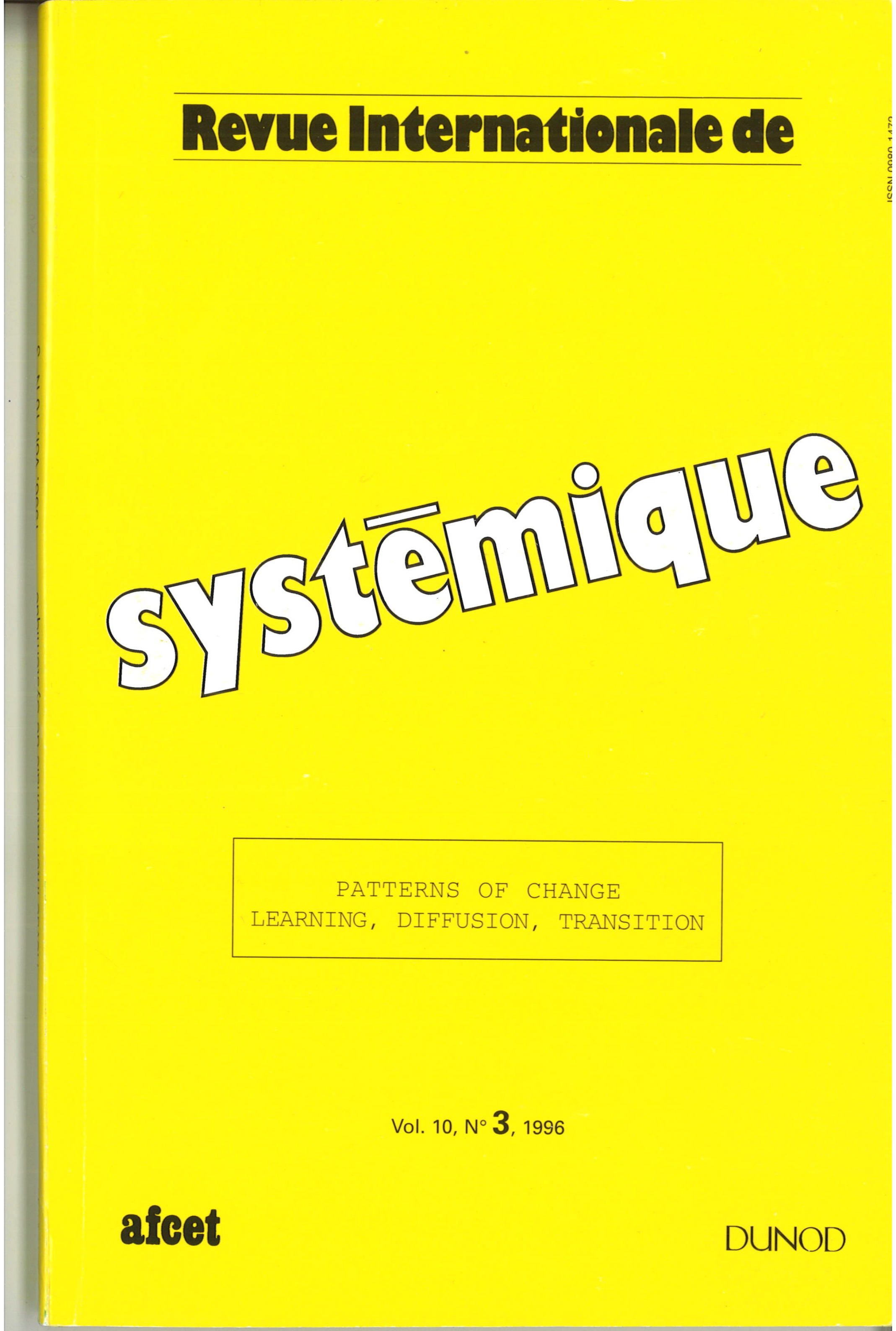

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Learning, selection, and evolutionary process; some explorations in frequency-dependency systems

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R. NELSON and S. WINTER, *An Evolutionary Theory of Economic Change*, Cambridge, Harvard University Press, 1982.

I. PRIGOGINE, Order through Fluctuation : Self-Organization and Social Systems, in E. Jantsch and C. H. Waddington (eds.), *Evolution and Consciousness*, Reading, Addison-Wesley, 1976.

G. F. RAY, *The Diffusion of Mature Technologies*, Cambridge, Cambridge University Press, 1984.

W. J. REED, The Effects of the Risk of Fire on the Optimal Rotation of a Forest, *Journal of Environmental Economics and Management*, 1984, vol. 11, pp. 180-190.

P. ROMER, Are Non-Convexities Important for Understanding Growth?, *American Economic Review*, 1990*a*, vol. 80, no. 2, pp. 97-103.

P. ROMER, Endogenous Technical Change, *Journal of Political Economy*, 1990*b*, vol. 98, no. 5, pp. 71-105.

N. ROSENBERG, *Perspectives on Technology*, Cambridge, Cambridge University Press, 1976.

W. SEMMLER, Solving Nonlinear Dynamic Models by Iterative Dynamic Programming, *Computational Economics*, 1995, vol. 8, pp. 127-154.

W. SEMMLER, Information, Innovation and Diffusion of Technology, *Journal of Evolutionary Economics*, 1994, vol. 4, pp. 45-58.

W. SEMMLER and M. SIEVEKING, On the Optimal Exploitation of Two Interacting Resources, *Journal of Economics*, 1994, vol. 59, no. 1, pp. 23-49.

M. SIEVEKING and W. SEMMLER, *Optimization without Planning: Economic Growth and Resource Exploitation when the Discount Rate Tends to Infinity*, University of Frankfurt/New School for Social Research, working paper, 1990.

M. SIEVEKING and W. SEMMLER, The Present Value of Resources with Large Discount Rates, forthcoming, *Journal of Applied Mathematics and Optimization*, 1996.

G. SILVERBERG, Embodied technical Progress in a Dynamic Model: A Self-Organizing Paradigm, in R. M. Goodwin, M. Krueger and A. Vercelli (eds.), *Nonlinear Models of Fluctuating Growth*, Heidelberg/New York, Springer-Verlag, 1982, pp. 192-208.

G. SILVERBERG, G. DOSI and L. ORSENIGO, Innovation, Diversity and Diffusion: A Self-Organization Model, *Economic Journal*, 1988, vol. 98, pp. 1032-1054.

V. SMITH, Economics of Production from Natural Resources, *American Economic Review*, 1968, vol. 58, pp. 409-431.

P. STONEMAN, *The Economic Analysis of Technological Change*, Oxford, Oxford University Press, 1983.

Y. M. SVIREZHEV and D. O. LOGOFET, *Stability of Biological Communities*, Moscow, Mir-Publishers, 1983.

S. WINTER, Schumpeterian Competition in Alternative Technological Regimes, *Journal of Economic Behavior and Organization*, 1984, vol. 9, pp. 137-158.

Wolfram Research Inc., *Mathematica - A System for Doing Mathematics by Computer*, Version 2.0, Champaign, Illinois, 1991.

A. YOUNG, *Substitution and Complementarity in Endogenous Innovation*, Sloan School of Management, MIT, mimeo, 1992.

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LEARNING, SELECTION, AND EVOLUTIONARY PROCESS. SOME EXPLORATIONS IN FREQUENCY-DEPENDENCY SYSTEMS

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Abstract
In this paper we are attempting to describe how learning (private or public) change the process of competition selection among competing firms. By this way we introduce more heterogeneity in industrial structure. We basically use frequency dependency approach and replicator dynamics models.

Résumé
Dans cet article nous essayons de montrer comment l'apprentissage (privé ou public) modifie le processus de compétition sélection entre les firmes en présence. De ce fait nous introduisons une plus grande hétérogénéité dans la structure industrielle. Fondamentalement nous utilisons une approche de type « frequency-dependency » et des modèles de dynamique de réplication.

INTRODUCTION

Generally most analyses illustrate the main features of the evolutionary competition of an industry in a framework within firms differing in only one dimension: technology and internal organization (Metcalfe, 1986, 1992). *We want here to extend this perspective by taking into account two aspects, differences in technology and differences in learning capabilities.* For this reason we shall assume that unit costs in each firm vary during the process of evolutionary selection. For us, selection means competition between firms

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for which technologies and learning capabilities differ. We will describe some economic implications generated by such a model of competition and selection. Needless to say it is really of great significance to mark why learning is important.

The economic activity provides many opportunities for learning, that is to say a special process by which repetition or experimentation enable tasks to be performed better and new production opportunities to be identified (Dosi *et al.*, 1992). As a very general process, learning has several properties: cumulative, irreversible, path dependent, localized (Stiglitz, 1987). Sometimes learning drives the evolution of technologies and produces innovations. But, here, we derived to take into account learning in the context of the firm in an evolutionist environment. We distinguish three forms of learning: private, public and spillover learning.

• Private or Corporate Learning

Corporate or private learning means that firm learns with its own skills (individual, social, organizational) from its own activities (products, processes, markets). This process requires a code of communication between individuals inside and outside the firm. Knowledge generated by processes of learning is incorporated in routines (Dosi *et al.*, 1992). From all this we can conclude that learning is partly endogeneously determined, in particular, by technological opportunities. Economists have proposed approaches of learning: Arrow (1962) with the macroeconomic implications of learning by doing, Stiglitz (1987) with the study of learning by learning and the theory of technical progress, Abernathy and Wayne (1974) with the limits of the learning curve, Pavitt (1984) with a new taxonomy of sectoral patterns of technological change, Cohen and Levinthal (1990) with the perspective of the absorptive capacity of the firm...

• The importance of public learning in the process of diffusion

As we consider competition in an industry we must take into account a public technological learning. So we want to underline *the importance of formal and informal cooperations between firms* which enhance the speed of information diffusion. Many studies have stressed this fact

⇒ Sahal (1981) have described the learning by sharing within an industry.

⇒ Silverberg *et al.* (1988) has shown that a good circulation of information and knowledge enables a process of imitation between rival firms.

⇒ The role of third-parties acting through regulation is to day better known better with the typology of third parties institutions suggested by Mantell and Tosseger (1987).

⇒ Midgley (1992) from Australian Graduate School of Management, examined how specific innovation communication links (in short network structures) can have a substantial effect on the manner in which innovation diffuses.

For all these reasons we can't suppose that all firms have free access to the most efficient knowledge (Iwaï, 1984). Not only different methods of production coexist, but in an industry, for a same method of production, firms exhibit different levels of productivity. Early adopters build efficient technological and organizational competencies more quickly than others. They accumulate the first more experience.

• Learning by spillover

It is a special kind of public learning. With public learning productive or technological information is shared by the firms of an industry, with spillovers information or knowledge is applicable from one technology to others. There is spillover when a change in a specific technology will have a slight (or an important) effect on another technology according to degrees of proximity. The fact that this change may affect more or less remote technologies means that learning, as technical progress, is partly localized (Stiglitz, 1987). Spillover effects are not only of intra-industrial type but inter-industrial type as well. So some new information which drives to technical improvements can come from outside industry.

Finally we assume from this survey

1. In the same industry forms have different rates of learning, because they have different capacities and core skills in technological, organizational or managerial systems.

2. Different industries have different rates of public learning. It depends on History, core technologies, market structures or institutional configurations.

In a first part we set out some methodological principles of an Evolutionary Model of Selection, in a second part we stress the main assumptions and prediction of a model of technological competition, finally we analyse the economic implications of competition and selection in presence of different kinds of learning.

I. METHODOLOGICAL PRINCIPLES OF EVOLUTIONARY TECHNOLOGICAL DYNAMICS

I.1. From Non-binary diffusion (multisubstitution) to selection effect

We can describe the development of intra-industry diffusion theory by saying that, in a first time, diffusion theory dealt with *binary* scheme of substitution, one new technology displaces gradually another one old technology. Theories differ on the degree of industrial heterogeneity (for instance firms are homogeneous or differ along their size) they differ also on their approaches: Epidemiological Model (Mansfield, 1961). Probit Model (David, 1969; Davies, 1979), Evolutionist Model (Silverberg, 1988). In a second time, we find *non-binary* diffusion. According to this multi-technology scheme of diffusion (or multisubstitution) several new technologies compete with one another (and of course with old ones). Sharif and Kabir (1976) provide the first empirical scheme for shaping diffusion paths (a further step was made by Girifalco, 1985). Iwaï (1984) gave an evolutionary model of imitation (and innovation too) where diffusion process of several technologies works with a *Schumpeterian competition*. He assumed that firms always wish to adopt the most efficient method of production. With Nelson and Winter (1982, especially Chapter 10) and Metcalfe (1986) multi-technology environment stands in a larger framework devoted to analyzed innovation and competitive process: a model of technological variety with different mechanisms of selection. The working of a multi-technology diffusion process can be studied as a mechanism for reducing variety. In the same model we have together the growth and the decline of a market share of technology. This approach of competition shares some basic implications with the paradigm of natural selection (Alchian, 1950; Enke, 1951; Penrose, 1952).

II.2. Selection as an evolutionary process, some stylised facts

Selection is an important mechanism driving the dynamic evolution of industry. We present here some stylised facts depicting the main characteristics of this economic process.

1. Heterogeneity describes in a relevant way the state of an industrial structure. We can analyze it at several levels. Each industry can be characterized by a great variety: variety of products and services (Saviotti, 1991), variety of methods of production (Dosi *et al.*, 1990), variety of technological competencies (Pavitt and Patel, 1993). Heterogeneity means also different performances, different levels of profitability. Each agent is perfectly unique, specific. So the assumption of a "representative agent" is really irrelevant. On the contrary, selection thinking becomes possible because the agents population is heterogeneous.

2. There is a variety in behavior within a population of competing economic agents. Each agent builds its strategy on the basis of its own experiment. "Procedural rationality" is the rule. Nevertheless as Silverberg (1988) has pointed out it must be admitted that the behavioral level has been relegated to a mostly ad hoc part in the economic model of selection (with the exception of the work of Nelson and Winter on the selection of decision rules).

3. Selection is accomplished through market processes removing firms (exit). But a less drastic phenomenon than entry (of new firms) and exit is growth and declining path with this smooth phenomenon: selection eliminates behavior which falls below a standard one and changes the relative proportions within the remaining population of economic agents (Metcalfe, 1993).

4. Selection environment may be stronger or weaker. It depends on the level of economic competition, regulation, technological race, degree of collusion. For this reasons less efficient firms can sometimes survive.

5. Selection is more a Lamarkian process than a Darwinian one, institutional and organizational memory devices allow the transmission of experience (Zuscovitch, 1993). The memory of the past (probably associated with the expectation of future events) produces some regularities as path-dependency, irreversibility, inertia phenomena...

6. Capacity to yield profit margin, or cash flow (Lesourne, 1991) and its availability is the best operatir of selection process ("market rationality").

7. Through such a non-linear process of selecting new technologies, old technologies disappear. We are far from epidemiological model of binary diffusion for which a new technology diffuses within a space of homogeneous firms.

I.3. To the core of analysis: replicator dynamics and frequency dependency effect

Current models of economic selection share the same basic mathematical structure labelled as *Replicator Dynamics*. "Replicator Dynamics" has been persuasively put forward by Dawkins (1982) as a fundamental piece of a natural selection. Schuster and Sigmund (1983) have sketched four models of replicator from a biomathematical viewpoint: Fisher's selection equation, Lotka-Volterra's equation, hypercycle equation... They underlie many patterns of evolution and selection. We find frequency-dependency property at the core of analytical structure as well.

Frequency dependency effect expresses "the fact that an individual makes a decision in a way that in some respect depends on how many other members of the population have already made a particular choice" (Witt, 1993). The probability $f_a(t)$ that a rather than b is chosen at time t is supposed to vary monotonously with two factors (which summarize advantages for the solution a): first on $F_a(t)$, the relative frequency with which a has already been chosen in the population up to time t, and second on $Z(t)$ which describes the influence of the diverse idiosyncratic factors (with $f_a + f_b = 1$). These considerations lead to

$$f_a(t) = \Psi[Z(t),\ F_a(t)]$$

The frequency dependency effect helps us understand micro-behavior and forms conducts. This is a kind of interdependency (of interactions between macro conduct and micro behavior) well known in biological evolutionary Theory. We find it at the core of many approaches.

■ In *Technological diffusion processes* based on contagion, imitation (Mansfield, 1961). For instance in "epidemiological" approach of diffusion the population of firms becoming users in an increment of time (dt) is proportional to the fraction of potential adopters who have-already adopted the innovation at time t. We have the same relation as in Bass's model of diffusion. We know this kind of model predicts a logistic curve for diffusion pattern. Iwaï (1985) used frequency dependency effect for shaping a Schumpeterian process of imitation.

■ In the analysis of *network externalities*. In many important industries the benefit that a consumer derives from the use of a good often is an increasing function of the number of others consumers purchasing compatible items. In industries where there are no physical networks as in communication industry (telephone, telex,...), there is a direct externality; the more subscribers there are on communication network the greater are the services provided by this network (Katz and Shapiro, 1985, 1986). There are network effects with compatibility and standardization as well (David, 1985; Farrel and Saloner, 1985).

■ In technological "lock in" (Arthur, 1988, 1989) with the self-reinforcing phenomenon (technologies become more attractive the more they are adopted).

Finally we can say that frequency dependency effect in a kind of path-dependency effect.

We now consider two different expressions of the general form of the frequency-dependency effect along $Z(t)$ is positive or negative. In Mansfield-Bass models of diffusion (two epidemiological formulations) we are in a binary scheme (one new and another one old technology), generally $f_a(t)$ is *monotonously increasing*. Turn now, to the pure evolutionary model of diffusion, we still have a frequency-dependency effect, but in a sense, it is more complex. In Silverberg (1988) the evolution of the market structure is governed by an equation relating the rate of variation of a firm's market share to the difference between its competitiveness and average industry competitiveness. We have the same relation in Metcalfe (1986, 1988), but with a key difference: the market shares concern not firms but technologies. So this model deals with the non binary scheme of diffusion. Nevertheless the *two models* predict the possibility of a *decreasing* path for the diffusion indicators (market's share or population of firms) in contrast with epidemiological approach (Mansfield-Bass model).

II. "NATURAL SELECTION" AND TECHNOLOGICAL COMPETITION IN EVOLUTIONARY TRADITION

II.1. Core hypothesis of an evolutionary model of industrial change

■ We consider an industry in which a large number of firms are in competition.

■ These firms which participate in the working of industry produce a product that is homogeneous. So we don't consider a monopolistic competition. The price p is unique.

■ We are concerned only by an "*imitation* process of technology" not by innovation. A firm cannot put a new method of production in practice by its own RD, the firm can only direct its eyes towards outside and imitate one among the most profitable methods used by other firms.

■ A firm can use only one technology and not several as in Metcalfe-Gibbons (1986). This hypothesis is directly related to our approach of intra and inter firm technological learning. But one technology can be used by several firms.

■ We identify each technology (each firm) by its unit cost $[c_i(t)]$. Bur for each technology i this number can vary over time along the space of technological learning. We have n technologies. So $c_1(t), c_2(t), \ldots, c_n(t)$ describe the "state" of technology at time t.

There are no returns to scale, unit cost don't vary with production scale.

The distribution of market shares $[s_i(t)]$ summarize at a point in time the economic weight of technologies.

II.2. The competitive process: some predictions

Here we are following hypotheses due to metcalfe (1986). Moreover, we consider that the "growth capacity of firms" (that is the ratio of the firm's growth rate of production to its profit margin per unit of output) which is the same for the entire industry equals one for convenience. In this way the growth of the market share i is a function of the differential of evolution between the growth (in volume) of the market of the technology i and the general growth of industry. According to this set of hypothesis we can say that the evolution of a market share, denoted $s_i(t)$, which represents the relative frequency of technology (firm) i in the industry, is expressed by the differential equation.

$$\frac{ds_i(t)}{dt} = s_i(t) \cdot [cm(t) - c_i] \qquad i = 1, \ldots, n \tag{1}$$

where c_i is the constant unit cost of the technology (firm) i and $cm(t)$ the industry's average unit cost. The latter is defined by the equation.

$$cm(t) = \frac{\sum_i c_i \cdot s_i(t)}{\sum_i s_i(t)} \tag{2}$$

where $\sum_i s_i(t) = 1$.

The main predictions of this approach are

■ *Selection principle.*

The non binary diffusion scheme gives place to a selection principle. The progression of the technology i, that is the rate of diffusion of this technology, is a function of the distance between the efficiency of i *th* technique and the whole technology's average efficiency. A technology with a unit cost less than the average cost would spread and conversely. This formula depicts *a non binary diffusion scheme in which some technologies are growing and others are decreasing.* Hence it should be pointed out that, to all appearances, cm plays the same part as the diffusion threshold in the non binary diffusion models. But it could be saif that cm is not an exogenous variable, it is necessarily endogenous, since this variable, like all other weighted averages, reflects the changes in weights due to competitive conditions.

■ *Convergence principle.*

Equations (1) and (2) give us a sufficient amount of information in order to study how each technology's market share is evolving during time. The progress of a leader technology (which is in possession of an advantage in sense of costs) leads to a diminishing average unit cost of the industry and therefore produces a break down in the diffusion of some technologies and the shrinking of some others (for which $cm(t) - c_i < 0$). The average unit cost is constantly decreasing until the technological variety of the industry converges towards the unit cost of the optimal technology. This result is connected with the implicit assumption that there is no new technology appearing in the industry. The selection model rules out the possibility of technological "creation", (nevertheless it would be possible to relax this last assumption as Iwaï (1985) put it).

■ *Fundamental theorem of natural selection (Fisher's Theorem).*

Given the definition of the average unit cost and from (1) we get

$$\frac{d}{dt} cm(t) = -Var[c_i(t)]$$

where $Var[\ ]$ is the variance of the unist cost of the whole technologies. This variance necessarily converges to zero when the selection (*i.e.* competing pressures) reduces the variety, the amount of features of the population under investigation (Metcalfe, Gibbons, 1986). The above expression tells us that the greater the scattering of the efficiency levels of technologies the higher the tempo of developments (measured by the variation of average cost) will be. Nelson and Winter (1982) reached the same results on the basis of practically similar hypotheses.

III. AN EVOLUTIONARY MODEL OF COMPETITION IN THE PRESENCE OF LEARNING PROCESSES

If we suppose we have learning effects (private or public) the main relations of the competition model have to be rewritten. We shall start with the description of the analytical form taken by the intra or inter firms learning effects.

III.1. How we measure the effects of private and public learning

We "measure" technical learning by way of an experience effect primarily function of time. So we retain a phenomenon described by the "learning curve", the organizational content of which have been lately strongly appraised (Abernathy and Wayne, 1974). This learning effect acts upon all technologies. The cost function of each technology is now written

$$c_i(t) = \frac{cb_i}{1 - \nu_i \cdot e^{-\mu_i t}} \qquad i \in (1, n) \tag{3}$$

where cb_i is the "basic cost", the one towards which unit cost asymptotically converges. For ν_i we have

$$\nu_i = \frac{cd_i - cb_i}{cd_i} \tag{4}$$

where cd_i is the "unit departure cost", that is the cost when $t = 0$. Notice that at every moment the slope of the cost curve is equal to

$$c_i' = \frac{-\nu_i \cdot \mu_i \cdot cb_i \cdot e^{-\mu_i t}}{(1 - \nu_i \cdot e^{-\mu_i t})^2} \tag{5}$$

These cost functions have basic properties of learning curves (decreasing path, convergence,...). These curves have three characteristic parameters, the departure cost (which is given in a way, or intrinsic), the basic cost (asymptotically reached), the speed of learning. The following figure illustrates these features

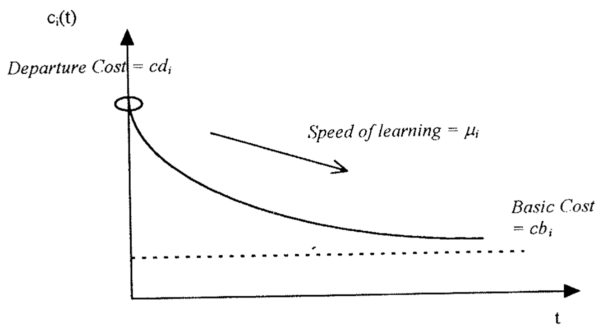

Figure 1. Cost function as learning curve.

Now, how can we modelise public learning? Let us assume that a technology i is brought into operation by two types of firms, leader firms (index $j = 1$) and follower firms (index $j = 2$). before the follower firms the leader firms succeed in developing skill and experience so that they quickly

derive higher productivity from equipment. The unit costs of leader firms are ever lower

$$c_{i1}(t) < c_{i2}(t) \tag{6}$$

For more convenience we shall only consider two new technologies ($i = 1, 2$) competing with an old one ($i = 3$) with an higher constant cost (c_3). We consider that follower firms develop experience with delay (with a lag), so we can write the following system of equations.

$$\frac{ds_{ij}(t)}{dt} = s_{ij}(t) \cdot [cm(t) - c_{ij}(t) \qquad i \in [1, 2] \quad j \in [1, 2] \tag{7}$$

$$\frac{ds_3(t)}{dt} = s_3(t) \cdot [cm(t) - c_3] \tag{8}$$

$$cm(t) = \frac{\sum_{i,j}^{2} c_{ij}(t) \cdot s_{ij}(t) + c_3 \cdot s_3(t)}{\sum_{i,j}^{2} s_{ij}(t) + s_3(t)} \qquad \sum_i s_{i\bullet}(t) = 1 \tag{9}$$

To put it more precisely define lag operator L, $Lx(t) = x(t-1)$, then

$$c_{i1}(t) = cb_i \cdot (1 - \nu_i \cdot e^{-\mu_i t})^{-1} \tag{10}$$

$$c_{i2}(t) = L^{\mathrm{del}_i} c_{i1}(t) \; \mathrm{del}_i \geq 1 \in \mathbb{N} \tag{11}$$

where del_i is the experience time lag for firms using technology i. When del_i is weak we consider that *public learning is high*, that is to say that productive knowledge and experience diffuse very quickly inside the industry. There is a peculiar case (or limit case) for which the rate of public learning is high, when $\mathrm{del}_i = 0$, then $c_{i2}(t) = c_{i1}(t)$. Conversely for high del_i public learning is low.

Since we only consider two new technologies ($i = 1, 2$) competing with an old one, we basically have two kinds of industrial heterogeneity, a technological heterogeneity (more than one technology compete) and a capacity of learning heterogeneity (which depends on the specific competencies of the firms). As mentioned early we postulate the existence of spillover effects between technologies (more accurately between technology 1 and technology 2), but we don't define a relationship devoted to their measurement.

III.2. Selection with high rate of public learning

We start by studying a limit case for which the rate of public learning is high. In other words all the firms of the industry using the technology i have the same performances (the same unit costs). Taking (3) into account, (1) is rewritten now.

$$\frac{ds_i(t)}{dt} = s_i(t) \cdot [cm(t) - cb_i \cdot (1 - \nu_i \cdot e^{-\mu_i t})^{-1}] \qquad (12)$$

with

$$cm(t) = \frac{\sum_i c_i(t) \cdot s_i(t)}{\sum_i s_i(t)}$$

We have as many equations (12) as technologies. A serious difficulty is that differential equation (12) is a nonlinear one so it is not analytically integrable. It is this non linearity which proves to be most awkward in attempts at solving the associated differential equation. Therefore we shall deal with the kind of approximation methods used to tackle non linear problems. That is, we shall have recourse to simulation methods in order to know the impact of various parameters on the time behavior curves of s_i.

If we actually deal with two new technologies (1 and 2) we have added up *an old one* with a very high constant cost for which there is no learning process. In fact, we have the system of equations

$$\frac{ds_i(t)}{dt} = s_i(t) \cdot [cm(t) - cb_i \cdot (1 - \nu_i \cdot e^{-\mu_i t})^{-1}] \qquad i \in [1, 2]$$

$$\frac{ds_3(t)}{dt} = s_3(t) \cdot [cm(t) - c_3] \qquad (13)$$

It means that $cb_3 = cd_3 \equiv c_3$ and $\mu_3 = 0$.

By virtue of selection principle this old technology will be gradually ruled out and replaced by the two new ones. For this reason at the start of the process the market shares of the new technologies are very small (close to zero). This diffusion process is however unbalanced because the market shares of the two new technologies (a diffusion indicator) don't follow a similar course. We shall distinguish between two cases depending on whether the basic costs of technologies are the same or not.

Case 1. *Different basic costs.*

– In such a case when the technology which converges towards the lower cost wins the competition, its market share tends to one whereas the market share of the other tends to zero.

– Nevertheless it may converge in many ways towards its limit: following a logistic or pseudo-logistic path, by passing through a relative maximum, etc. according to the ratio of speed of learning and initial unit costs. Here we rediscover ***all*** the predictions of modern selection approach (namely the "Fisher Theorem" of Natural Selection).

For example we made the assumption that technology I has lower departure cost (favored technology). We have two subcases.

Subcase 11. Same speeds of learning ($\mu_1 = \mu_2$).

If we suppose, for example, that $cb_2 < cb_1$, then whatever μ_i technology converging toward lower cost (*i.e.* technology 2) wins the competition and $s_2 \to 1$, $s_1 \to 0$. See Figure 2.

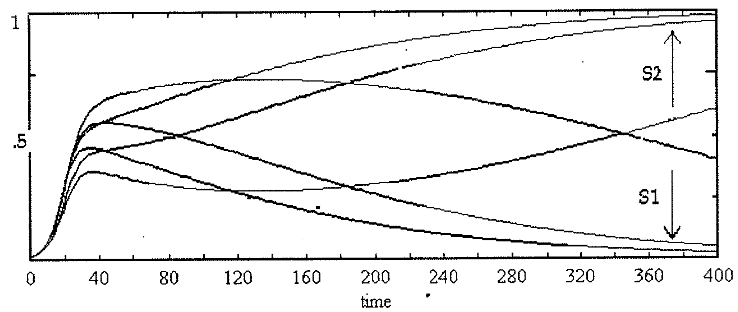

Figure 2.

Subcase 12. Different learning speeds.

We have the assumptions: $cd_1 < cd_2$, $cb_1 > cb_2$. In an attempt to diminish final advantage of technology 2 we may act by two ways, either a *relative* ***decrease*** *of* μ_2 in comparison with μ_1 (0.0005) [case **121**], or a *relative* ***increase*** *of* μ_1 in comparison with μ_2 (0.005) [case **122**].

Case 121. We discover the **existence of a critical value for** μ_2 so that s_2 decreases, tends to ε then increases and tends to an upper limit equals one. The result is mathematically correct but economically very strange. See Figure 3.

Case 122. The increase of μ_1 only delays long rang results. See Figure 4.

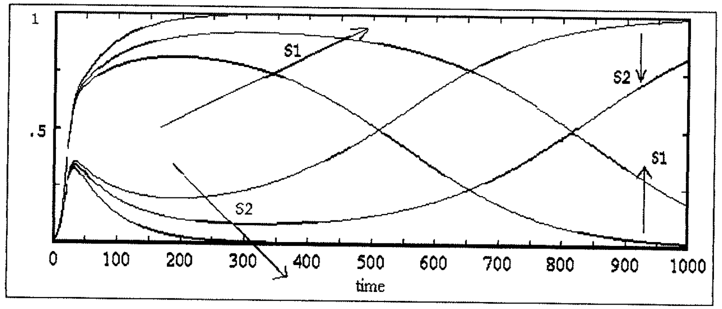

Figure 3.

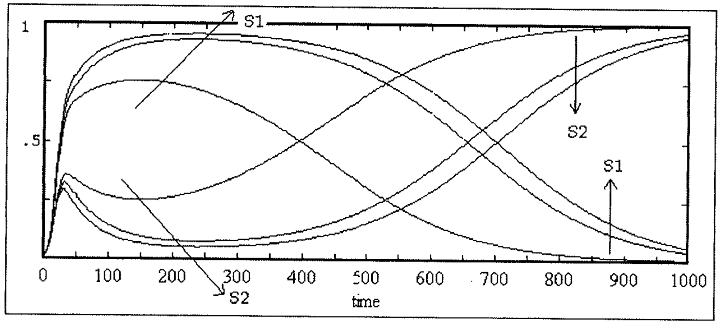

Figure 4.

Hence in every case the technology having the lowest basic cost wins the technological race.

Case 2. *Asymptotically identical basic costs.*

This pattern can't be precluded. Moreover it is to be thought of as realistic. Because on the one hand, the prevailing technologies into the industry may be dependent on similar technical principles, hence we hardly conceive a durable deviation of costs. On the other hand we can't exclude spill-overs from one technology to another (especially if they are closed each other). This type of inter-technological learning differs from the "public learning" we have been speaking about until now; it refers to firms using the same technology. This pattern is very interesting for us. The model of natural selection which supposes constant unit costs during the diffusion process should predict that since basic costs are the same, the two technologies should converge to the same market share. Hence we shall end at a unequal

splitting of the market. Now, *this prediction is not valid anymore once we account for a learning dynamics.*

Subcase 21. *For identical learning speeds.*

Although there is a convergence towards the same basic cost, we verify the common saying by the terms of which "*we never make up for lost time*". As a matter of fact the *technology having lower departure costs is favored.* It converges in a pseudo logistical way to a threshold, a steady state value, greater than that of the other one technology. This latter, on the other hand, for a certain field of values of μ_i, passes through a maximum with increasing value (less than proportionally to the increase of μ_i), less and less marked, reached later and later. Then it converges by upper value to a steady state value less than that of the other technology (the favored technology). Beyond a certain value of μ_i maximum disappears and market share s_2 approaches a steady state value by lower value. Having said this it is obvious that steady state values should only be the same for a learning speed approaching infinity, that is the limiting case of an instantaneous adjustment to basic cost.

For example if we made the assumptions, $cd_1 < cd_2$, $cb_1 = cb_2$, then $s_1 \to s_1^* > s_2^*$, and we have the followings diagram (*see* Figure 5).

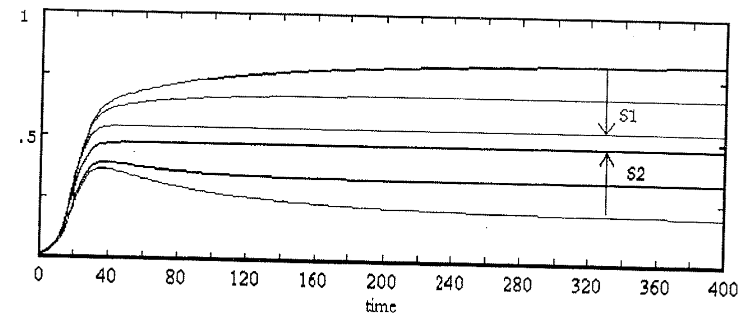

Figure 5.

Subcase 22. *For different learning speeds.*

Technology having greater learning speed triumphs over when it has departure costs advantage, but this is not ever true depending on other parametric values. For example insofar as technology 2 has an original disadvantage we can act upon parameter μ_2 making the assumption that μ_1 is constant ($\mu_1 = 0.01$). We may distinguish two cases.

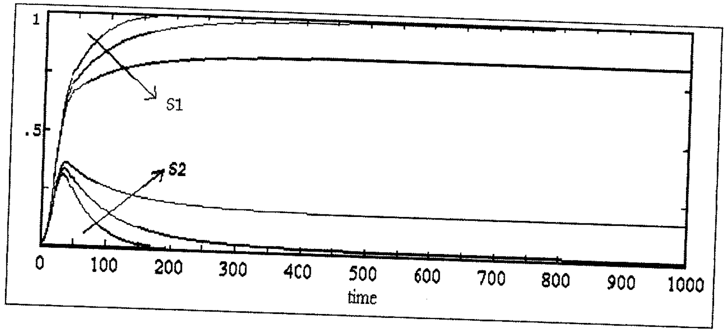

Figure 6.

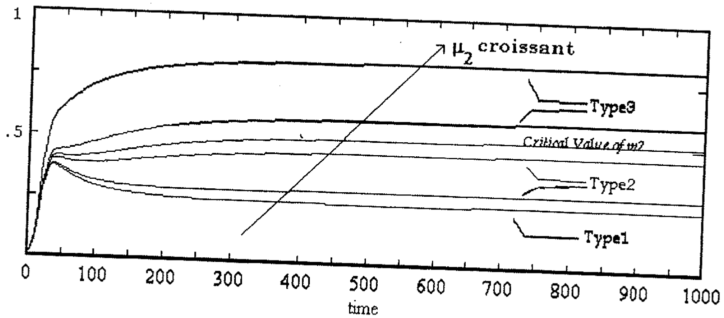

Figure 7.

Case 221 ($\mu_2 < \mu_1$ **and** μ_2 **increases**) then $s_1^* > s_2^*$. We have almost the same behavioural time structure with an increasing gap between s_1 and s_2. Hence we have the following graph (*see* Figure 6).

Case 222 ($\mu_2 > \mu_1$ **and** μ_2 **increases**). There are different patterns of behavior especially for s_2. As follows we distinguish between three types of behaviour (*see* Figure 7).

Type 1. Quick logistic growth, passage trough a maximum convergency toward lower boundary value.

Type 2. Quick logistic growth, passage trough a maximum then a minimum, convergency toward upper medium boundary value. The maximum is either absolute ($> S_2^*$) or relative ($< S_2^*$).

Type 3. Quick logistic growth. Maximum and minimum both become an inflection point (which disappears) and we have monotonic convergence toward upper high boundary value.

Notice that there is a critical value of μ_2 (namely μ_2^c) so that we have the next relations

$$\text{If} \quad \mu_2 \lesseqqgtr \mu_2^c \quad \text{then} \quad s_2^* \lesseqqgtr s_1^*$$

Hence technology having a sufficient learning speed (relative to that of the other technology) may triumph over eben if it has departure cost disadvantage. It depends on parametric values.

III.3. Selection with variable rate of public learning

Now we leave the limiting case of an instantaneous diffusion of experiences (high rate of public learning). We shall argue about cases in which the learning capacities of firms are heterogeneous including the case where firms implement the same technologies. We somewhat simplify the variety of the industry by distinguishing four states of costs. In fact we can regard prevailing technologies used by followers as different from those used by leaders (performances of the formers follow behind those of the latters).

Technology Capacity of learning	1	2
Leader	c_{11}	c_{21}
Follower	c_{12} ($\geq c_{11}$)	c_{22} ($\geq c_{21}$)

Two kinds of industrial heterogeneity (c_{ij} = unit cost).

With this configuration we can take it for granted, that, making allowance for the working of the model, the technology which has the lower unit cost (the leader's one) shall win the technological race. Nevertheless some configurations of parameters allow to consider other situations.

■ Under certain circumstances followers can pull through. The speed of learning has been chosen so that the market shares of the two new technologies (1 and 2) are equal to half of the market. With such an equalitarian splitting of the market no comparative advantage occurs for any technology. Such a state of things allows for a better evaluation of the impact of public learning. Evolution of final values of s_{ij} as a function of del_1 and del_2 may be depicted by surfaces in a three dimensional space. *See* Figure 8.

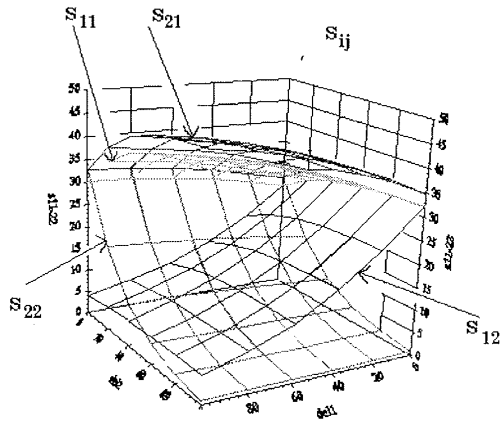

Figure 8.

Hence the model predicts that

■ Whatever time lags may be, the market shares of the leaders increase [s_{11} and s_{21} are surfaces increasing cocave for del_1 and del_2], of course they grow up with different paces according to the importance of lags.

■ Followers' market shares always act in an opposite way [s_{12} is decreasing convex for del_1 and increasing concave for del_2, conversly s_{22} is increasing concave for del_1 and decreasing convex for del_2]. So taking into account parametric values, we shall have, for example.

$$\forall\, \mathrm{del}_1,\ \mathrm{del}_2\ S_{21} > S_{11} > (S_{12},\ S_{12})$$

and

$$S_{22} > S_{12}\ IF\ \mathrm{del}_1 \geq 2\,\mathrm{del}_2$$

even when s_{22} increases and s_{12} decreases. One result of the model, given parametric values, is that **a follower is not necessary condemned**.

The evolution of s_{ij} for varying μ_2 is shown graphically in next figure (*see* Figure 9). In this case we suppose that the speed of learning of firms using technology 2 (μ_2) is varying whilst μ_1 is assumed to be constant. The public learning rate is the same for all the firms. In the corresponding figure we can see that as the speed of learning of firms using technology 2 is increasing relatively to that of firms using technology 1, the last one group is more and

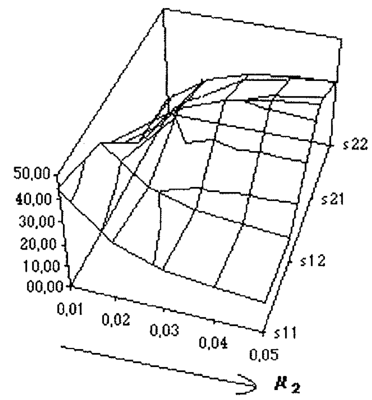

Figure 9.

more favoured. In fact curves for s_{11} and s_{12} are decreasing while curves for s_{21} and s_{22} are increasing.

For a group of firms using technology i we call "market share of the group" the variable

$$pm_i = \sum_{j=1}^{2} s_{ij} \qquad \text{with} \qquad \sum_i pm_i = 1$$

Then we can see how a market share is evolving when public learning varies either for the firms using technology 1 ir firms using technology 2. Graphically the evolution of pm_1, for example, as a function of del_1 and del_2 may be depicted by a surface in a three-dimensional space (*see* Figure 10). This surface is decreasing convex for del_1, that is an increase in del_1 leads to a less than proportionate decrease in pm_1 (the convexity becomes weaker when del_2 increases). It is increasing concave for del_2, that is an increase in del_2 leads to a less than proportionate increase in pm_1 (with concavity slightly growing when del_1 increases). The surface has a non-symmetrical "saddle" form. In other words to increase del_2 would come back to bear injustly upon the group using technology 2 and this imbalance increases more especially as del_2 is high. On another hand an increasing del_1 handicaps the group using technology 1, but this effect is attenuated by the increase of del_2. Notice that these conclusions depend on the parametric values taken here, that is fundamentally the group using technology 2 is initially enduring unfavourable conditions by having a departure cost higher than that of the group using

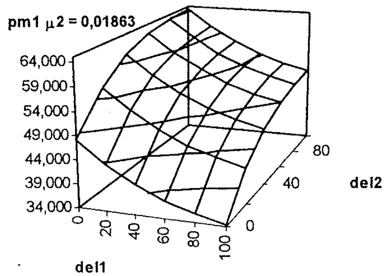

Figure 10.

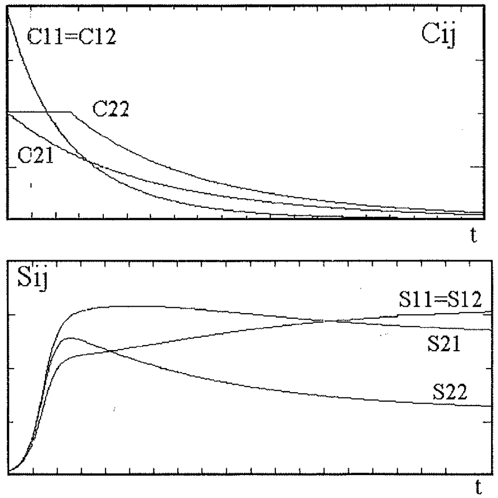

Figure 11.

technology 1, [$cd_2 = 0.12$, $cd_1 = 0.10$ and $cb_1 = cb_2 = 0.08$]. Hence we have the next figure (*see* Figure 10).

■ Here we have a framework for studying spatial or territorial effects of technological dynamics. Consider the very simple sketch of an industry deivided into an "industrial district" (a set of firms geographically concentrated within which information, learning, experience... quickly circulate) and the set of the other firms very scattered geographically. Technology one is used by the district with high public learning ($\mathrm{del}_1 = 0$), technology two us implemented by other forms with a medium rate of

public learning ($\mathrm{del}_2 > 0$). The private learning speed is higher for 1 than 2 ($\mu_1 > \mu_2$), but, at the departure, technology 2 is the most efficient [$c_{2j}(0) < c_{1j}(0)$]. By the more fact of propitious factors acting into the district, the technology one get the better of the followers, then the leaders using the other technology. It will win technological race owing to its high learning rate. For example, in the next figure (*see* Figure 11) we give, for such a parametric case, the time behavior curves of the unit costs and the corresponding curve for the market shares.

Some conclusion

In this paper we examine how technological competition-selection is achieved in an environment marked by the peculiar features of the industrial evolutionary approach: technological variety, heterogeneity of behaviours,..., when compared to previous studies we explicitly consider the part and the impact of the *learning process* on the competition-selection progress and not the lower end cost at the departure of the process of learning. We start from a simple modelisation of the evolution of an industry according to Downie-Metcalfe analysis and we add some relations devoted to describe different kinds of learning. Some predictions are altered:

■ The "best practice" technology is the one having the asymptotically lower unit cost (basic cost). To put it in others terms, we introduce the possibility for economic agents to improve technology by accumulation of knowledge. We then consider a lamarkian aspect in the "darwinian process competition".

■ Convergence to thos cost may follow different trajectories.

■ If several technologies tend to the same lower basic cost (which is very realistic of spillover effects are under consideration), now there are more thna one technology sharing the market. The persistant coexistence of techniques is to day a point acknowledged in the literature for which there are many evidences. (Dalle, 1994; Kirman, 1992; Le Bas, Sylvestre-Baron, 1995). For this reason our own approach seems more realistic. We show that, in this case, the technology favoured at the departure preserves its advantage in terms of market shares (the prevailing technology is the one having initially, at the start of the technological race, a cost advantage). We may look for a relevant development in order to decide which of the two new technologies is the better. If we bring in a sectir producing capital goods, increasing return to adoption may play a part in favour of the technology having higher market share.

■ Making allowance for a public learning (still analysed in a rather succinct manner) would be fruitful in studying firms' trajectories (as in Silverberg, 1991) or differentiated territorial dynamics in a same industry.

It is obvious that this paper has some limitations, firms behaviour is analysed here rather succinctly, however we may take into account non uniform fitness as Metcalfe (1986) did. Another assumption has simplified our discussion about the impact of learning on selection, we have supposed that firms have myopic behaviour. So equation (1) stresses there is a *contemporaneous relation* between unit cost, profit margin, growth and variations of market shares. Conversely Stiglitz (1987) has shown that in presence of learning the choice of technique should be made in a non myopic way.

In this article, we have attempted to describe how learning processes can be introduced in multitechnology model of selection and how these processes change diffusion and selection. It is a very simplified scheme, it needs some extensions.

References

W. J. ABERNATHY, K. WAYNE, Limits of the Learning Curve, *Harvard Business Review,* 1974, september-october.

A. ALCHIAN, Uncertainty, Evolution and Economic Theory, *Journal of Political Economy*, vol. 58, 1950, n° 3, pp. 211-221.

K. ARROW, The Economic Implications of Learning by Doing, *Review of Economic Studies*, 1962, pp. 155-173.

B. ARTHUR, Competing Technologies: an overview, in G. Dosi *et al.*, Eds., *Technical Change and Economic Theory*, Pinter Publishers, 1988.

B. ARTHUR, Competing Technologies, Increasing Returns and Lock-in by Historical Events, *Economic Journal*, 1989, n° 99, pp. 116-131

W. M. COHEN, D. A. LEVINTHAL, Absorptive Capacity: A New Perspective on Technological Systems, *Administrative Science Quarterly*, 1990, vol. 35, pp. 128-152.

P. DAVID, *A Contribution to the Theory of Diffusion*, Standford Center Research in Economic Growth, Memorendum n° 71, 1969.

P. DAVID, Clio and the Economics of Qwerty, *American Economic Review. Papers and Proceedings*, 1985, pp. 332-337.

S. DAVIES, *The Diffusion of the Process Innovations*, Cambridge University Press, 1979.

G. DOSI , D. J. TEECE, S. WINTER, Les frontières des entreprises : vers une théorie de la cohérence de la grande entreprise, *Revue d'Économie Industrielle*, 1990, n° 51, pp. 238-255.

S. ENKE, On Maximizing Profits: a Distinction between Chamberlin and Robinson, *American Economic Review*, 1951, vol. 41, pp. 566-578.

J. FARREL, G. SALONER, Installed Base and Compatibility: Innovation, Product Preannoucement and Predation, *American Economic Review*, 1986, pp. 940-955.

L. A. GIRIFALCO, S. SIMOZAR, Multilevel Substitution, *Journal of Resource Management and Technology*, 1985, vol. 14, pp. 45-54

K. IWAÏ, Shumpeterian Dynamics. An Evolutionary Model of Innovation and Imitation, *Journal of Economic Behavior and Organization*, 1984, pp. 159-179.

M.-L. KAZT, C. SHAPIRO, Product Compatibility Choice in a Market with Technological Progress, in D. J. MORRIS *et al.*, Eds., *Strategic Behaviour and Industrial Competition*, Clarendon Press, Oxford, 1986.

M.-L. KAZT, C. SHAPIRO, Network Externalities, Competition and Compatibility, *American Economics Review*, 1985, n° 3, pp. 425-440.

J. LESOURNE, *Économie de l'ordre et du désordre*, Économica, Paris, 1991.

E. MANSFIELD, Technical Change and Rate of Imitation, *Econometrica*, 1961, n° 29, pp. 741-765.

S. J. MANTEL, G. ROSEGGER, The Role of the Third-Parties in the Diffusion of Innovations: A Survey, in R. Rothwell, J. Bessant, Eds., *Innovation: adaptation and Growth*, Elsevier, 1987.

J. S. METCALFE, The Diffusion of Innovation: an Interpretative Survey, in G. Dosi *et al.*, Eds., *Technical Change and Economic Theory*, Pinter Publishers, 1988.

J. S. METCALFE, Variety, Structure and Change: An Evolutionary Perspective on the Competitive Process, *Revue d'Économie Industrielle*, 1992, n° 59, pp. 46-62.

J. S. METCALFE, Some Lamarkian Themes in the Theory of Growth and Selection: A Provisional Analysis, *Revue Internationale de Systémique*, 1993, vol. 5, pp. 485-504.

J. S. METCALFE , M. GIBBONS, Technological Variety and the Process of Competition, *Économie Appliquée*, 1986, n° 3, pp. 493-520.

D. F. MIDGLEY *et al.*, The Effect of Network Structure in Industrial Diffusion Process, *Research Policy*, 1992, n° 21, pp. 535-552.

R. R. NELSON, S. G. WINTER, *An Evolutionary Theory of Economic Change*, Harvard University Press, 1982.

K. PAVITT, Sectoral Patterns of Technical Change: Towards a Taxonomy and a Theory, *Research Policy*, 1984, vol. 13.

K. PAVITT, P. PATEL, *Patterns of Technological Activity: their Measurement and Interpretation*, Mimeo SPRU, 1993.

PENROSE, *The Theory of the Growth of the Firm,* Oxford, 1959.

G. ROSEGGER, Diffusion trough Interfirm Cooperation, *Technological Forecasting and Social Change*, 1991, vol. 39, pp. 81-102

D. SAHAL, *Patterns of Technological Innovation*, Addison-Wesley Publishing Compagny Inc., 1981.

M. N. SHARIF, C. KABIR, System Dynamics for Forecasting Multilevel Technological Substitution, *Technological Forecasting and Social Change*, 1976, vol. 9, pp. 89-112.

M. N. SHARIF, C. KABIR, A Generalized Model of Forecasting Technological Substitution, *Technological Forecasting and Social Change*, 1976, vol. 8, pp. 353-361.

P.-P. SAVIOTTI, J. S. METCALFE Eds, *Evolutionary Theory of Economic and Technological Change*, Harwood Academic, 1991.

P. SCHUSTER, K. SIGMUND, Replicators Dynamics, *Journal of Theoretical Biology*, 1983, pp. 533-538.

G. SILVERBERG, G. DOSI, L. ORSENIGO, Innovation, Diversity and Diffusion: a Self-Organization Model, *Economic Journal*, 1988, pp. 1032-1054.

G. SILVERBERG, Adoption and Diffusion as a Collective Evolutionary Process, *Technological Forecasting and Social Change*, 1991, vol. 39, pp. 67-80

M. SHARP, Technological Trajectories and Corporate Strategies in the Diffusion of Bio Technology, in *Technology and Investment Crucial Issues for the 1990's*, OCDE Pinter Publishers, 1990.

J. E. STIGLITZ, Learning to Learn, Localized Learning and Technological Progress, in *Economic Policy and Technological Performance*, P. Dasgupta, P. Stoneman, Eds., Cambridge University Press, 1987.

U. WITT Ed., *Evolution in Markets and Institutions*, Physica Verlag, 1993.

E. ZUSCOVITCH, Evolutionary Economics and Lamarkian Hypothesis: Towards A "Social Imperfect Competition"?, *Revue Internationale de Systémique*, 1993, pp. 459-469.

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TECHNOLOGY EVOLUTION AND THE RISE AND FALL OF INDUSTRIAL CLUSTERS*

Peter SWANN [1]

Abstract
This paper explores how the evolution of technologies influences the relative success of different regions or clusters at producing those products. In particular, it explores how the convergence of communications, computing and software technologies influences the relative success of "one-technology clusters" (concentrating on one sub-sector of the industry) and "multi-technology clusters" (with strengths is a number of different subsectors). The paper shows how some multi-sector clusters tend to outperform single-technology clusters when technological convergence is strong..

Résumé
Cet article explore comment l'évolution des technologies influence le succès relatif que connaissent les différentes régions ou zones à produire leurs biens. L'article traite particulièrement de la question de la convergence des techniques de la communication, de l'informatique et des logiciels, et de l'influence qu'elle peut avoir sur, d'une part le succès des zones mono-technologiques (concentration sur un seul sous-secteur d'industrie) et d'autre part, des zones multi-technologiques (concentration sur plusieurs sous-secteurs). L'article montre comment certaines zones multi-sectorielles ont une tendance à mieux réussir que les zones mono-sectorielles, quand la convergence est forte.

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