herd networks. These are typical subcontracting networks, where firms are related because they work for the same client and belong to the same keiretsu. These networks are efficient when the environment is stable. In fact, incremental adaptations are not possible because of the lack of internal ties, since the use of collective resources is insufficient. In case of major changes, when a client is lost, each firm undertakes individual activities to adapt, which leads to a chaotic situation and a progressive dissolution of a network. This phenomenon is partly due to the weak diversity of clients. Thus, for example, following the closure of the Nissan plant in Musashi Murayama, the network has progressively disappeared. The situation is similar in Hitachi network where numerous small firms disappear.

> "When Ghosn came he said that he wanted to dissolve the keiretsu. It is true that the process speeded up from that moment (…) Many firms closed." (Musashi Murayama)
>
> "From 1000 (firms) we came to 700 (…) Hitachi transferred the plant to South-East Asia, in Malaysia. (…) We went from "only Hitachi" to zero Hitachi. I could not think about the future. I did not know, I did not understand what they were thinking at Hitachi." (Hitachi)

In the NKCS model, the performance of local optima is greater for the moderated values of K and C than for the values 0. For Kauffman, "epistatic interactions appear to buckle up the landscape like heaving mountain ranges." (1993: 56).

In the "herd networks", the number of firms only enables to take advantage of various effects of agglomeration, such as the sharing of infrastructure (in zebras, the size of the herd does not enable them to find more grass or to adapt alimentation to long dry seasons that rarify resources, it only enables them to reduce the proportion of losses when a predator chases the herd).

3.4. Equilibrium between internal and external co-evolution: "colony network"

The fourth type of network is the "colony network". It is characterized by strong internal and external co-evolution (figure 1), which allows it to combine exploitation of existing resources and exploration of new ones.

Ota-ku, Higashi Osaka and Shizuoka are examples of “colony networks”. In the Ota-ku network, firms are specialized in one or a few tasks in the parts processing, in the fields of metal, mechanic and plastic. They combine competencies to respond to interdependent needs of their numerous clients. Firms are tied not only by business, but also by social ties. Due to the geographical proximity of firms and the density of their ties, they can rapidly organize production and respond to a particular order. They are also capable of engaging in exploration of new fields, alone or in partnership with research institutes. For example, the network has worked on the development of cables used in the rail traffic (in particular for the speed train, the shinkansen), on artificial hart or on parts for the nuclear industry. The Higashi Osaka network, rich in competencies and internal ties, has a multitude of clients that belong essentially to metal, mechanic and electronic industries. Parallely to the production of parts, the network has engaged in R&D. New fields are explored, like nano or biotechnologies. In the Shizuoka network, groups of entrepreneurs are formed and each member invests in common projects, to respond to Yamaha and numerous other clients. In some cases, one of entrepreneurs acts like coordinator. The firm that has the idea to develops a product or a production process in cooperation with a small number of specialized firms.

“There are things other than work that tie us. Ties between persons (…) For example, we get a call and within one or two hours we can get the material. And we can organize different tasks right away.” (Ota-ku)

“Our field of work is processing, that is, giving a wanted form to metal, cutting it in a certain way. (…) Some time ago, different projects started. We think about nano-business, environment and satellites. For example we use micro-organisms to decrease odors. We did that research in cooperation with other firms for different clients. (…) In five minutes on foot, I can reach the persons I need. (…) we can organize different tasks rapidly. (…) The speed here is really extraordinary.” (Higashi Osaka)

“I think that for us, the small firms, it is beneficial to belong to a network. Because we cannot do everything, we are small and then, there are also projects (…) there are quite a lot of movements in fact. At the moment we are working on several projects. For example, my firm is specialized in this, another one is in that, and we help each other. In the project that we are working on now, I am more or less the center of the group.” (Shizuoka)

In a network, the presence of simultaneously strong internal and external ties allows it to combine exploitation of existing resources and exploration of new possibilities, limiting “competency traps” (Levitt and March, 1998). These results can be formalized through Kauffman’s model. When NK is sensibly superior to CS, the system adapts rapidly and is stable afterwards. Conversely, when NK is significantly inferior to CS, the system changes rapidly in a chaotic manner. The optimal level of adaptability, combining exploitation of available resources and exploration of new ones is reached when NK is close to CS. For Kauffman, “internal epistatic coupling of each member of a species should be sufficiently important to counterbalance epistatic coupling between species” (1999: 280). In other words, networks have to adjust their internal complexity to the environment to which they are confronted. This finding ties up with the differentiation/integration dialectics of Lawrence and Lorsch (1967). To be adaptable, networks have to not only search for short-term efficiency (exploitation) but also constantly renew their bundles of competencies (exploration), by developing original responses to interconnected groups of clients.

“Colony networks” are thus capable of exploiting efficiently their environment (like ants that dig galleries or use twigs to build their nests) but also of responding to brutal variations (like termites that 500 millions of years ago had no predators managed to adapt to the arrival of ants, and then spiders or chimpanzees). Abecassis and Benghozi (1999) have shown this duality of adaptation in the fashion industry, in which firms alternate the mobilization of proximity networks and that of more distant ones, according to the advancement in the development process.

Conclusion

The study of networks from the point of view of the NKCS model has enabled to perceived advantages and drawbacks of internal and external co-evolution. Table 2 presents the typology of networks that emerges from the analysis.

		External co-evolution	
		Strong	**Weak**
Internal co-evolution	**Strong**	Colony networks	Pack networks
	Weak	Migratory networks	Herd networks

Table 2- Typology of networks based on the co-evolution of species

In this paper, we have shown that co-evolution plays a central role in the adaptability of a network. At the theoretical level, this work sheds light on the optimum level of co-evolution within a network, necessary for an efficient adaptation, combining exploitation and exploration. At the methodological level, it allows to envisage a rapprochement of qualitative and simulated data. Basing our study on the real cases, we have shown that the NKCS model represents a relevant tool for the understanding of adaptation processes in populations of firms. As Anderson (1999: 227) notes: “what is needed is an approach that melds empirical observation with the computer’s power to simulate the many possible paths through which complex networks of interacting agents can evolve.”

This research has two main limits. First, even though we study nine networks, only one "pack network" (Kiryu) and one "migratory network" were isolated. Literal replication of the results concerning their adaptation dynamics could not be accomplished. Internal validity of these results is therefore limited. Second, while the study of networks in Japan enables to isolate some elements of context, it also reduces external validity of our results. This research should thus be replicated to another geographical zone, namely to occidental networks.

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