Technological Change, Uncertainty and Innovation Networks: Towards a Dynamic Theory of Economic Space

4

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4.1 Introduction

The theoretical and empirical literature on the relationships between space and technological change is literally immense, and scattered along different directions that may be listed tentatively in the following:

- the theory of innovation diffusion;
- the spatial geography of R&D;
- the spatial preconditions for (and obstacles to) innovation: presence of human capital, availability of producer services, ‘urban’ environment, industrial structure;
- the characteristics of innovative environments: valleys, corridors, routes, parks; the ‘Third Italy’ phenomenon; the ‘milieux innovateurs’ of the new Gremi approach (see below);
- the regional differentials in productivity growth;
- the effects of technological change on regional development the effects of technological change on urban development;
- the spatial effects of specific technologies: industrial automation, information technologies, telecommunications, . . .

This chapter was previously published in D. Boyce, P. Nijkamp and D. Shefer (eds.) (1991), *Regional Science: Retrospect and Prospect*, Springer-Verlag, Berlin, 211–250.

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R. Capello (ed.), *Seminal Studies in Regional and Urban Economics*,
DOI 10.1007/978-3-319-57807-1_4

The aim of this paper is not really to make an overview of this literature; the task would be overwhelming in comparison to the scarce resources of a single researcher and the limited ambitions of a paper.

A different perspective seems however more fruitful in the present state-of-the-art of our discipline, as far as technological change problems are concerned; namely:

(a) to inspect in some depth the characteristics of the *new scientific paradigm* through which the field is approached by general, non-spatial economic theory, the *evolutionary paradigm*;
(b) to link it with the *new 'network' behaviours of firms* in their struggle for dynamic excellence; and
(c) to highlight the *role of spatial variables* in the new interpretative context.

My approach starts therefore from the consideration of these three open issues, which in my view lie near the frontier of the present scientific debate and call for new substantial theoretical and empirical efforts. My general hypothesis is that, within the new 'evolutionary' paradigm, spatial variables are no longer relegated to a peripheral condition in the theoretical framework, no longer play the role of a simple extra-dimension of the problem, but represent central elements of the interpretative framework itself. This fact is particularly interesting in a context where the new firm behaviours of transnational cooperative agreements and network linkages at a first glance seem to annihilate space as a relevant economic operator.

In the theoretical framework that will be built throughout the chapter, the local spatial context, or the local 'milieu', will emerge as a necessary and crucial element in the process of technology creation and as the 'operator' that allows the individual decision-maker to cope with the problems of static and dynamic uncertainty which are intrinsic in innovative behaviours. The reflections presented here may therefore be intended as prolegomena to a new theorization of economic space in a dynamic context.

The characteristics of the emerging scientific paradigm in the study of technological change will be inspected first, keeping in mind both its actual limits of general consistency, coherence and completeness, and the important efforts made by the best representatives of the 'traditional' theory in enlarging its explicative power beyond abstract and often meaningless cases (Sect. 4.2).

Then the new behaviours of firms will be analyzed when, in a dynamic and innovative context, they are facing inescapable problems of 'uncertainty', imperfect and costly information collection, limited forecasting capability and rationality (Sect. 4.3). The central role of network relationships, developing both at a local-informal and at a formal-trans territorial level, will become clear in this context (Sects. 4.4 and 4.5).

Thirdly, the problems of innovation adoption and diffusion will be taken up in terms of evolving and competing technologies on the geographical pace (Sect. 4.6), and the most appropriate modeling approaches will be discussed.

4.2 The Emergence of the New 'Evolutionary' Paradigm in the Study of Technological Change

Traditional economic theory has directly transferred to a dynamic setting almost all the explicit or tacit assumptions that were employed to study optimizing firms' behaviours in the static context of given and perfectly known technologies. Conditions of perfect knowledge are projected along the time horizon of the firm, hypothesizing perfect foresight on both technological advances and their economic outcomes, and a perfect and 'rational' utilization of the existing information. Standard-choice theory assumes therefore hyper-rational, never-failing agents which always select actions in order to maximize expected utility based upon observed and free information.

In this framework, technological change is not really explained, but only 'assumed' and instantaneously adopted by firms (if the new technology proves itself superior to all previous ones in all points of the factor-price frontier, as often happens). In a world where technology is equated to perfectly free information (Arrow 1962) and where actors' expectations are by definition 'rational', all that firms have to do is dip into the pool of technological know-how (become a sort of public good), optimizing an inter-temporal objective function.

Needless to say, this vision trivializes both the concept of technology and the concept of time in economics. In Prigogine's words, dynamics is reduced to 'a movement in a timeless time', with no role to irreversibility, 'memory', or history. Along the same lines, Frank Hahn, the champion of most advanced neoclassical theorizing, has questioned the rationality assumptions in the presence of incomplete information and imperfect markets and has suggested that, on the contrary, 'dynamics should be viewed as a learning process both about demand conditions and the strategies of near competitors. When an equilibrium is defined relatively to such (dynamic) processes, it seems that they are undetermined unless history—that is information—is explicitly modelled and known... There is something essentially historical in a proper definition of equilibrium and of course in the dynamics itself' (quoted in Freeman 1988).

The new 'evolutionary' paradigm in the scientific interpretation of technological change emerged because of similar dissatisfactions, and committed itself to the full consideration of such 'real life' elements as imperfect information, limited search capabilities, 'bounded' rationality, cumulative learning processes, static and dynamic uncertainty, even at the expense of a lower formalization and a limited prediction capability. Pioneered by the works of Nelson and Winter (1982), the new approach was quickly developed thereafter and recently received an important state-of-the-art presentation (Dosi et al. 1988).

As the new approach takes these elements of market imperfection and uncertainty directly into account and incorporates the very nature of the Schumpeterian creative innovation processes, its main concern appears almost at the opposite side with respect to those of the neo-classical one. In the latter case, the evidence of a wide spectrum of differentiated, lagged and unexpected behaviours conflicts with the geometrical perfection of the theoretical model and its prediction of a unique optimal solution for all firms in each market. On the contrary, evolutionary approaches have to explain why and how the apparently anarchistic process of innovation creation and diffusion does not end up in a purely random aggregate phenomenon, but in a self-organized and ordered process showing regular patterns of change.

The rationale for this ordered pattern is found in the intrinsic learning nature of technological change, showing up on the double level of *microeconomic learning processes* (in both research units and firms) and *social-institutional learning processes*. These processes, embedded in the very nature of technological change, constrain its evolutionary path along ordered 'technological trajectories' and long-term, cyclical waves (Dosi 1982; Dosi and Orsenigo 1988; Peres 1985; Freeman and Peres 1986). At the microeconomic scale this effect stems from:

– the presence of specific technical properties, reducing the spectrum of possible behaviours;
– the sharing of similar problem-solving heuristics among firms;
– the cumulative agreement in the society on the definition of relevant problems and targets;
– the use of decision routines which limit the spectrum of possible actions;
– the cumulative nature of 'incremental' innovations within each 'technological paradigm'.

At the macroeconomic scale, 'order' may come from socio-cultural and institutional resistances to change and from the stabilizing characteristics of the economic and political rules that define each 'régime de régulation' (Boyer 1986).

According to the new approach, technological change may be interpreted and 'stylized' in the following way:

(a) it is an irreversible, path-dependent and evolutionary process, stemming from the behaviour of economic agents which explore only a limited part of the set of theoretically possible actions, that part which is strictly linked to previous innovation adoptions and to already acquired know-how. This is far from the traditional view of technological change as a fast, flexible and optimal reaction to changing market conditions, choosing among a wide spectrum of perfectly known alternatives;
(b) it lies therefore on a cumulative learning process, resulting in the 'creation' rather than the simple 'adoption' or imitation of already existing ideas (inventions or innovations);
(c) it implies search and decision routines which limit the cost of information collection and the cost connected with the presence of uncertainty;
(d) it implies the full commitment of all functions of the firm, and in particular a deep interlink among R&D, production, marketing and organization;
(e) due to its dependence on internal learning processes (learning-by-doing, by-using, by-searching and, more indirectly, learning-to-learn) it cumulatively

builds on tacit, firm-specific know-how and on 'intangible' assets: its transfer or imitation is therefore a highly difficult process;

(f) its historical path may by no means be interpreted in terms of 'optimality'. From a macro point of view, in fact, its path-dependent nature and the non-linearities connected with the learning processes may act as dynamic 'entry-barriers' with respect to possible, possibly more efficient, alternative technologies. Once a bifurcation point is overcome in the development path of a particular technology and a specific trajectory is chosen, cumulative processes reinforce and perpetuate that choice, highly reducing the spectrum of possible outcomes and alternatives (see, as an example, the 'genetic' limits of nuclear power technologies, which deeply influenced the subsequent trajectory). On the other hand, from a micro point of view, conditions of limited information and 'bounded rationality' limit (or change) the meaning of optimizing behaviours.

New reflections are still needed for the full development of the new scientific approach to technological change. In particular, the definition and the meaning of possible 'evolutionary equilibria' have not been stated in a sufficiently sound way. Analogies from other sciences suggest to employ in this respect the concept of an '*attractor*', or a series of attractors, leading the evolution within each established technological paradigm towards some sort of stationary adjustment path (Dosi and Orsenigo 1988). These attractors, however, are thought as partly endogenous, in that they, too, are path-dependent and behaviour-dependent: 'it is the very process of approaching any one attractor which may well change the value of the attractor itself' (ibidem). By this, the entire process being modelled may become excessively cumulative and 'hyper-selective', depending almost exclusively upon initial conditions and opening the door to a new sort of 'technological determinism', similar in principle, though in a different theoretical context, to the old determinism of the production function approach (Gaffard 1986; Camagni 1986a).

Emphasizing perhaps a teleological element of a more subjective nature, I might better utilize the concept of an attractor to indicate the final goal assigned to technology in a specific historical phase of the capitalist society, which informally leads the incremental development of technological innovations. Goals of this kind may be found in the full exploitation of economies of scale and division of labour in the 'fordist' society, and in the attainment of full managerial control over the production conditions in the information and flexible automation society (Camagni 1986b) (see, for an example, in the latter case, the choice of programmable vs. 'play-back' factory automation technologies in the 1950s at MIT, clearly inspired by the objective of limiting the labour-force responsibility, which highly constrained the trajectory thereafter).

4.3 Uncertainty and the Innovation Process

In spite of these and other difficulties, the new approach to technological change in industrial economics brings important insights on the genetic elements of technical advances, in a way that in my opinion highlights the role of spatial variables in this context.

The key concept in this respect is that of *uncertainty* in its different forms. Uncertainty, and the correlated presence of imperfect ‘information’, prevents a pure price mechanism from allocating resources in an optimal way and driving economic activities to any kind of competitive equilibrium. In fact, as Arrow has shown (Arrow 1974), uncertainty can be incorporated in a competitive equilibrium system only by assuming an equal (imperfect) access of all individuals to the same information, a condition which, in the presence of highly differentiated firm sizes, market structures and spatial situations, is to be considered as highly unrealistic.

In their economic behaviour and decision-making processes, firms face five important kinds of uncertainty:

(i) static uncertainty coming from an ‘information gap’ linked to the complexity, the width and the cost of the information collection activity; in the real world, the firm is usually left with a huge lack of relevant information on the occurrence of already known events;
(ii) static uncertainty, coming from an ‘assessment gap’ linked to the difficulty of inspecting ex-ante the qualitative, mainly hidden, characteristics of inputs, components, production factors, technical equipment;
(iii) static uncertainty coming from a ‘competence gap’, linked to the firm’s limited ability of processing and understanding available information; the existence of technical problems whose solutions are obscure are an example of this wide category of situations;
(iv) dynamic uncertainty coming from the so called ‘C-D gap’ (competence-decision gap); uncertainty in this case involves the impossibility of precisely assessing the outcomes of alternative actions, even in presence of full and free information on past events, due to the complexity of the decision problems themselves and inherently imperfect foresight. The probability of choosing a wrong or inferior technology is therefore large;
(v) dynamic uncertainty coming from a ‘control gap’: the outcomes of present actions depend in fact on the dynamic interaction among independent decisions of many actors on which the firm has by definition a minimum control.

All these forms of uninsurable uncertainty and, in particular, the dynamic ones call for mechanisms of reduction of the general cost they imply. The firm therefore has to develop new and specific functions, rules, routines and procedures which are not considered in the conventional neoclassical theory of decision-making under conditions of perfect information, but which emerge indirectly from the new evolutionary approach to technological change. These functions are designed to

Table 4.1 Uncertainty and firms' behaviour: functions and operators

Sources of uncertainty	Type of uncertainty	Functions involved	Traditional instruments for coping with uncertainty	Outcomes	New "Operators"
Information gap (imperfect, costly information	Static	Search	Technology monitoring	Formation of beliefs on state-of-the-world	Local Environment or 'Milieu'
Assessment gap (presence of hidden characteristics	Static	Screening/ signalling	Quality control/ certification		
Competence gap (imperfect information, processing ability)	Static	Transcoding	R&D	Know-how acquisition	
Decision gap (imperfect assessment of decision outcome)	Dynamic	Selection	Decision routines/ managerial style	Decision	
Control gap (imperfect control on others' decisions)	Dynamic	Control	Hierarchy	Reduction of complexity	Firms' networks and network-Firms

cope with each specific type of uncertainty, and may be listed as follows (Table 4.1):

(i) search functions and procedures regarding information collection, information organization, technological monitoring;
(ii) screening functions of market signals and inspection of hidden characteristics with regard to inputs and equipment; signalling functions and quality certification with regard to outputs;
(iii) transcoding functions, which translate external information into a language that the firm may understand. These functions are perhaps the most critical, though widely overlooked by economic theory, in that they control the process of inter-firm know-how transfer and information appropriation. Utilizing codified information, both freely available or costly, and merging it with tacit and informal information, transcoding activities convert a chaotic and unordered 'information' flow into a firm-specific 'knowledge' and possibly into potential business ideas at the disposal of the managerial decision-making. The main aim of the R&D efforts should be considered under this

new perspective, rather than on the traditional and naive perspective of the 'invention' task (Foray and Mowery 1988);

(iv) selection functions, governing the proper decision-making process through the adoption of decision routines and firm-specific management styles (Nelson and Winter 1982);

(v) control functions, aiming at a drastic reduction of the complexity of the external environment, through an expansion of the power limits of the firm. Long since, Williamson has pointed out that the most likely firm strategy in presence of limited rationality, imperfect markets, dynamic uncertainty and risk of opportunistic behaviours is an expansion of the 'hierarchy', through acquisitions, mergers and any other form of equity participation in the direction of both customers/supplier firms (vertical integration) and competing firms (horizontal integration) (Williamson 1985).

The first two types of functions address the creation of the firms' 'beliefs on the state-of-the-world' under conditions of imperfect information, and are implicit in the behavioural models proposed by recent neo-classical approaches to decision-making under uncertainty such as search theory, market-signalling theory and the economics of qualitative uncertainty (Hey 1979; Spence 1973; McKenna 1986). The third kind of functions, the 'transcoding' ones, control the process of technology transfer to the firm and the development of its internal know-how: they are hidden, mainly tacit functions and processes, often overlooked by economic theory, as mentioned before.

The fourth and fifth kind of functions, selection and control, project the firm into a truly dynamic context, and aim at reducing complexity both in the decision procedures and in the external context itself.

The instruments utilized within all the previously mentioned functions in order to reduce uncertainty and complexity (information monitoring, quality control and certification, R&D, decision routines and equity control) may be labelled as traditional in that they stem from a standard interpretation of the firm as an *individual* agent, clearly separated with respect to all other agents, interacting with its external environment only through the canonic (but abstract) 'operators' of *markets* (and market transactions) and *organizations*.

But these operators have proved to be highly inefficient, particularly in a dynamic context, one which is relevant in the perspective of technological change; therefore, some new, though equally imperfect, operators have to be found and added, both at the theoretical level and at the level of the real firms behaviours.

These new '*operators*', performing different but parallel tasks and, in particular, the task of 'reducing the degree of uncertainty in dynamic behaviours, may be found, in my view, in the *local environment* (the '*milieu*') and in cooperation networks among firms. Both imply specific functions, procedures, costs and risks, as will be clarified in the next section, and are linked by the nature of their genetic principle: synergy and collective action, as opposed to (market) competition and (organizational) *power*.

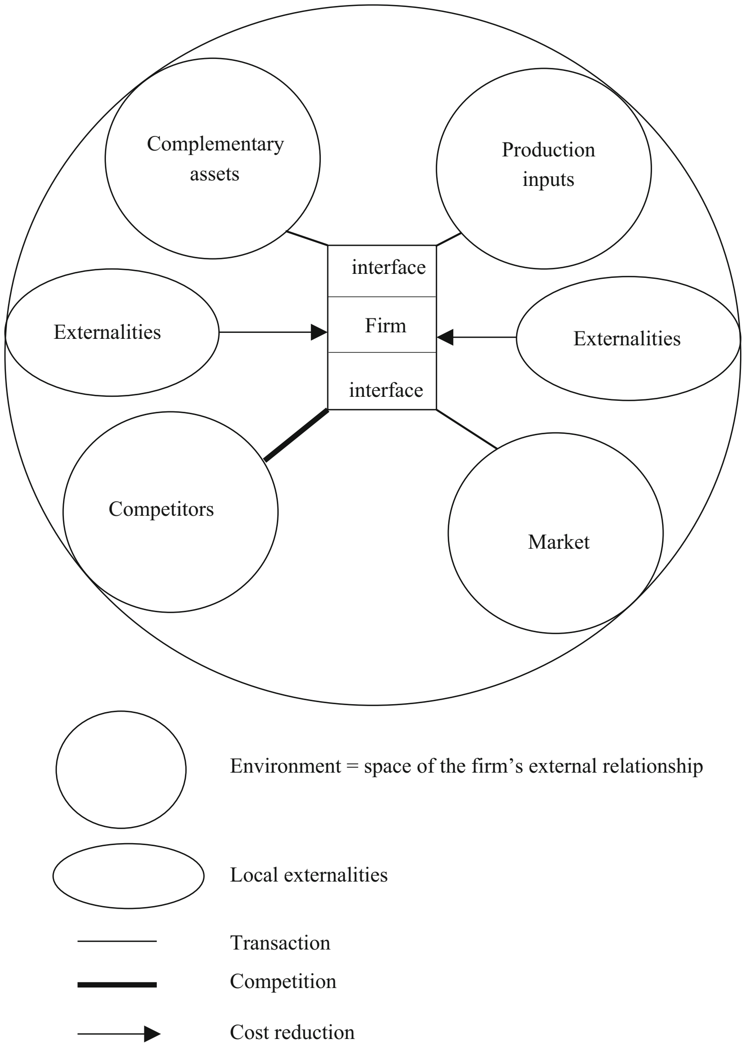

Fig. 4.1 The firm and its environment in a condition of perfect information and a static setting

4.4 The Firm and Its Local 'Milieu'

In a world of free and perfect information, the boundaries between the market and the organization (firm) are clear and stable; in fact, in the case of zero information and transaction costs, these boundaries are defined only by the shape of the organizational cost curve (Fig. 4.1). In order to communicate with the external environment, the firm utilizes internal interface functions like marketing and procurement offices.

But the presence of inescapable static and dynamic uncertainty in the real world and in particular in the process of innovation and technical change implies the presence of:

– extra-costs ('use costs of the market', in Williamson's terms), and therefore
– new functions to cope with these costs, as seen before, and therefore
– new 'operators' or institutions organizing these functions and shaping factual behaviours, beyond perfect markets and hierarchies.

In my view, the *local environment* of the firm, or the local '*milieu*' as it is called by the GREMI Association approach (Aydalot 1986; Aydalot and Keeble 1988; Maillat and Perrin 1990) may be considered as one, and perhaps one of the most important, of these uncertainty-reducing operators. In general terms, the local 'milieu' may be defined as a set of territorial relationships encompassing in a coherent way a production system, different economic and social actors, a specific culture and a representation system, and generating a dynamic collective learning process (Crevoisier et al. 1990).

In our specific theoretical context, the 'milieu' performs most of the functions mentioned in the previous paragraph, in strict integration and 'synergy' with the firm, through a *collective and socialized process* allowing cost reductions and enhancing the effectiveness of the dynamic decision-making process of local firms (Fig. 4.2). In fact, the local environment performs:

1. a collective information-gathering and screening function, through informal interchange of information between firms operating in the same markets, signalling of success decisions on markets and technologies, public or cooperative monitoring on factor markets and technical change, selection of information channels through repeated experience and 'memory' ('*search function*');
2. a function of '*signalling*' in the direction of the market of local firms, in terms of product image and 'reputation', cooperative advertising, and supply of a sort of 'quality certification';
3. a *collective learning process,* mainly through skilled labour mobility within the local labour market, customer-supplier technical and organizational interchange, imitation processes and reverse engineering, exhibition of successful 'climatization' and application to local needs of general purpose technologies, informal 'cafeteria' effects, complementary information and specialized services provision ('*transcoding function*');
4. a *collective process of definition of managerial styles and decision routines,* through managerial labour mobility, imitative decisions, cooperative decision-making through local industrialists' associations, complementary innovation processes ('*selection function*');
5. an *informal process of decision coordination,* through interpersonal linkages (families, clans, clubs, associations), easier and faster information circulation on innovative decision-making, easier financial-industrial linkages, similar cultural background of decision-makers ('*control functions*').

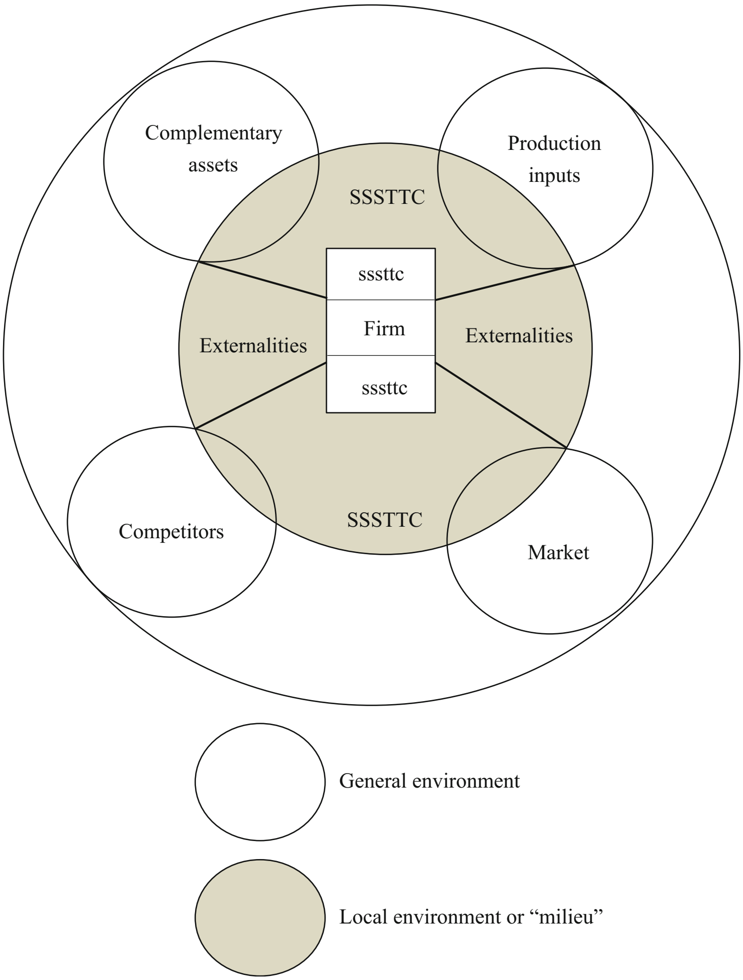

Fig. 4.2 The local and external environment of the firm and their functions in a dynamic setting. SSSTTC = uncertainty—reducing functions performed by the "milieu": search, selection, signaling, transformer, transconding, control, sssttc = uncertainty—reducing functions performed by the firm (same)

Beyond these functions, linked to specific kinds of static and dynamic uncertainty, another important function is performed by the local 'milieu', contributing to enhancing local firms' effectiveness and innovativeness:

6. *a function of conversion of external energies* to the needs of local firms, this function being particularly important in the labour market, human capital and educational sphere: in fact, not only is information decoded and collectively

organized, but also potential energy, as represented by availability of generic production factors, is channelled and trans-formed in order to match with the qualitative claims of actual and potential demand of the local structure (‘*transformer function*’).

In the abstract neo-classical scheme, all these functions are performed automatically by the market. But, as we have mentioned earlier, many difficulties emerge for the firm, even in a static context, in the form of lack of transparency, the presence of hidden qualities in the products (the market is full of ‘lemons’, whose characteristics are discovered only after purchase), opportunistic behaviours, imperfect knowledge of the codes and channels by which information may be gathered. In a dynamic context, which is the most important in the context of technology and innovation decisions, these difficulties are amplified, the signalling function of the market becomes weak, and the utilization of routines, the reference to widely accepted beliefs, the effort to control the decision-making process of the other actors becomes an inescapable must for the firm. The local ‘milieu’ may be considered under this respect as an extension and a specification of an ‘organized market’, where not just quantities and prices are fixed but also institutions, real actors, languages and codes interact with each other.

Consequently, the definition that may be proposed of the ‘milieu’ or the local environment is that of a collective operator reducing the degree of static and dynamic uncertainty for the firms by tacitly or explicitly organizing the functional and informational interdependence of local actors and informally performing the SSSTTC functions (search, signalling, selection, transcoding, transformer and control) (Fig. 4.3).

As far as the function of signalling and the parallel formation of accepted ‘beliefs’ in the case of quality uncertainty or dynamic uncertainty are concerned, it is important to remember that even in mainstream neo-classical models an explicit condition for the existence of an equilibrium solution is the good matching of the two elements (signals and beliefs) (McKenna 1986, Chap. 8). The local milieu, through repeated experience and localized ‘memory’, performs exactly this function, attributing reliability to signals and spreading the acceptance of a common vision about the state-of-the-world.

From all the preceding arguments it becomes clear that ‘proximity matters’; and in fact, it does in a threefold way:

(i) because of the presence of local resources of human capital, that are quasi-immobile with respect to the external territory and highly mobile within the local territory; their presence accounts for much of the local collective learning process and in so far as it contributes in effect to the enhancement of productivity of local firms and to the creation of a local external “image”, it cumulatively reinforces itself through polarization effects and attraction of external firms (the example of Silicon Valley is enlightening in this respect; see Gordon 1989a);

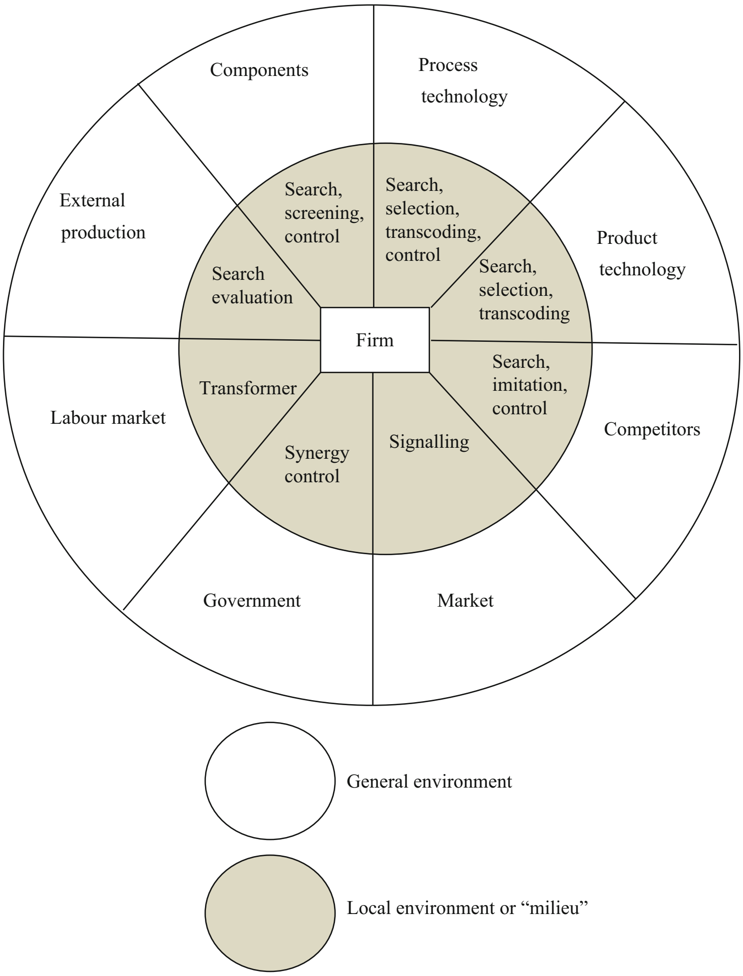

Fig. 4.3 Main uncertainty-reducing functions performed by the 'Milieu'

(ii) because of the presence of an intricate network of mainly informal contacts among local actors, building what Marshall called an 'industrial atmosphere' within industrial 'districts', made up of personal face-to-face encounters, casual information flows, customer-supplier cooperation and the like (see the contributions of Stöhr, Perrin, Quevit, Gordon and Dilts, Camagni in the Gremi publications);

(iii) due to the presence of synergy effects stemming from a common cultural, psychological and often political background, sometimes enhanced by the effectiveness of some local 'collective agent'; the common cultural roots are highly important in that they contribute to the establishment of tacit codes of conduct, to the decoding of complex messages (Lundvall 1988) and to the formation of common 'representations' and widely shared 'beliefs' on products and technologies (Planque 1983; Crevoisier et al. 1990).

All these territorial and proximity elements explain why innovation creation and diffusion is highly enhanced in those special territories such as big metropolitan areas, industrial districts, 'valleys', 'corridors' and 'parks'. In particular, they explain the very nature of agglomeration economies and their role in the early, information-intensive phases of product life cycles, and in the 'incubation' of small firms which are particularly unarmed with respect to uncertainty. It may be affirmed that if the existence of uncertainty in its multiple forms raises the minimum efficient firm size, the presence of an information-rich and synergetic local 'milieu' performing an uncertainty reducing function allows this efficient size to stay low enough to let small firms survive and prosper.

It is interesting to note that other branches of the social sciences have long since arrived to similar conclusions, even if not taking in direct consideration the territorial aspects of the theoretical problem. In particular, organization theory, organization psychology and strategies choice theory have highlighted the important relationships between the individual actor, the organization and its 'context' in a world characterized by uncertainty (Johannisson 1987). This approach has been used to analyze, *inter alia,* the locational decision-making process of the firm. 'An adequate model for understanding policy making must start with the individual and its many types of *fallibility,* but it must also take into account the *collective* situation in which executives function' (p. 274; our italics).

What is called the 'context of operations' allows the individual to overcome the inescapable presence of (static) uncertainty in the process of gathering and interpreting of information, supplying him both with 'current views of bow situations should be classified' and 'current objectives and appreciation of constraints'. The consequent picture of a dynamic process of interaction and mutual modification of the 'context' and the 'organisation' (a 'system learning process' in Townroe's words) is theoretically similar to the collective learning process taking place in our model within the local *milieu.*

4.5 Networking

4.5.1 Definition

The effectiveness of the local 'milieu' as an uncertainty-reducing operator has its limits, however.

Some of these limits are implicit in the nature of the relationships that constitute the milieu itself. These relationships are mainly informal and tacit relationships, operating better on information circulation and on imitating behaviours than on more direct linkages among economic actors. Therefore, the role of the milieu becomes weaker when control functions are directly concerned (as can be seen in Fig. 4.1).

Secondly, the behaviour of the milieu, even if it can be considered as the outcome of a collective learning process going far beyond the possibilities of individual firms, is subject to explicit risks of aggregate and generalized decline, especially in the case of very specialized and homogeneous local structures. The crisis of many specialized old industrial areas in the 1960s and 1970s, bit by sectoral crises (iron and steel, ship-building, textile and motor-vehicle regions in the UK, Belgium, the United States, Germany) and the present crisis of a new success area like Prato in Italy are examples of how local know-how and synergies may be unable to face big dynamic changes in markets or technologies. By the same token, diseconomies of scale and environmental problems may well overcome urbanization advantages in big metropolitan areas in particular historical circumstances.

Therefore, endogenous and exponentially growing locational costs, which may be considered as the opportunity cost of utilization of the 'milieu', and evident limits in the static or dynamic performance of the 'milieu' itself, push towards the creation of a new organizational and behavioural model, a new 'operator' enhancing the control capability of the firm upon its turbulent environment (Boissevain and Mitchell 1973; Johannisson 1987; Kamann and Nijkamp 1988).

This new operator, superior in some respects to the local 'milieu' and the synergies it may develop, and intermediate between (market) competition and (organizational) power, may be found in inter-firm *cooperation;* its specific behavioural model is the 'network firm'. With this new model—occurring through joint ventures, strategic alliances, consortia, technical cooperation, cross-commercialization, licensing and franchising agreements—firms obtain access to important complementary assets, markets and technologies without incurring organizational or locational costs (which are typical of internal growth strategies), and free themselves from the limits of local (and internal) competence. In addition, through this strategy a wider control is acquired on both technological trajectories and competitors' conducts.

In our view, a 'network' may be defined as a closed set of selected and explicit linkages with preferential partners in a firm's space of complementary assets and market relationships, having as a major goal the reduction of static and dynamic uncertainty.

Network relations, of a mainly informal and tacit nature, exist also within the local environment, linking through *open* chains, firms and other local actors as we have seen before. Our proposal is, nevertheless, to use the term 'network' ('réseau') only in the case of explicit linkages among elected partners and to refer to the former as 'milieu' relationships (Fig. 4.4).

At first sight, cooperation and networking on a trans-regional or trans-national basis represent a sound alternative to the exploitation of local synergies and seem to annihilate space in both its geographical and its relational dimension. In fact, 'certaines analyses se réfèrent à la notion de "réseau" pour caractériser une organisation de la circulation entre entreprises de plus en plus affranchie de la matérialité d'une configuration spatiale locale; l'organisation "en réseau" marque le

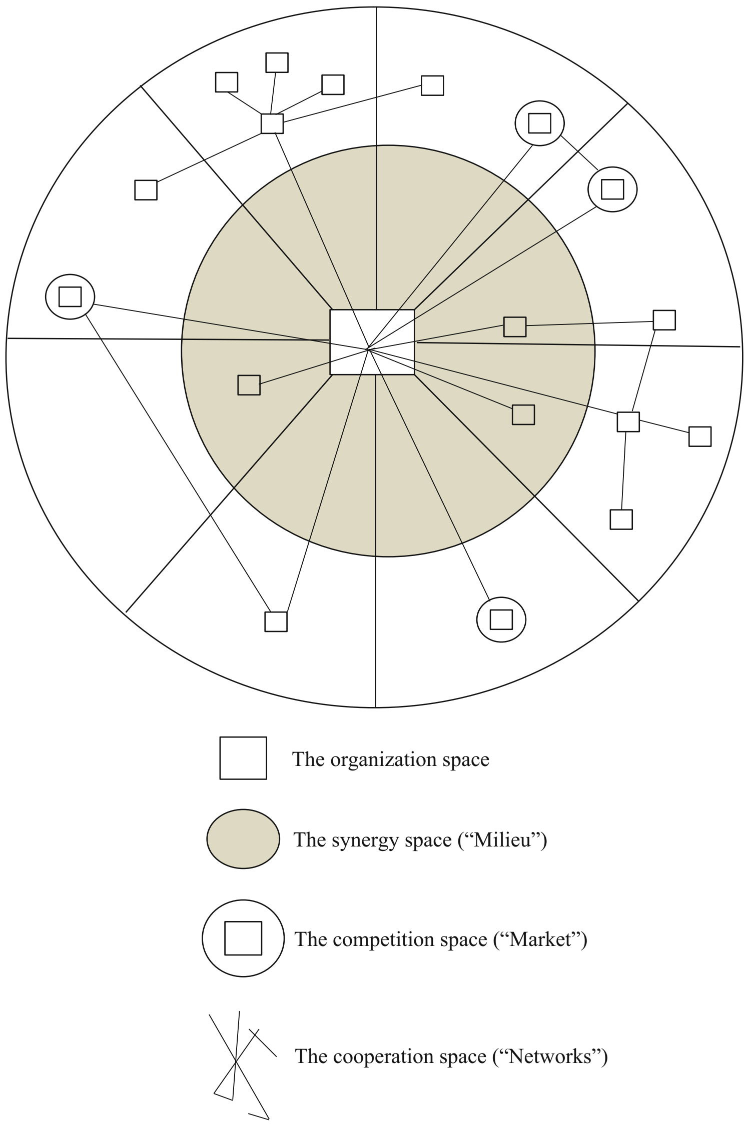

Fig. 4.4 Networking and the external environment of the firm

passage d'un espace de place à un espace de flux, ou encore celui d'un espace topographique à un espace topologique' (Plan Urbain 1989). We will come back to this issue later on.

4.5.2 Relevance

The most important fact at this moment is to recognize the increasing or booming utilization of those new forms of external development by firms of various sizes, particularly in those areas of production characterized by fast innovation and technological change like electronics equipment, telecommunications, semiconductors, software, and factory automation devices; in a word, the 'information technology' sectors. This new empirical evidence has to be considered and included in all theoretical framework addressing the interpretation of technological and spatial development.

Up to now, due to the relative originality and novelty of the process, the relevant and already rich literature has mainly been addressed towards field inquiries or descriptive and taxonomic reflections (among the most recent: Foresti 1986; OECD 1986; Vickery 1988; Chesnais 1988; Camagni and Gambarotto 1988). The main conclusion of the fertile debate may be summarized in this way:

- cooperation agreements represent new forms of international competition, intermediate between market resort and hierarchy, taking place within oligopolistic sectoral structures;
- they are specific to a context characterized by the emergence of a new technological '*paradigm*', that of the information technologies, featuring *pervasiveness, technology convergence* and fast innovation processes;
- they have as final objectives the traditional ones of *profitability* and *market power,* to be gained through:
  - synergies and economies of scale in production, marketing and R&D;
  - scope economies and product differentiation;
  - cross fertilization and development of technological complementarities;
  - the increase of a fast-reaction capability to external shocks;
  - the control over those innovation assets that define future application patterns of information technologies;
  - the formation of new kinds of entry barriers (proprietary standards).

The possibility of incorporating the new 'network' behaviour in established economic models depends on the nature of the goals pursued by the firm. In this respect, we may distinguish three broad categories of goals:

(A) the first category encompasses the goals of achieving *scale and scope economies,* through the merging of R&D facilities and resources, distribution channels and variety of products. This is the more traditional behaviour, easily interpreted in terms of standard microeconomic theory. Networking and strategic alliances in this case prove superior with respect to traditional behaviours such as equity participation and mergers in that they allow limited cooperation in well-defined fields or 'partial merging', leaving aside the possibility of competition in other fields (this element is important in the case of big conglomerate and multi-division firms).

(B) A second and more important category of goals regards the stable utilization of complementary assets, the control of specific technologies and market channels, *avoiding the costs of search, screening and decoding* complex information and the uncertainty elements involved. Thus, we are back to the first three kinds of static uncertainty defined earlier, and we are therefore able to include networking and cooperation agreements within the same theory of evolutionary firm behaviour.

The new behavioural model overcomes the high use-cost of the market, or the high transaction costs which are caused by the presence of market imperfections and episodes of market failure; transaction costs may in fact be defined as 'the opportunity costs of any localized inefficiency in prices to deliver correct signals' (Antonelli 1987a). In addition, the presence of important 'intangible assets' stemming from long internal learning processes prevents any localized technical progress from being easily transferred by means of simple market transactions (Camagni 1989) and calls for closer cooperation between the donor and the accepting firm.

Cooperation may be considered as imposing itself as the most efficient firm conduct with respect to market resort or internal development at high levels of transaction costs and organizational costs (Fig. 4.5). A third element to be considered in this picture is the appropriation regime of the technology concerned, in that a tighter appropriation condition, stemming from intrinsic complexity or from the presence of institutional barriers like patents, may emphasize the case for direct cooperation.

(C) The third category of goals are the most interesting ones: they regard the dynamic behaviour of the firm directly and confer the cooperation agreement a true nature of 'strategic' alliance. Here the objective is not just the control over a given technology or a given stock of complementary assets, but rather *the control over the optimal development trajectory of these assets or technologies*. The agreement regards products which do not yet exist, and it seeks to control the processes that are considered as crucial for their conception and attainment.

It is evident that in such a new context, which fits perfectly with the original and innovative characteristics of cooperation agreements and network behaviour, theories based on static efficiency and also transaction-cost approaches seem completely useless. Future profits stem from a series of strategic decisions, oriented to fast-reaction and continuous innovation, to the early pre-emption of newly discovered market niches, to an aggressive marketing policy in order to discourage potential competitors. All these decisions are projected in a dynamic framework, incompatible with merely static approaches of allocative efficiency: markets (which do not yet exist) and (routine-oriented) organizations are intrinsically unable to produce the right signals on prices and the right standards for costs.

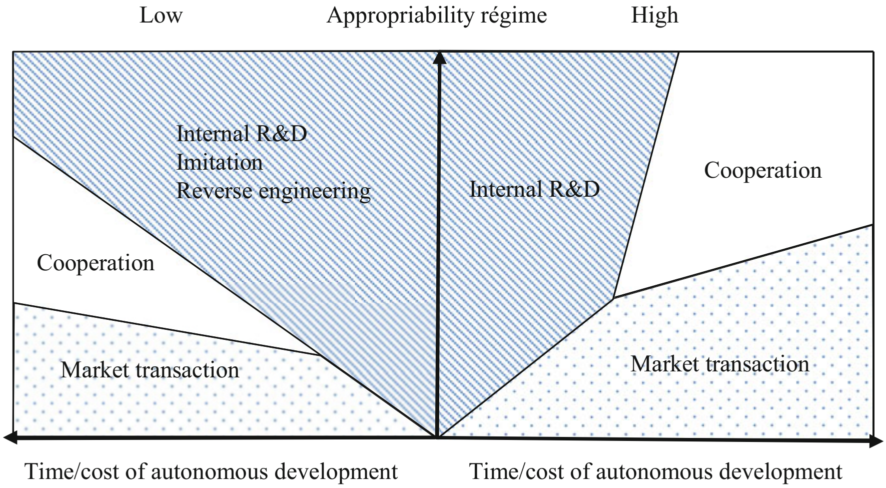

Fig. 4.5 Alternative firm strategies in technology acquisition. Source: Adapted from an idea by Teece and Pisano (1987)

On the contrary, the theoretical areas which it would be useful to address seem to be the analysis of strategic competition, negotiation theory and the theory of cooperative and non-cooperative games (Raiffa 1982; Jacquemin 1987). In fact, the concept emerging from this view is that of 'strategist firms that by force or by bluff try to control in a dynamic process their rivals and their environment to their own advantage. They calculate, anticipate, and invest in irreversible capital, thus segmenting markets, increasing their rivals' costs, tying up their suppliers and their clients, and manipulating information' (Jacquemin 1987, pp. 123–124).

We are now back to the second type of uncertainty defined earlier, namely dynamic uncertainty, not just created but explicitly enhanced by the decentralized decisions of independent actors. Under these conditions, cooperation may stem tacitly from collusive behaviours (as in the prisoner's dilemma with repeated games: history and memory are once again important!) or derive from the explicit choice of the firm, trying to reduce the complexity of its decision parameters and to enhance the control on some of its supposedly strategic assets (and on their time trajectory).

4.5.3 Collective Operators

A fourth behaviour space (and a fourth operator) is therefore at the firm's disposal, beyond the *organization space* (growth by internal development and acquisitions), the *competition space* (market transactions), and the *synergy space* (the local 'milieu'): we have called it the *cooperation space* and 'networking' represents its related behavioural model (Fig. 4.4).

Two problems will be faced hereafter which may derive from the theoretical scheme hitherto presented: the relationships between the two new ‘operators’, namely the ‘milieu’ and network cooperation, and the difference between our approach and the transaction-cost approach applied to territorial analysis.

As can be seen in Fig. 4.4, ‘milieu’ relationships and network relationships appear as complementary and mutually reinforcing ‘operators’, the former linking the firm to its contiguous environment through mainly informal, tacit (and often even overlooked and apparently unappreciated) relationships, the latter linking it explicitly to selected partners in its operational environment.

Both operators bring an element of ‘socialization’ into the picture of economic behaviour stemming both from the collective learning process, happening at the local scale, and from the cooperation nature of network linkages: ‘innovation does not emerge from the singular efforts of entrepreneurial firms or corporate research centers, for the contributions of individual actors are themselves produced within linkage networks that are collective in character and retain a critical territorial dimension’ (Gordon 1989a). Firms’ networks work as a sort of ‘collective participation’ to the process of appropriation of quasi-rents and innovation profits stemming from the cooperative behaviour (Allen 1983; Antonelli 1987b). The explicit nature of network and cooperation linkages may, at first glance, obscure the importance of local relationships and leave the researcher with the impression of a collapse of the concept of space, both in its geographical and relational meaning, into that of trans-territorial networking. On the contrary, the two concepts and related ‘operators’ are deeply interlinked and complementary.

On the one hand, the ‘milieu’ has to open up to external energy in order to avoid ‘entropic death’ and a decline in its own innovative capability; firm networks seem the most important instruments (but hardly the only ones) to cope with the problem. On the other band, when choosing a partner to link up with, not only does the firm choose a single partner, but also a ‘collective’ one (speaking allusively), at the same time linking itself with a ‘local’ culture and acquiring partial access to the synergies of its ‘milieu’. A link-up with a firm located in Silicon Valley is more a link with the Valley itself than with a special firm, with which, if otherwise located, no agreement would probably be made.

Sometimes, for example, in the Third Italy or once again in Silicon Valley, the territorial specificities are so profound and crucial for the process of innovation and technical change that it might be rightly claimed that ‘firms tend to be relatively contingent manifestations of technical projects developed in the region’s professional culture’ (Gordon 1989a).

Will these new territorial and trans-territorial relationships be properly analyzed through the concepts of the Williamsonian Institutionalist School, and in particular, through the transaction-cost approach? As we have seen before, many of these concepts were in fact utilized in the preceding theoretical framework and recently some interesting works have considered agglomeration economies showing up in industrial ‘districts’ and urban areas as the outcome of transaction cost-reducing processes (Lambooy 1986; Scott and Angel 1987; Cappellin 1988).

The transaction-cost approach and the approach proposed here are, in fact, similar in some respects in that both point out the role of information and information gathering costs in determining allocative efficiency, and give spatial proximity (or networking) the role of reducing these later costs. Nevertheless, in spite of the fact that information represents the bridge between static and dynamic behaviours, the transaction-cost approach remains basically a static one, addressing itself more to problems of allocative efficiency and design of organizational structures than to problems of dynamic efficiency and innovative behaviour. Through the related concepts, static but not dynamic uncertainty may be understood.

In fact, between the two general operators of market and hierarchy, there lies the possibility of inserting a third one, cooperation, using the same Williamsonian general framework. However, in this case only the more traditional firm behaviours and goals may be grasped, those pertaining to complementary assets control. In contrast, the true dynamic objectives of 'strategic alliances' and their innovation enhancing role remain obscure in this context (Gordon 1989b; Camagni 1989). Furthermore, with respect to the general uncertainty-reducing role of the 'milieu', a transaction-cost-reduction hypothesis seems rather limiting and prevents us from truly incorporating spatial variables into an evolutionary theory of innovation and technical change.

4.6 From the Firm Space to the Technology Space

The problem now is how to model the previous relationships in explicit dynamic terms, passing from the space of single firms deciding upon innovation, to the space of competing and evolving technologies. In a word, passing from a (micro-economic) adoption perspective to a mesa-economic perspective of technological diffusion.

Two main theoretical approaches may be followed, while still remaining within the context of ecological-evolutionary models:

(A) an approach which, once again drawing from the biological analogy, we may call a *selection approach,* looking at the competition between mutually exclusive technologies and their '*substitution*' in space; and
(B) an approach which we may call *a mutation approach,* looking mainly at problems of true *technological creation* within the context of development and diffusion.

The alternative stems from a mainly theoretical consideration of the nature of the technological evolutionary process: a process of competition between species or between already known technologies on the one band, and a process of mutation and technology 'creation' along a trajectory of evolving (vintage) techniques as well as through changes of trajectories. From a modeling point of view this difference blurs a little because potential advancements in technology have to be, in one way or another, pre-defined into the space of the possible outcomes of the evolutionary process.

The first category encompasses mainly (but not exclusively) deterministic models considering and simulating a process of dynamic 'adjustment to an equilibrium condition where the most profitable technology completely replaces the competing ones. The second category encompasses mainly stochastic models of search and innovation creation, building mainly on a self-organization approach and on the consideration of collective learning and cooperation processes.

It is important to say that an explicit consideration of space and spatial relationships is still lacking in the relevant literature, as a sort of trade-off seems to exist between the inclusion of spatial variables and the explicit consideration of evolutionary processes. Simplifying assumptions are therefore generally adopted in spatial models which limit their heuristic capability.

4.6.1 Selection Models

In Table 4.2 a taxonomy of historical approaches to technological diffusion is presented according to the two dimensions previously proposed.

The main concern of non-orthodox models of technological selection is to explain the existence and causes of the lag structure of adoptions. At the firm level, the most comprehensive analysis of the process is made by Scherer (1980), introducing the variability among firms in the two variables determining the adoption (and the adoption time): *relative profitability* of the new technology (depending on factor price differences among firms, the depreciation share of the existing equipment, etc.) and *adjustment costs* from the old to the new technical structure (here, inter-firm differences come from R&D commitment, internal labor relations in case of labor-saving technologies, managerial capability in handling the organizational aspects of change).

In determining the right timing for adoption, firms have to consider both the extra costs of an anticipated adoption and the profits which may come from market niches completion and early adopter strategy (Scherer 1980, p. 427; Cappellin 1985).

Recently, an interesting insight into the problem of understanding the causes of the slow pace of technological adoptions of advanced and profitable technologies came from Heiner's works (1988a; b). Even in a world of perfect information and no adjustment costs, if there exists what we previously called C-D uncertainty (a gap between competence and decision) and consequently the possibility of decision errors, the 'optimal' strategy for the firm will be one of imperfect, delayed and sluggish adjustment to changing external technological possibilities.

At the 'meso' level of the diffusion of competing technologies and their mutual substitution, the main approaches through which the process has been modeled may be sketched as follows:

Table 4.2 Some ecological–evolutionary models of technological development

	Dimensions		
Approaches	Firm (adpotion)	Technology (diffusion)	Space (spatial diffusion)
Selection models (technology substitution)	Adoption of a new technology: (a) Presence of adjustment costs (Scherer 1980) (b) Presence of imperfect decisions and expectations Heiner (1988a, b)	Competition between known technologies (a) Profitability Gibbons and Metcalfe (1989), Iwai (1984) (b) Adopters heterogeneity and perfect information David (1975), Davies (1979) (c) Information exchange between technologies Sonis (1986) (d) Dynamic learning Metcalfe (1981), Camagni (1985)	(a) The firm level Cappellin (1985) (b) The single technology level Hagerstrand (1967), Camagni (1985), Capello (1988)
Mutation models (technology creation)	Evolutionary models (a) Search and decision-making models Nelson and Winter (1982)	Self-organisation models (a) Stochastic models of technology evolution Jimenez Montano and Ebeling (1980), Silverberg et al. (1988)	Urban self-organisation models (a) Urban innovation Camagni et al. (1986: Soudy 1) (b) Urban synergies Camagni and Diappi (1991: Soudy 3)

– deterministic adjustment models where *relative profitability* is the central element for convergence towards the best technology: this process may stem from the simple reinvestment in the same technology of the higher profits it allows or come from investment shifts from technology i to j, according to higher relative profitability of technology j and to its market share (acting as an information element) (Iwai 1984);
– equilibrium adjustment models with *adopters heterogeneity* and instant-perfect information: reaction characteristics among the potential adopters may come from size and efficiency diversities (David 1975) or be stochastically distributed as in probit models (Davies 1979);
– dynamic models of *information interaction* between technologies; in the most advanced model of this family (Sonis 1986) the time variation of the relative market shares of different competing technologies is linked to the interaction of an anti-symmetrical 'competition' matrix A presenting the values of an iterated game among technologies (the effects of the adoption of technology i on j with an 'information' matrix M presenting the information which originate from the adoption of i and go to j). The substitution curves generated by this interaction are proved to be generalized logistics, and from their empirical estimation in simplified cases, an estimation of the two matrices is made possible. Particularly interesting is the fact that the superior technology (gaining in the competitive game) defines the asymptotic shares of all technologies through the information

it releases on them (Colla and Leonardi 1984). Differently from 'mutation' models, matrices A and M, and consequently also the characteristics of the competing technologies in time, are assumed as constant;
– dynamic models where endogenously determined variations in the price of *the new technology* and *learning processes* of their adopters determine a shift in the size of its adoption potential (Metcalfe 1981) or where this potential more simply evolves through a logistic expansion of the number of sectors or firm size classes interested by the technology (Camagni 1985).

All these models bear only an implicit spatial dimension. When this dimension is made explicit, as in the well-known Hägerstrand model (1967), the simplified assumption of equal contact probability of all actors, underlying all epidemic diffusion models, is made. This assumption highly reduces the coherence of this approach: a spatial context is in fact characterized by the opposite condition of differentiated profitability, adjustment costs and willingness to accept risks. A possible escape from this problem could be that of fitting single models in different but homogeneous regional spaces, and to interpret lag and diffusion speed parameters in a second step on a cross-regional base (Camagni 1985; Capello 1988).

4.6.2 Mutation Models

More recently the element of technology evolution and technology 'creation' along the diffusion path has been taken into full account through stochastic models incorporating Schumpeterian innovation. The technological frontier evolves in time in a way that is only imperfectly anticipated by firms.

Still from Table 4.2 we see that in this case the natural quotation as far as the behaviour of the single firm is concerned, is the work by Nelson and Winter (1982, Chap. 9) on *evolutionary search behaviours*. Here the firms, dissatisfied with actual profit levels, may enter a process either of imitation of existing external technologies or a process of search on a metric space of potential technologies (ordered in terms of distance with respect to the present know-how of the firm).

Dynamic self-organization models have enlarged the view from the firm space to the technology space. A 'master equation' approach, defining the change in the probability of finding a specific distribution of technologies at a given time, may give us the evolution of the entire spectrum of actual and potential technologies, starting from the individual transition probabilities of technology imitation, improvement, creation (Jimenez Montano and Ebeling 1980; Silverberg 1988). Perhaps the most advanced attempt in this direction is the Silverberg, Dosi, Orsenigo self-organization model (1989) in which transition probabilities are modeled carefully in terms of both the choice of a particular vintage within a specific technological trajectory and the change of trajectory happening at certain points in time. These changes are a function of the evolution of the internal know-how and of an external 'public' skill made available to all actors.

The inclusion of spatial and collective learning processes allowing an easier innovation decision could easily be introduced in the model, allowing the transition probabilities to be influenced by the decisions taken in previous times by surrounding firms.

In a different context, one of interurban competition for innovating functions, a similar kind of self-organization model was presented some years ago (Camagni et al. 1986) where a master equation controls for the transition probabilities from a set of urban functions to an upgraded one, and urban size represents the control function in the same way as firm productivity does in the preceding models.

A further refinement of this model in the same logic was presented recently, allowing spatial synerg1es to explicitly affect the innovation probabilities of each area (Camagni and Diappi 1991). Synergies may come from vertical, 'filière-type' integration or from horizontal interaction among similar productions, two elements that represent an early quantitative treatment of the spatial relationships which produce an innovative 'milieu'.

4.7 Conclusions

'*Technological progress is in the first instance the reduction in uncertainty*. The product of a research and development effort is an observation on the world which reduces its possible range of variation' (Arrow 1969). Nobody could have stated in a more concise and effective way the central role that uncertainty plays in any theory of technical change.

The main point made in this paper is that the inescapable presence of static and dynamic uncertainty in any dynamic model of economic behavior calls for the development of specific 'operators' that, well beyond pure market and hierarchy, may limit its paralyzing impact on firms dynamic behavior, complement the imperfect signaling function of the price system, organize a viable learning process for both individual firms and society and enhance their creativity potentials.

Two important 'operators' of this kind are found, on the one hand, in the local 'milieu' or the 'synergy space' that it potentially represents, and on the other hand, in the 'cooperation space' and the possibility of trans territorial network linkages between firms. Both these operators act as uncertainty-reducing devices, performing the functions of information searching and screening, signaling, transcoding of complex messages, selecting appropriate decision routines and controlling other actors' economic conduct, in a collective and socialized way.

The territoriality of the first operator is apparent, as proximity plays a necessary (but not sufficient!) role in the creation of local synergies. The second operator, that apparently departs from a strict territoriality, in fact also bears a territorial nature: in fact, the assets firms bring into the network agreement are often the outcome of a complex local culture and of localized social learning processes.

Therefore, on the one hand, territorial relationships and the local 'milieu' emerge as necessary and crucial elements in the innovation process; on the other hand, a proper vision of the evolutionary process of technology creation has led us towards the construction of a new, intrinsically dynamic interpretation of economic space. From a modeling point of view, dynamic self-organization models seem to be the most apt in incorporating the new approach and its related concepts into an operational and coherent mathematical framework.

Acknowledgement I am indebted for useful comments and suggestions on an earlier draft of the paper to many friends and colleagues; among them, I am particularly grateful to Olivier Crevoisier, David Keeble, Linda Kimball, Alfred Thwaites, and Peter Townroe.

References

Allen RC (1983) Collective invention. J Econ Behav Organ 1:1–24
Antonelli C (1987a) New information technology and industrial organisation: experiences and trends in Italy. OECD, Directorate for Science, Technology and Industry, Mimeo, Paris
Antonelli C (1987b) Dall'economia industriale all'organizzazione industriale. Econ Polit 2:277–320
Arrow K (1962) Economic welfare and the allocation of resources for invention. In: The rate and direction of inventive activity. NBER, Princeton University Press, Princeton
Arrow K (1969) Classificatory notes on the production and transmission of technological knowledge. Am Econ Rev 1:29–35
Arrow K (1974) The limits of organisation. W.W. Norton, New York
Aydalot P (ed) (1986) Milieux innovateurs en Europe. Gremi, Paris
Aydalot P, Keeble D (eds) (1988) High technology industry and innovative environments: the European experience. Routledge, London
Boissevain J, Mitchell J (eds) (1973) Network analysis: studies in human interaction. Mouton, The Hague
Boyer R (1986) La Théorie de la Régulation: une Analyse Critique. La Découverte, Paris
Camagni R (1985) Spatial diffusion of pervasive process innovation. Pap Proc Reg Sci Assoc 58:83–95
Camagni R (1986a) Dinamica Industriale, Tempo, Memoria. Economia e Politica Industriale 51:159–166
Camagni R (1986b) The flexible automation trajectory: the Italian case. In: Arcangeli F, David P, Dosi, G (eds) Paper presented at the international conference on innovation diffusion, Venice
Camagni R (1989) Alleanze Strategiche: Nuove Comportamenti e Nuovi Approcci Teorici. Economia e Politica Industriale 59:255–265
Camagni R, Diappi L (1991) Soudy 3: a supply oriented urban dynamics model with innovation and synergy effects. In: Boyce DE, Nijkamp P, Shefer D (eds) Regional science. Springer, Berlin
Camagni R, Gambarotto F (1988) Gli Accordi di Cooperazione Come Nuove Forme di Sviluppo Esterno delle Imprese. Economia e Politica Industriale 58:93–138
Camagni R, Diappi L, Leonardi G (1986) Urban growth and decline in a hierarchical system: a supply oriented dynamic approach. Reg Sci Urban Econ 1:145–160
Capello R (1988) La Diffusione Spaziale dell'Innovazione: il Caso del Servizio Telefonico. Economia e Politica Industriale 58:141–175
Cappellin R (1985) Regional factors in productivity growth. In: Camagni R, Cappellin R (eds) Sectoral productivity and regional policy, document. Commission of the European Communities, Bruxelles
Cappellin R (1988) Transaction costs and urban agglomeration. Revue d'Economie Régionale et Urbaine 2:261–278
Chesnais F (1988) Technical cooperation agreements between firms. STI Rev 4:51–120

Colla L, Leonardi G (1984) Modelli di Diffusione dell'Innovazione. In: Camagni R et al (eds) Cambiamento Tecnologico e Diffusione Territoriale. F. Angeli, Milano

Crevoisier O, Maillat D, Vasserot JY (1990) L'apport du Milieu dans le Processus d'Innovation: le Cas de l'Arc Jurassien. In: Maillat D, Perrin J-Cl (eds) Entreprises Innovatrices et Réseaux Locaux. GREMI, Paris, ERESA-Economica

David P (1975) The mechanization of reaping in the ante-bellum midwest. In: Technical innovation and economic growth. Cambridge University Press, Cambridge

Davies S (1979) The diffusion of process innovations. Cambridge University Press, Cambridge

Dosi G (1982) Technological paradigms and technological trajectories. Res Policy 3:147–162

Dosi G, Orsenigo L (1988) Coordination and transformation: an overview of structures, behaviours and change in evolutionary environments. In: Dosi G et al (eds) Technical change and economic theory. Pinter, London, pp 13–37

Dosi G, Freeman C, Nelson R, Silverberg G, Soete L (1988) Technical change and economic theory. Pinter, London

Foray D, Mowery DC (1988) Industrial research and technological change: towards a new economic representation. In: Paper presented at the European Summer Institute of the RSA, Arco

Foresti J (1986) Une Toile d'Araignée se Referme Autour de l'"Industrie Européenne: Les Accords de Coopération Industrielle, Commission des Communautées Européennes, Mimeo

Freeman C (1988) Introduction to part 1. In: Dosi G et al (eds) Technical change and economic theory, Pinter, London, pp 1–8

Freeman C, Peres C (1986) Innovation, diffusion and new techno-economic paradigms. In: Arcangeli F, David P, Dosi G (eds) Paper presented at the international conference on innovation diffusion, Venice

Gaffard J-L (1986) Restructuration de l'Espace Economique et Trajectories Technologiques. In: Aydalot P (ed) Milieux innovateurs en Europe. Gremi, Paris, pp 17–28

Gibbons M, Metcalfe JS (1989) Technological variety and the process of competition. In: Arcangeli F et al (eds) The diffusion of new technologies. Oxford University Press, Oxford

Gordon R (1989a) Alleanze Strategiche e Socializzazione del Capitale. Economia e Politica Industriale 59:267–270

Gordon R (1989b) Entrepreneurs, firms and the social foundation of innovation. Sociologie du Travail 1:25–48

Hagerstrand T (1967) Innovation diffusion as a spatial process. University of Chicago Press, Chicago

Heiner RA (1988a) Imperfect decisions and organisations: towards a theory of internal structure. J Econ Behav Organ 10:29–55

Heiner RA (1988b) Imperfect decisions and routinized production: implications for evolutionary modeling and inertial technical change. In: Dosi G et al (eds) Technical change and economic theory. Pinter, London, pp 147–169

Hey JD (1979) Uncertainty in microeconomics. M. Robinson, Oxford

Iwai K (1984) Schumpeterian dynamics: an evolutionary model of innovation and imitation. J Econ Behav Organ 5:159–190

Jacquemin A (1987) The new industrial organisation: market forces and strategic behaviour. Claredon Press, Oxford

Jimenez Montano MA, Ebeling W (1980) A stochastic evolutionary model of technological change. Collectiv Phenom 3:107–114

Johannisson B (1987) Organising: the network metaphor. Int Stud Manag Organ 27(1):1–9

Kamann D, Nijkamp P (1988) Technogenesis: incubation and diffusion. In: Paper presented at the European Summer Institute of the RSA, Arco

Lambooy J (1986) Information and internationalisation: dynamics of the relations of small and medium sized enterprises in a network environment. Revue d'Economie Régionale et Urbaine 5:719–731

Lundvall BA (1988) Innovation as an interactive process: from user-producer interaction to the national system of innovation. In: Dosi G et al (eds) Technical change and economic theory. Pinter, London, pp 349–469
Maillat D, Perrin J-Cl (1990) Entreprises Innovatrices et Réseaux Locaux. GREMI, Paris, ERESA-Economica
McKenna CJ (1986) The economics of uncertainty. Wheatsheaf Books, Brighton
Metcalfe JS (1981) Impulse and diffusion in the study of technical change. Futures 13:347–359
Nelson R, Winter S (1982) An evolutionary theory of economic change. Harvard University Press, Cambridge, MA
OECD (1986) Technical cooperation agreements between firms: some initial data and analysis, Paris, May, Mimeo, pp 49
Peres C (1985) Microelectronics, long waves and world structural change. World Dev 3:441–463
Plan Urbain (1989) Les Entreprises et Leur Environnements: Flux et Réseaux. Consultation de Recherche, Paris
Planque B (1983) Innovation et Développement Régional. Economica, Paris
Raiffa H (1982) The art and science of negotiation. Harvard University Press, Cambridge
Scherer FM (1980) Industrial market structure and economic performance. Rand McNally, Chicago
Scott AJ, Angel DP (1987) Tue US semiconductor industry: a locational analysis. Environ Plann A 19:875–912
Silverberg G (1988) Modeling economic dynamics and technical change: mathematical approaches to self-organization and evolution. In: Dosi G et al (eds) Technical change and economic theory. Pinter, London, pp 531–559
Silverberg G, Dosi G, Orsenigo L (1988) Innovation, diversity and diffusion: a self-organization model. Econ J 98:1032–1054
Sonis M (1986) A unified theory of innovation diffusion, dynamic choice of alternatives, ecological dynamics and urban/regional growth and decline. Ric Econ 4:696–723
Spence M (1973) Job market signaling. Q J Econ 87:355–337
Teece D, Pisano G (1987) Collaborative arrangements and technology strategy. In: Paper presented at the conference on new technologies and new intermediaries, Stanford University, June, pp 33
Vickery G (1988) A survey of international technology licensing. STI Rev 4:9–50
Williamson O (1985) The economic institutions of capitalism. Free Press, New York