Table of Contents

Go Back

Inter-organisational learning
Lotka-Volterra modelling of different types of relationships

Annick Castiaux
Business Administration Department, University of Namur
8 Rempart de la Vierge, B-5000 Namur, Belgium
Telephone: +32-81-724880 – Fax: +32-81-724840
E-mail: annick.castiaux@fundp.ac.be

Abstract

In this paper, we propose a simple model, based on Lotka-Volterra system, to simulate knowledge building in various configurations of inter-organisational partnerships. This model allows to differentiate the impacts of internal interactions and external collaborations on knowledge growth in an organisation. Following the type of partnership, i.e. competition, symbiosis or predation, we analyse the efficiency of inter-organisational knowledge building on a long-term perspective. The only relationship that demonstrates a long-term interest in the building of strictly new knowledge is predation. This kind of relationship allows large and lean organisations to complete their exploitative capabilities with explorative skills coming from small and agile organisations. Through such a relationship, a balance between exploration and exploitation can be found. This approach is a first step in a research dedicated to the study of complex adaptive systems, a well-suited framework to analyse management phenomena occurring at the edge of chaos, between stability and instability.

1 Introduction

More and more, accelerated environmental changes push organisations to evolve, adapt themselves, innovate, be flexible, etc. Managers are faced with the emergency to create newness more rapidly and efficiently than competitors. This race to innovation can only be won through an efficient knowledge management that includes two main issues: the exploration of new knowledge, in order to create variety and open the frontiers of the organisation, the exploitation of newly acquired knowledge, in order to propose new products to the market and to introduce new processes in the company (March 1991; Levinthal and March 1993). The simultaneous management of both – exploration and exploitation – is a strong paradox. Such a paradox has been called by other authors the "productivity dilemma" (Benner and Tushman 2003). While exploitation requires management skills focused on control (minimising complexity and uncertainty), standardisation, repetition and incremental innovation, exploration calls upon opposed capabilities as flexibility (with high complexity and uncertainty), creativity, variety and radical innovation. In this perspective, the efficient management of knowledge associated with innovation is a key issue (Hall and Andriani 2003; Patrucco 2002).

In this paper we use a theoretical framework borrowed from biology to study the influence of this paradox on knowledge creation, in the particular configuration of two interacting organisations. We focus our attention on the effect of this interaction following the forms that it can take: competition, predation or symbiosis. We try to understand which mechanisms could be more relevant following the organisations respective management styles, exploration or exploitation oriented. We briefly introduce complex adaptive systems as an interesting framework to understand such management paradoxes and we show that our models are a first approach of this formalism, based on the unstable equilibrium between a negative and a positive feedback, leading to behaviours at the edge of chaos. Finally, we propose some potential improvements of the models and research perspectives in this domain.

2 Context of the modelling

In this section, we explain the context of our modelling. First, we consider the recent evolution of inter-organisational relationships. From lean supply chains to agile networks of competencies, relationships are more and more flexible but also more and more complex to manage. We briefly look at the place of knowledge building in this inter-organisational context. Second, we try to understand the exploitation-exploration paradox of knowledge building through the well-known similar paradox of organisational learning. We use feedback loops representations to enlighten our discourse and anchor our reasoning in system science (Forrester 1961). This leads us to introduce briefly complex adaptive systems. We finally propose the theoretical background of our modelling, a first approach of knowledge building as a management phenomenon at the edge of chaos (Senge 1990).

2.1 Inter-organisational relationships and knowledge building

In this section, we analyse the recent evolution of inter-organisational relationships, as it has been described by several authors (Choi, Dooley and Rungtusanatham 2001; Huemer 2004; Tidd, Bessant and Pavitt 2001). We consider supply relationships that could apply to our study if we consider that some organisations are knowledge suppliers, while others are knowledge buyers.

As shown in Figure 1 (adapted from (Tidd, Bessant and Pavitt 2001, 204)), recent decennials have seen a real transformation of the supply market. Until recently, buyers were faced with a homogeneous supply market where they simply made a choice based on market considerations. The choice of the supplier was formalised with a contractual relationship in which both organisations (supplier and buyer) were uncoupled. In the eighties, more and more companies realised that a strong coupling with their suppliers could help them to reduce time-to-market and transactional costs and to enhance quality. Suppliers favouring this coupling by providing the best interoperability (thanks to information systems, standard products and processes) were thus preferred to others. The supply market became differentiated, the organisations making strong partnerships with their favourite suppliers in order to reach lean supply. For some years, this tight coupling raises some issues: a *flexibility issue*, since strong partnerships have created dynamic inefficiencies, an *equity issue*, since some buyers have abused from their powerful position to completely control their suppliers, and an *innovation issue*, since those partnerships are working as autarchic entities, on the basis of repetitive and controlled processes, excluding the emergence of radical newness. Some organisations have thus evolved to a lighter coupling, based on supply alliances where each partner benefits from the others' skills and knowledge to innovate. New inter-organisational types appear as networks of co-innovation, where each organisation focuses its efforts on its core business, finding well-suited partners to complement those assets (Prahalad and Hamel 1990; Quélin 2000). This is particularly true when innovation is at stake and new knowledge must be found and developed, since no organisation can develop knowledge and competencies outside its core business without adequate partners.

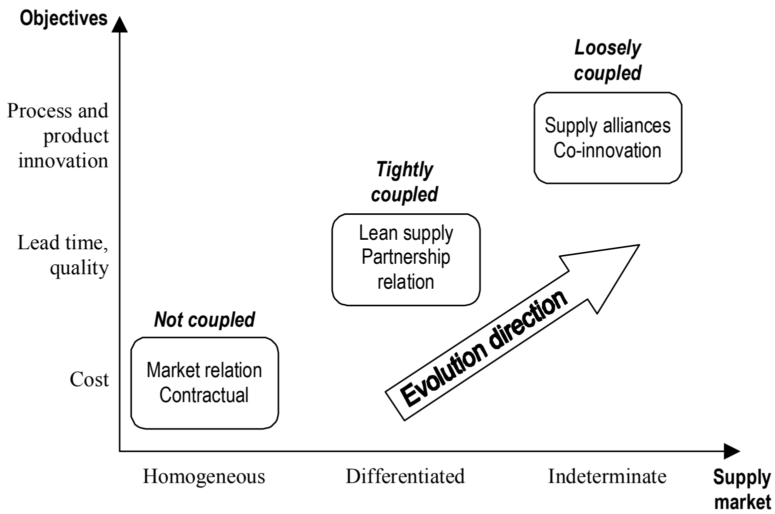

Figure 1 - Evolution of inter-organisational relationships with the changes in the supply market (adapted from (Tidd, Bessant and Pavitt 2001, 204))

Considering that the supply object is knowledge, these three supply forms also exist:

- *Contractual market relation*: The buyer wants to obtain a given and well-defined knowledge, available from various sources with an equivalent quality. The supply market is homogeneous and the choice criterion is the price proposed by the various possible suppliers. This kind of contractual relationship does not couple parts together. There is no interest to model it with Lotka-Volterra system.
- *Lean supply through strong coupling*: A supplier clearly differentiates itself with a knowledge that is particularly well-suited for the buyer in a short-term perspective. This knowledge will spare the buyer long and costly knowledge developments that are of prime importance for his business quality. A tight coupling between the supplier and the buyer takes place. We can distinguish between a tight symbiotic behaviour, where partners are mutually very dependent to create their own new knowledge, and a predation behaviour, where the buyer or the supplier benefits from the relationship while the other partner looses part of its knowledge in the operation. If the buyer is the predator, this behaviour can end in the integration of the supplier inside the buyer organisation (for instance through a buyback). If the supplier is the predator, this behaviour means that the buyer is captive of the supplier because of its high dependence on the supplier's knowledge.
- *Co-innovation through loose coupling*: Suppliers have all their particular skills and knowledge, complementary to the ones of the buyer. Each protagonist finds benefit in the relationship without being prisoner of it. We find here a light symbiotic relationship, generally concretised in a partnership network that evolves following environmental changes. This kind of relationship can also be seen as a light

predation relationship if one of the organisations clearly exploits the knowledge the other explores, each organisation evolving through this schema in its more adapted mode. Examples of this are co-innovation alliances between big firms and small start-ups (Gans and Stern 2003).

We must add a fourth relationship pattern, which is not related to supplier-buyer relationship: the *competition relationship*, where every protagonist tries to develop new knowledge more rapidly than the other.

2.2 Positive and negative feedbacks in organisational learning

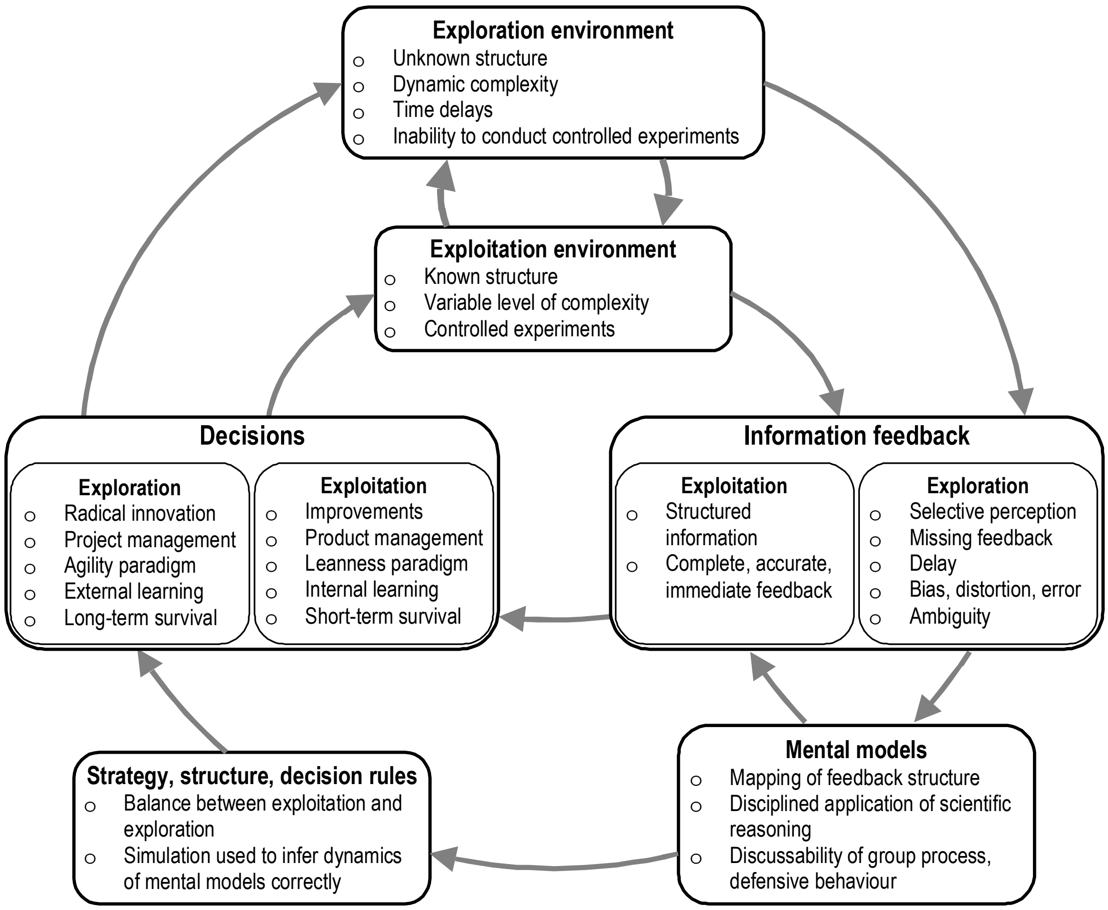

Figure 2 - Double learning loop including both exploitation and exploration processes (adapted from (Sterman 2000, 34))

In the introduction, we have underlined the influence of exploitation-exploration balance on both the intra-organisational and inter-organisational rates of knowledge growth or decline. The feedback structure proposed at Figure 2 helps to understand this influence. This feedback structure is based on the famous double loop learning model developed by Argyris (Argyris 1977). This framework has demonstrated its interest to understand the factors influencing systematic organisational learning. Recently, Sterman (Sterman 2000) proposed an interesting adaptation of this double loop learning, differentiating the feedback influence of

- the virtual world to which the organisation can easily refer as "formal models, simulations, or 'microworlds', in which decision makers can refresh decision-making skills, conduct experiments and play" (Sterman 2000, 34);
- the real world, uncertain, dynamically complex, beyond control.

We have adapted this feedback structure to discriminate between the feedback due to an exploitation environment (that can be assimilated to Sterman's virtual world) and an exploration environment (similar to Sterman's real world). Considering that the result of a learning loop is the acquisition of knowledge, the exploration environment would provide new knowledge, through mainly external relationships, while the exploitation environment would give the necessary feedback to select, control and exploit newly acquired knowledge, through efficient internal and external interactions with known and assessed partners. On one hand, the exploration environment opens the knowledge perspectives of the organisation, bringing newness and variety. On the other hand, the exploitation environment limits knowledge expansion, eliminating useless or obsolete knowledge and codifying useful knowledge to allow its transfer to operational personnel and its transformation in definite processes and/or products.

Using an analogy from physics, we can say that the exploration of new knowledge increases the entropy of the organisation (i.e. its uncertainty and its complexity) to maintain it alive and make it evolve, while the aim of exploitation is to keep the organisation entropy at a sufficiently low level to diminish the management risks associated with uncertainty and complexity.

One should underline here, as it is indicated by the arrows between exploitation and exploration environments in Figure 2, that both environments are not independent. Exploration environment will invade exploitation environment, changing the perspectives for usual and controlled business, while exploitation environment will condition and bias exploration environment, in order to diminish uncertainties and threats. We are in a dynamic context, where definite borders can difficulty be designed.

2.3 Between stability and instability: complex adaptive systems

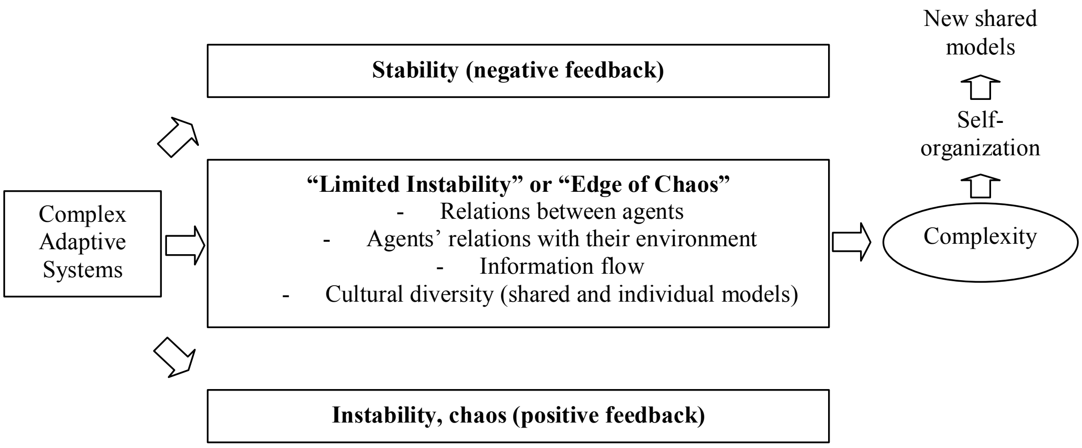

Figure 3 - The organisation as a complex adaptive system (adapted from (Chiva-Gomez 2003))

Complex adaptive system theory finds its roots in evolutionary biology, non-linear dynamical systems and artificial intelligence. Such systems adapt themselves spontaneously to the changing environment and influence this environment, with the objective to co-evolve as harmoniously as possible. A CAS is characterised by a series of dynamic capabilities that can be sorted under three foci (Choi, Dooley and Rungtusanatham 2001): its internal mechanisms, its environment and the co-evolution between the system and its environment.

As explained in Figure 3, a complex adaptive system can evolve to stability if negative feedback prevents the emergence of newness and variety. This stability often means the death of the system. It can also evolve to instability or chaos if positive feedback prevents a minimal control of variety growth. This instability also means the death of the system or, at least, the impossibility to manage it. Finally, a CAS can evolve to a balanced state between stability and instability, at the edge of chaos. In this state, it presents complex dynamic capabilities that allow it to self-organise in order to co-evolve with its environment in a flexible way.

If we consider the double side of knowledge building that we have developed through the double loop learning model in the previous section, it is obvious that CAS formalism is well-suited to study knowledge creation in organisations. As described in Figure 4, new knowledge creation is regulated by a negative feedback loop, due to the necessary control on knowledge growth to make its exploitation possible, as well as a positive feedback loop, due to exploration of new knowledge. This leads the organisation in a state between stability and instability. Following the strategic orientation of the organisation – more oriented towards exploitation or exploration – negative or positive feedback can be dominant. Respectively, the organisation will ten evolve more or less rapidly to a stable or unstable state. From a knowledge building viewpoint, stability means that the organisation subsists on the basis of its existing knowledge and competencies and does not seek new knowledge, while instability means that the organisation cumulates more and more new knowledge that it cannot manage anymore.

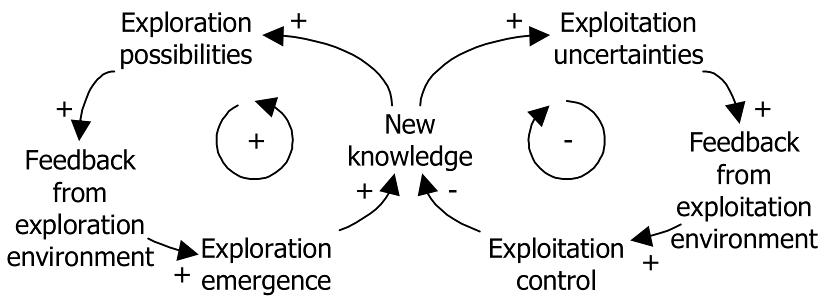

Figure 4 - Positive and negative feedbacks in new knowledge creation

The formalism of complex adaptive systems is considered in recent literature as a powerful tool to understand complex behaviours in highly uncertain management problems as product development (Chiva-Gomez 2003), organisational networks (Choi, Dooley and Rungtusanatham 2001) or ecological economics (Ramos-Martin 2003). In the next section, we present Lotka-Volterra system as a first approach of this formalism and explain the pertinence of this approach to analyse knowledge building in the context of two interacting organisations.

2.4 A first approach through Lotka-Volterra system

2.4.1 Generalised Lotka-Volterra system

In the twenties, the American Lotka (1925) and the Italian Volterra (1926) proposed a model to describe the evolution of two populations interacting in such a way that one of them – the predator population – feeds itself from the other – the prey population. If we name P_x, the predator population and P_y, the prey population, the equations governing their co-evolution are Lotka-Volterra well-known system:

$$\begin{cases} \dfrac{dP_x}{dt} = P_x\left(a_x + c_{xy}P_y\right) \\ \dfrac{dP_y}{dt} = P_y\left(a_y + c_{yx}P_x\right) \end{cases} \qquad \text{(Eq. 1)}$$

where the a_i coefficient gives the endogenous growth rate of population P_i, negative for the predator population and positive for the prey population, whereas the c_{ij} coefficient represents the growth effect of population P_j on population P_i, positive for the predator population and negative for the prey population.

To take into account intra-population interactions that can have a positive impact on growth (mutual assistance of the population members) or a negative impact on growth (internal competition due, for instance, to the lack of space or scarcity of resources), these equations can be generalised to the following system:

$$\begin{cases} \dfrac{dP_x}{dt} = P_x\left(a_x + b_xP_x + c_{xy}P_y\right) \\ \dfrac{dP_y}{dt} = P_y\left(a_y + b_yP_y + c_{yx}P_x\right) \end{cases} \qquad \text{(Eq. 2)}$$

where the b_i coefficient gives the growth effect of internal interactions in population P_i, positive in case of mutual assistance, negative in case of competition. In this last case, the most realistic, if K_i is the maximal capacity of population P_i, b_i equals a_i / K_i. This maximal population level is due to the finiteness of material resources available for each species (space, food).

Finally, if we consider N interacting populations, we obtain a system of N coupled differential equations that can be written as:

$$\frac{dP_i}{dt} = P_i\left(a_i + \sum_{i=1}^{N} c_{ij}P_j\right), \forall i = 1, N \qquad \text{(Eq. 3)}$$

where $c_{ii} = b_i$.

These equations have recovered interest in the recent management literature since they constitute a simple model helping to understand phenomena as technology substitution (Morris and Pratt 2003; Pistorius and Utterback 1997), organisational change (Modis 1997) or organisational learning (Zangwill and Kantor 2000).

2.4.2 Lotka-Volterra system and inter-organisational knowledge building

Our aim is to understand mechanisms governing new knowledge creation when organisations are interacting. Considering Lotka-Volterra system given at (Eq. 2), this means that the population levels P_x and P_y represent knowledge levels respectively in organisation x and in organisation y. In this respect, the meaning of coefficients and the factors influencing their value are different of those that could be used when the interest variable is a physical population level. Let's see how we can interpret endogenous growth rate a_i, intra-population (internal) interaction rate b_i, and inter-population (external) interaction rate c_{ij}.

- *Endogenous growth rate*: This is the intrinsic rate of knowledge building (or knowledge destruction) inside the organisation. It corresponds to the rate of knowledge creation (or destruction) that would exist if the organisation had no contact with the other organisation under study and if the groups and individuals composing the organisation were not interacting. Factors influencing positively the value of the endogenous growth rate are, for instance, creative orientation of the individuals, hiring of new persons, collaborative contacts with other creative organisations as universities, microscopic interactions of individuals inside a given team or group, existence of an R&D department, continuous training of individuals, etc. Factors influencing negatively the value of the endogenous growth are, for instance, personnel departures due to retirements or job changes, short-time view and lean strategy. As it has been demonstrated in the empirical literature (Kazanjian 2000; Leenders, van Engelen and Kratzer 2003; McAdam and McClelland 2002), organisational practices concerning individual motivation, creativity, training and collaboration management will strongly influence these factors.
- *Internal interaction rate*: This is the rate at which knowledge is created or destroyed in the organisation through interactions between the groups and persons composing the organisation. In inter-species interaction, this coefficient is generally negative since it reflects the existence of a maximal level for population density due to material resource constraints (space, food). When knowledge is considered, conservation properties that govern physical variables do not hold any more. The theoretical maximal limit to knowledge creation can hardly be defined. A positive value of the internal interaction coefficient allows to take into account the non-conservative property of knowledge. However, the archiving, maintenance and exploitation of knowledge will introduce limits to its growth. If it is negative, this internal interaction rate reflects the necessity for the organisation to use internal interactions to control, sort and limit knowledge in order to be able to exploit it. The more the organisation has developed a control culture, focusing the majority of its efforts on exploitation, the more this factor will be negative. If it is positive, this internal interaction rate reflects the important place of emergent matters in the organisation. The more the organisation gives place to exploration and flexibility, the more this factor will be positive. It should be mentioned here that both extreme situations (exclusive exploitation or exclusive exploration) are damageable for the organisation: focusing only on exploitation, the organisation will miss opportunities brought by emergent knowledge, while focusing on exploration, it will not benefit from learning to enhance the profit of exploitation. The internal interaction rate can be considered as a measure of the balance between exploitation and exploration

inside the organisation. This concept has been illustrated in previous sections. Factors influencing the value of this coefficient are, for instance, the management style of the organisation (exploitation, exploration), the openness of individuals to newness, cross-functional communication, strategic importance of R&D, etc.

- *External interaction rate*: This is the rate at which knowledge is created or destroyed in the organisation through interactions with the other organisation. This rate can be positive if the interaction brings new knowledge to the organisation or negative if the organisation looses knowledge during the interaction with the other organisation. Factors influencing positively the value of this coefficient are, for instance, trust between the organisations, interactions between their research departments, common objectives or interests, cultural proximity… Factors influencing negatively the value of this coefficient are, for instance, competition between the organisations, size and/or stability differences between the organisations, information retention, loss of intellectual property, personnel moves from one organisation to the other…

To summarise, mechanisms that bring new knowledge in the organisation are:

- Endogenous growth (positive part of rate a_i), due to creativity of individuals or teams, knowledge transfer from the environment (excluding the other organisation);
- Constructive internal interactions (positive part of rate b_i), allowing to build architectural knowledge when individuals from different groups collaborate and build new knowledge on the basis of their particular knowledge;
- Constructive interactions with the other organisation (positive part of rate c_{ij}), favouring knowledge transfers from an organisation to the other.

Mechanisms that remove new knowledge from the organisation are:

- Endogenous decline (negative part of rate a_i), due to standardisation of individuals, absence of knowledge transfer from the environment, departures of key persons;
- Destructive internal interactions (negative part of rate b_i), often necessary to be able to exploit new knowledge efficiently with limited resources;
- Destructive interactions with the other organisation (negative part of rate c_{ij}), where knowledge is stolen or transferred with negative consequences on one of the organisations, for instance with key personnel transfers.

3 Modelling patterns of relationships

3.1.1 Competition

Very often, competition situations lead to complete annihilation of both competitors or to instability. Here we have analysed situations where equilibrium can be reached. We consider that both organisation have some creativity (positive a_i) and must control their knowledge to exploit it (negative b_i). Organisation x is more creative and less exploitation oriented than organisation y.

Low competition

Values of interaction coefficients are set to relatively weak values, with a necessarily lower value for organisation *y* if we want to give it a chance to build knowledge. Competition is low. However organisation *y* is better than organisation *x* at this competition game. As shown in Figure 5, such systems are very sensitive to the initial conditions since a very small variation of those leads to opposite final states. Initially both knowledge levels tend to the equilibrium point and almost reach it, then they diverge from it to reach one of the extinction points (extinction of P_x or extinction of P_y). During a long time period, the system seems stable. However, at t ≅ 90, divergence from the equilibrium occurs. Since the system fakes equilibrium during a rather long time, organisations are not rapidly aware of the threat from their competitors. Concerning knowledge evolution, this situation is not profitable for any of the organisations, excepting once the equilibrium is abandoned. There, one of the organisations takes advantage from the other until this one does not possess any more interesting knowledge. The relationship is then of no interest.

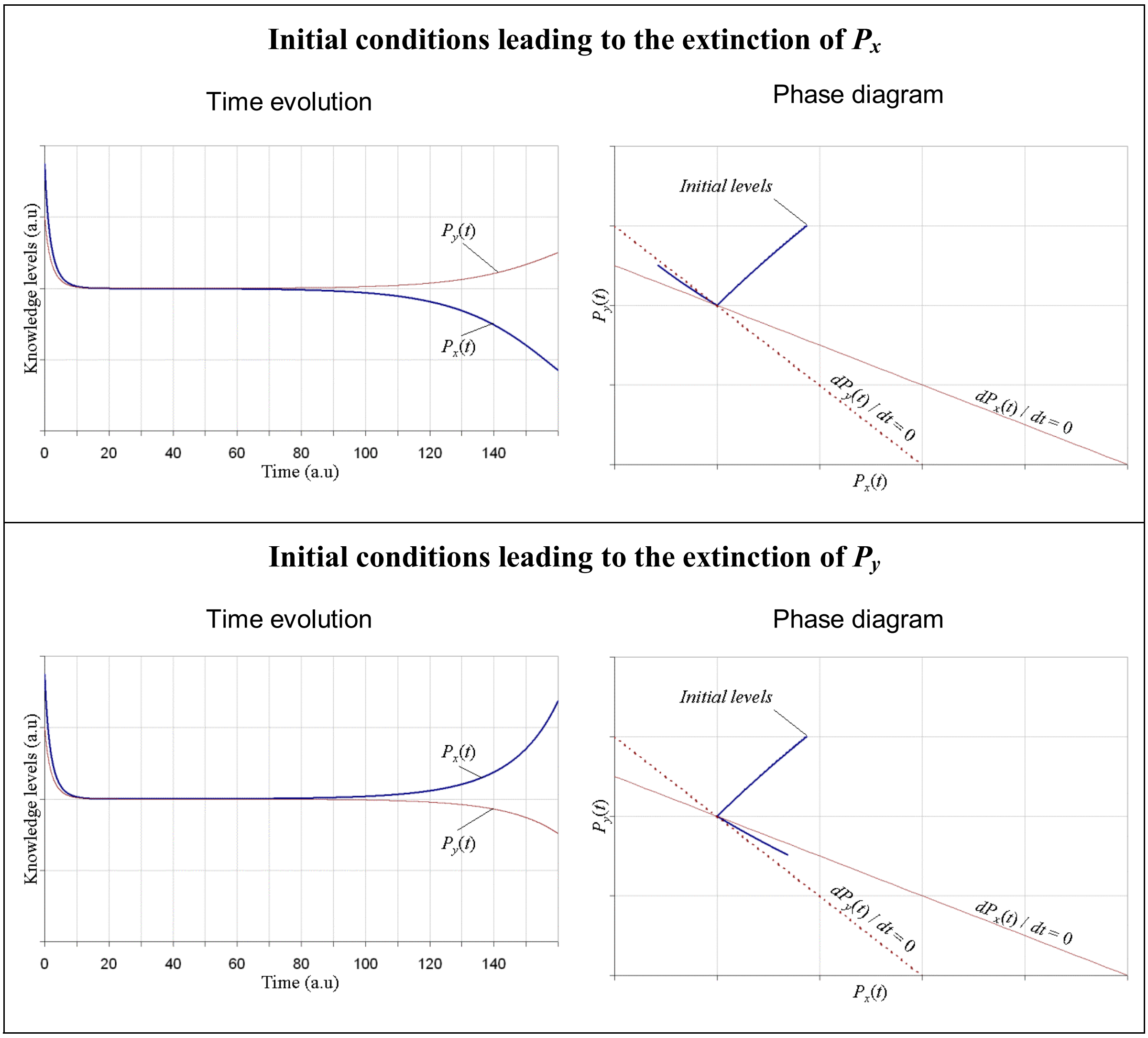

Figure 5 – Effect of low competition on knowledge creation and transfer
(a_x=0.5, b_x=-0.01, c_{xy}=-0.04, a_y=0.3, b_y=-0.02 , c_{yx}=-0.01)

<u>Strong competition</u>

This time we choose higher values for the interaction coefficients, in order to simulate a strong competition. Organisation y, less creative and more exploitative, is more aggressive to obtain new knowledge from organisation x. The same kind of behaviours can be met as for low competition. As can be seen in Figure 6, the difference lies in the acceleration of the process, due to higher competition. If a stagnation period appears, it is shorter that for low competition. Rapidly, one of the competitors has the advantage and the other sees all his knowledge disappear to the benefit of the first. Here also, when stability is reached, the relationship between both organisations has no interest any more.

The sensitivity to initial conditions is even higher than in low competition. Very similar initial conditions lead to the extinction of P_x or P_y.

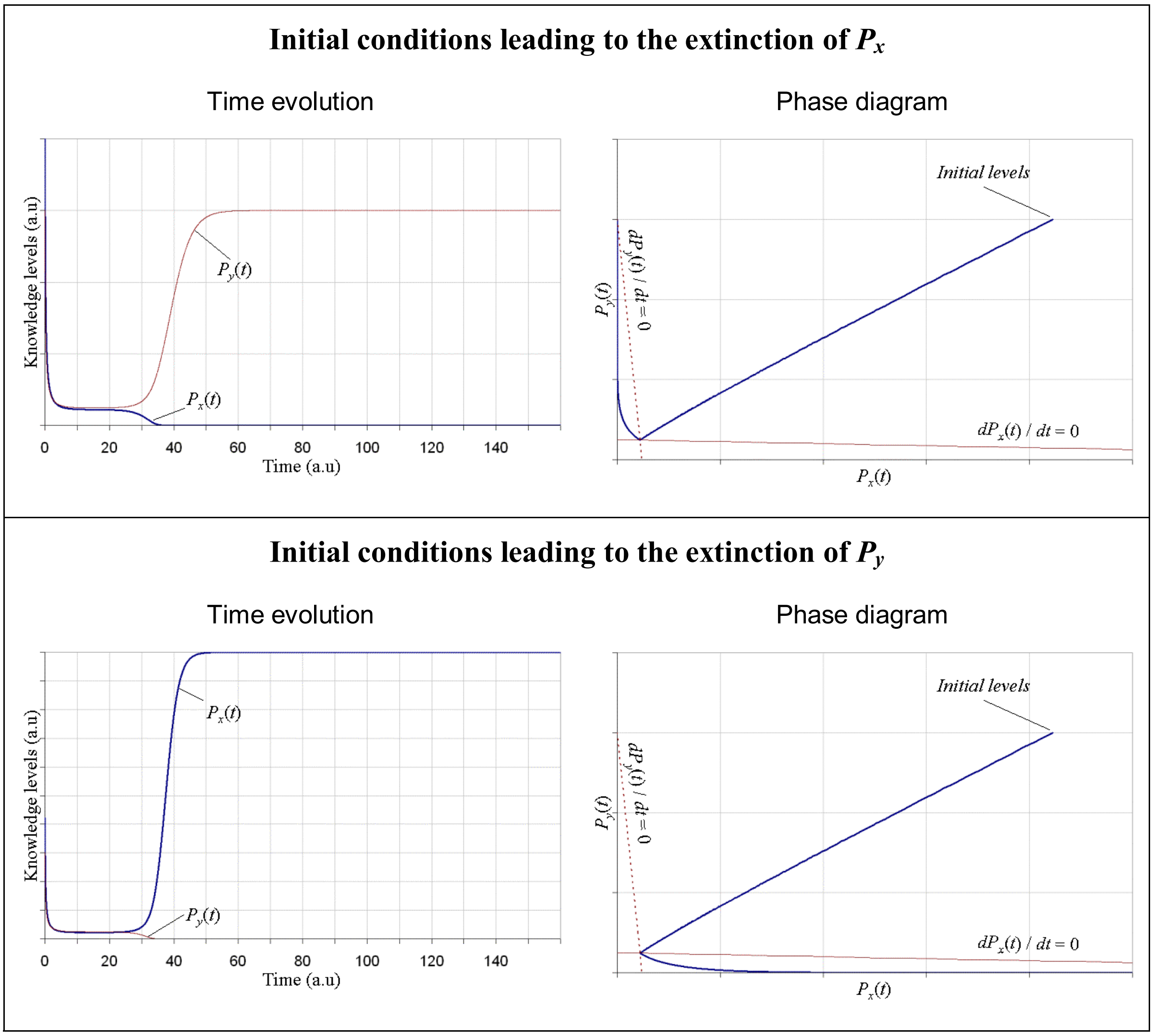

Figure 6 - Effect of strong competition on knowledge creation and transfer
(a_x=0.5, b_x=-0.01, c_{xy}=-0.4, a_y=0.3, b_y=-0.02 , c_{yx}=-0.25)

3.1.2 Symbiosis

A lot of symbiotic patterns are completely divergent or lead to annihilation of both knowledge levels. Some patterns also lead to chaotic behaviours (Pistorius 1995). We present here two cases that converge. It must be noted that both cases are weak symbiotic relationships.

Similar partners

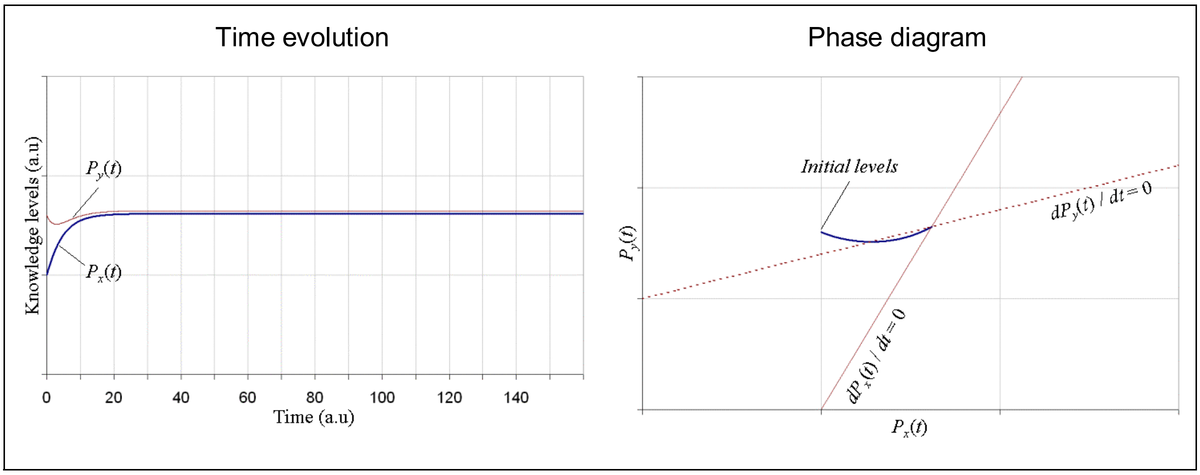

Figure 7 - Symbiotic pattern of knowledge creation and transfer between equilibrated partners (a_x=0.2, b_x=-0.04, c_{xy}=0.015, a_y=0.25, b_y=-0.05 , c_{yx}=0.02)

We first assume that both organisations have the same characteristics: similar levels of creativity and exploitation orientation. Their collaboration will thus be based on a rather equilibrated exchange of knowledge.

We see on the graphs of Figure 7 that both knowledge levels converge rapidly to an equilibrium state from which they do not evolve any more. At this point, the collaboration does not bring any new knowledge to any of our interacting organisations. It is thus without interest in the context of a knowledge building partnership.

Very different partners

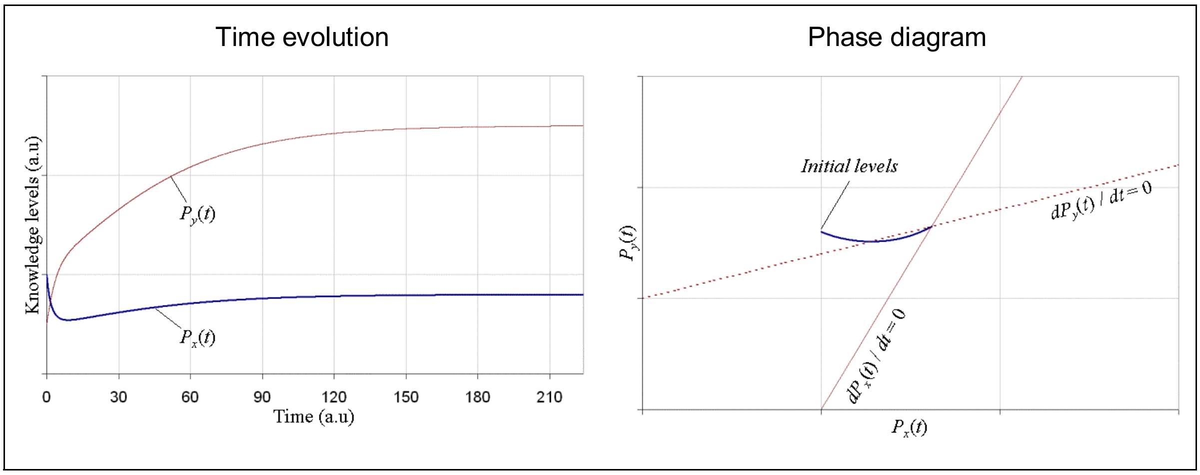

Figure 8 - Symbiotic pattern of knowledge creation and transfer between very different partners (a_x=0.15, b_x=-0.05, c_{xy}=0.01, a_y=-0.1, b_y=-0.012 , c_{yx}=0.05)

Now, we assume that one of the organisations looses knowledge, while the other is creative. The organisation that is not creative will use the partnership to gain knowledge, while the gain of the creative organisation is supposed to be lower.

We see in Figure 8 that, as in the previous example, both knowledge levels converge to the equilibrium point. The rate of progression to the equilibrium is however well slower that in Figure 7. If the equilibrium point is higher than the initial levels, both organisations learn from each other all along the time interval. Once this equilibrium is reached, the relationship does not bring any new knowledge to the partners.

3.1.3 Predation

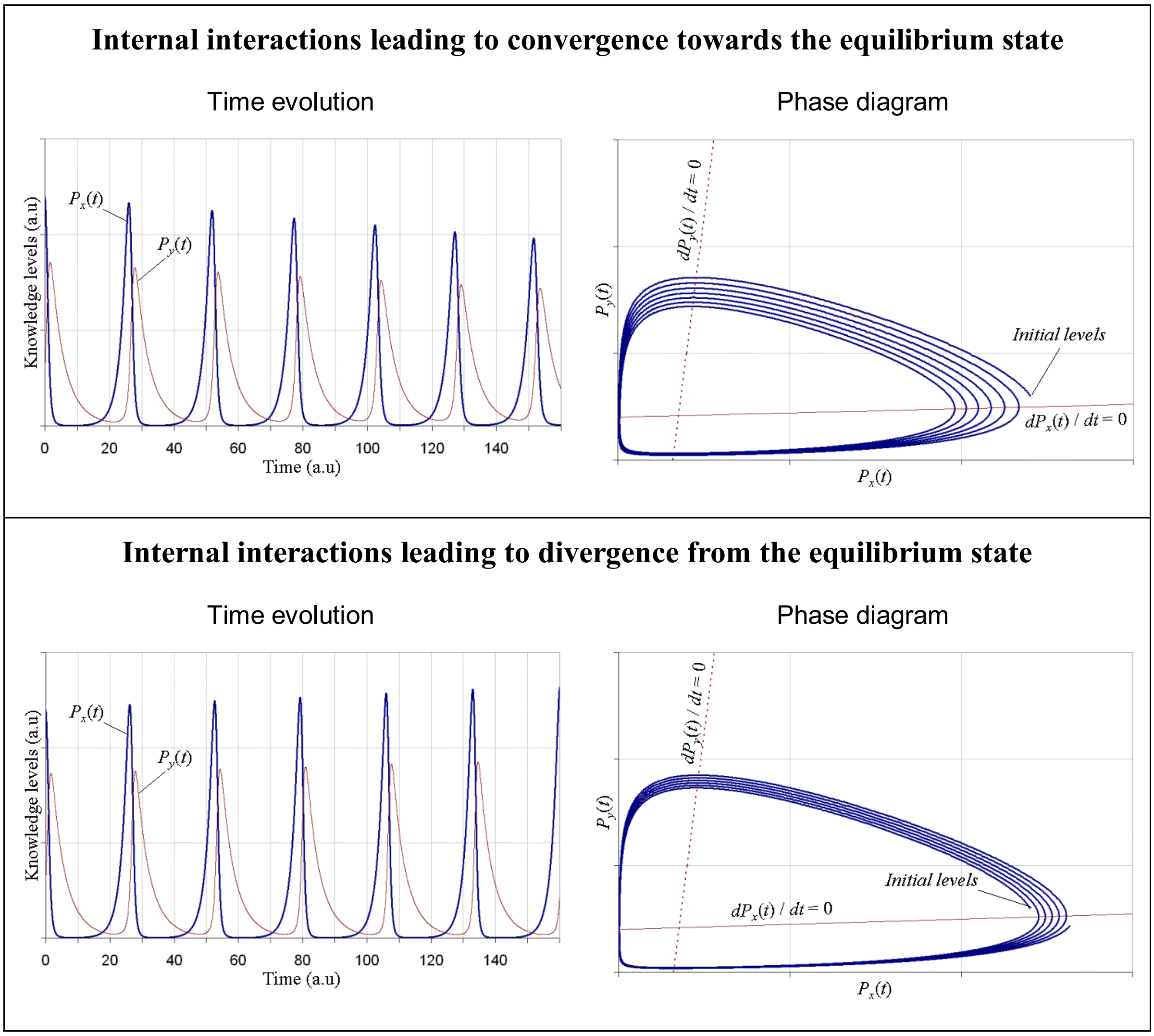

Figure 9 - Prey-predation pattern of knowledge creation and transfer
(a_x=0.5, b_x=0.01 (upper case) or b_x=0.012 (lower case), c_{xy}=-0.25, a_y=-0.2, b_y=-0.01 , c_{yx}=0.125)

We consider that organisation x is creative and has an exploration orientation (both a_x and b_x positive), while organisation y looses knowledge and has an exploitative culture (both a_y and b_y positive). So the predator is organisation y, which needs the knowledge of organisation x to evolve and survive. We consider here that the predation is light in order to allow a co-evolution of both organisations' knowledge. This means that organisation *y* just takes a part of organisation *x* knowledge in order to evolve slowly, in compliance with its exploitation orientation.

This leads to the traditional prey-predator curves, as presented in Figure 9, where we see regular peaks of knowledge created by organisation *x*, than transferred to organisation *y* for exploitation. This seems an interesting pattern for both organisations: we can see organisation *x* is a "knowledge lab", acquiring radically new knowledge thanks to its contacts and creativity, while organisation *y* is the "knowledge plant", with sufficient resources to exploit part of this new knowledge that it consider as strategically important. In the upper case of Figure 9, as it is shown in the phase diagram, both knowledge levels are circularly converging towards their equilibrium point, at the intersection between the equilibrium lines of both knowledge levels (dP_x/dt=0 and dP_y/dt=0). This convergence to a stable state is due to the negative sign of b_y, generating a negative feedback (stabilisation). However, this convergence is slow and the relationship can be interesting during a rather long period. It can even be balanced by a higher value of b_y (i.e. a more explorative organisation), as proposed in the lower case of Figure 9, where the spiral pattern of the phase diagram is divergent from the equilibrium point, evolving slowly towards an instable state.

This spiral pattern can be linked to Nonaka's knowledge spiral (Nonaka 1994) where four mechanisms of knowledge conversion between tacit and explicit modes lead to a cyclic creation of knowledge in the organisation. Tacit mode corresponds to a more explorative state while explicit mode leads to the exploitation of knowledge into products and processes. This predation relationship between an exploitative and established organisation and a flexible and creative organisation gives us an inter-organisational knowledge spiral.

4 Conclusions and perspectives

We have proposed Lotka-Volterra set of equations as a possible model to study business systems including a management paradox. In particular, we have modelled the effect of different inter-organisational relationships on new knowledge creation in the organisations. Our two-dimensional models have shown that symmetry between both organisations (as it is the case for competition or symbiotic patterns) is not favourable to new knowledge creation, since it leads to stability through negative feedback or to instability through excessive positive feedback. On the other hand, asymmetric patterns as prey-predator relationships appear as being more interesting for new knowledge creation. An adequate balance between negative feedback – essentially brought by the predator – and positive feedback – essentially due to the prey – leads to repeated creation of new knowledge by the prey, followed by the transfer of part of this new knowledge to the predator. We can see this pattern as the focusing of each partner on its management style and core competencies, complementary to the one of the other partner: the predator entity, on its exploitation capabilities, and the prey entity, on its exploration skills. Understanding the importance of complementarities in knowledge building, some organisations have implemented new management methods to favour radical innovation while still managing their existing competitive advantages. A successful case in the Japanese telecommunication industry is based on the creation of a dedicated and independent creative department and its collaboration with the traditional organisation (Kodama 2003). Such a collaboration is precisely the "predation" strategy that we have recommended in this paper.

Our models are a basic approach of the complex adaptive system paradigm. We see a lot of perspectives in such research. First, our models should be complemented with additional feedback structures in order to take into account the "adaptive" quality of organisations. As a matter of fact, if an organisation realises that its level of creativity is falling, it will react with several possible mechanisms as becoming more flexible, encouraging creativity, favouring informal communications, etc. This could be added in the models. A next step would also be to consider more than two interacting organisations and progressively model a network behaviour as it is more and more observed. Progressively, we want to understand complex adaptive systems, model them and use these models to have a better insight in management issues at the edge of chaos.

References

Argyris, Chris, 1977. Double Loop Learning in Organizations. *Harvard Business Review* 55: 115-125.

Benner, Mary J. and Michael L. Tushman, 2003. Exploitation, exploration and process management: The productivity dilemma revisited. *Academy of Management Review* 28: 238-256.

Chiva-Gomez, R., 2003. Repercussions of complex adaptive systems on product design management. *Technovation* in press.

Choi, Thomas Y., K.J. Dooley, and M. Rungtusanatham, 2001. Supply networks and complex adaptive systems: control versus emergence. *Journal of Operations Management* 19: 351-366.

Forrester, Jay W. 1987. *Industrial dynamics*. Boston: Walthan.

Gans, Joshua S. and Scott Stern, 2003. The product market and the market for "ideas": commercialisation strategies for technology entrepreneurs. *Research Policy* 32: 333-350.

Hall, Richard and Pierpaolo Andriani, 2003. Managing knowledge associated with innovation. *Journal of Business Research* 56: 145-152.

Huemer, Lars, 2004. Balancing between stability and variety: Identity and trust trade-offs in networks. *Industrial Marketing Management* 33: 251-259.

Kazanjian, Robert K., Robert Drazin, and Mary Ann Glynn, 2000. Creativity and technological learning: the roles of organization architecture and crisis in large-scale projects. *Journal of Engineering and Technology Management* 17: 273-298.

Kodama, Mitsuru, 2003. Transforming an old-economy company into a new economy - the case study of a mobile multimedia business in Japan. *Technovation* 23: 239-250.

Leenders, Roger Th.A.J., Jo M.L. van Engelen, and Jan Kratzer, 2003. Virtuality, communication, and new product team creativity: a social network perspective. *Journal of Engineering and Technology Management* 20: 69-92.

Levinthal, Daniel A. and James G. March, 1993. The Myopia of Learning. *Strategic Management Journal* 14: 95-112.

Lotka Alfred J. 1925. *Elements of physical biology*. Baltimore: Williams and Wilkins.

March, James G.,1991. Exploration and Exploitation in Organization Learning. *Organization Science* 2: 71-87.

McAdam, Rodney and John McClelland, 2002. Sources of new product ideas and creativity practices in the UK textile industry. *Technovation* 22: 113-121.

Modis, Theodore, 1997. Genetic Re-Engineering of Corporations. *Technological Forecasting and Social Change* 56: 107-118.

Morris, Steven A. and David Pratt, 2003. Analysis of the Lotka-Volterra competition equations as a technological substitution model. *Technological Forecasting and Social Change* 70: 103-133.

Nonaka, Ikujiro, 1994. A dynamic theory of organizational knowledge creation. *Organization Science* 5: 14-37.

Patrucco, Pier Paolo, 2002. Review article: social and contractual interactions in the production of technological knowledge. *Information Economics and Policy* 14: 405-416.

Pistorius, Carl W.I. and James M. Utterback, 1995. The Death Knells of Mature Technologies. *Technological Forecasting and Social Change* 50: 215-233.

Pistorius, Carl W.I. and James M. Utterback, 1997. Multi-mode interaction among technologies. *Research Policy* 26 : 67-84.

Prahalad, C.K. and G. Hamel, 1990. The core competencies of the corporation. *Harvard Business Review* 68: 79-91.

Quélin, B., 2000. Core competencies, R&D management and partnerships. *European Management Journal* 18: 476-487.

Ramos-Martin, Jesus, 2003. Empiricism in ecological economics: a perspective from complex systems theory. *Ecological Economics* 46: 387-398.

Senge, Peter M. 1990. *The Fifth Discipline: The Art & Practice of The Learning Organization*. New-York: Doubleday/Currency.

Sterman, John D. 2000. *Business Dynamics - Systems Thinking and Modeling for a Complex World*. Boston: Irwin McGraw-Hill.

Tidd, Joe, John Bessant, and Keith Pavitt. 2001. *Managing innovation – Integrating technological, market and organizational change*. Chichester: John Wiley & Sons.

Volterra, Vito, 1926. Variazioni e fluttuaziono del numero d'individui in specie animali conviventi. *Mem. R. Acadd. Lincei series IV* 2: 31.

Zangwill, Willard I., and Paul B. Kantor, 2000. The learning curve: a new perspective. *International Transactions in Operational Research* 7: 595-607.