TECHNOLOGICAL COMPLEXITY AND INDUSTRIAL NETWORKS: THE INSTITUTIONAL DIVERSITY OF HIBRID FORMS OF GOVERNANCE

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Abstract

The article discusses the institutional diversity of industrial networks, associating this diversity with the 'complexity' of the technological environment in which these networks are inserted. The article begins with a discussion of aspects related to a methodological perspective based on the concept of 'industrial networks'. After that, a critical analysis of the transaction costs approach is developed, emphasising some limitations of this approach when we consider stimulus related to a complex and dynamic technological environment. Then, some elements associated with the technological diversity of the environment are used to characterise different "stylised models" of industrial networks. The main characteristics of those "stylised models" are also presented, emphasising the specificity of governance structure in each situation.

1 - Introduction

The recent literature about Industrial Economics has recurrently discussed the characteristics of inter-organisational configurations adequate to face the instability and complexity inherent to the economic environment. These studies show the emergence of multiple forms of productive and technological co-operation among firms. The intensification of co-operative links has induced researchers to focus on the complex interdependencies between firms in the economy, through the use of a 'network approach' (Gabher, 1993; Hakasson, 1989; Axelsson and Easton, 1992; Karlsson and Westin, 1994). The emergence of industrial networks has been discussed by analytical approaches that correlate the evolution and transformation of industrial structures to the simultaneous modification of the organisational forms in these environments. These networks can be conceived as an institutionally structured form which enable an efficient organisation of economic activities, through the co-ordination of systematic links that are established among firms inserted in productive chains.

Despite its usefulness as an economic concept that captures the increasing importance of co-operative links among firms, it is virtually impossible to define a generic model of industrial networks that can be applicable to different industrial contexts. Due to the institutional diversity of these networks, analysis about the phenomenon have usually opted to reduce the focus, through the selection of an analytical cut specifically oriented to particular aspects of them. In contrast with others cuts, we shall emphasise the specificity of technologies mobilised at the network level. Specifically, we suggest that industrial networks should not be understood as generic inter-organisational arrangements, but as institutional forms conditioned by the characteristics of technologies that have to be mobilised to make feasible the production in these environments The analysis developed tries to qualify the concept of 'embeddedness' (Grabher, 1993), in order to consider how technological patterns affect the internal morphology and the governance mechanisms of inter-organisational arrangements.

Two hypothesis are implicit in the analysis developed. The first is based on the assumption that the patterns of inter-firm co-operation are technology-specific. The second hypothesis assumes that industrial networks should be seen as institutional arrangements that require a complex integration of productive activities, competencies and knowledge. On this basis, it is possible to identify the main objectives of the analysis to be performed. The first involves the definition of an objective criteria to map the institutional diversity of industrial networks, specifically associated with the 'complexity' of the technological system in which they are inserted. The second objective involves the characterisation of 'stylised models' of industrial networks with basis in the criteria previously defined. The third objective involves the characterisation of the mechanisms of co-ordination - associated with specific governance structures - that can be observed in each kind of arrangement.

The article is divided in five sections, besides this introduction. Section 2 discuss some aspects related to a methodological perspective based on the concept of 'industrial networks'. Section 3 develops a critical analysis of a theoretical background widely used to discuss hybrid forms of governace - the transaction costs approach - emphasising some limitations of this approach when we consider stimulus related to a complex and dynamic technological environment. Section 4 discuss some elements associated with the technological diversity of the environment in which industrial networks are inserted that can be used to characterise different 'stylised models' of structures. Section 5 discuss some characteristics of those 'stylised models', emphasising the specificity of governance structure in each situation. Finally, a conclusive section (Section 6) identifies some investigation lines to be explored in the future.

2 - The concept of 'industrial networks' as an analytical cut

The concept of 'network' has been increasingly used in economic analysis. 'Network', by itself, is an abstract notion referring to a set of nodes, to the positions occupied by them and to the various links that connect these nodes. We can also associated the structure of a network with internal flows that are interchangeable between nodes through specific links. 'Network analysis' tries to describe the structure of links among nodes, the flows associated to these links and the location of the resultant arrangement into a socio-economic environment, as well as the undercurrent of its development and evolution. The network approach incorporates several ideas originally formulated in the modern sociological literature, which develops concepts in order to discuss the consolidation of social groups (Granovetter, 1995). The basic hypothesis of this analysis is that the configuration of present and absent links among actors inserted in social arrangements reveals specific structures. Relationships among actors in 'social networks' are supposed to perform an extremely important role, either from the point of view of social systems, or through the consolidation of cognitive patterns which guide agents behaviour.

In the field of economic theory, network analysis has been correlated to a theoretical perspective which stress a point usually neglected in neo-classical analyses: the social dimension of inter-firm relations. Contrasting with the neo-classical view, it is supposed that agents behaviour is affected by the social relationship structure they are inserted, which withdraws them from maximising rational actions, resulting in the acquisition of habits, customs and routines that decisively affect its behaviour. Network analysis is developed from a critic to the artificial division between the economic agent and the external environment. It is assumed, therefore, that this environment is institutionally structured, with a basis on social bonds among agents. Considering the relevance of these bonds, two implications can be singled out: (a) the behaviour of an agent cannot be disassociated from the others with which it establishes systematic interactions (as suppliers and customers); (b) the market should not be seen as an amorphous and abstract 'locus', but as an institutionally structured environment, which is gradually modified by the relationships and conducts of the agents. The concept of 'embeddedness' (Grabher, 1993) - traditionally used is this kind of approach - refers to influences established between the relationship structure and agents behaviour, associated with an economic environment with institutional specificity.

The network approach can be extended to the relations between firms in productive chains, being associated with 'industrial networks' in which the generic morphological elements of 'networks' - nodes, positions, links and flows - assume a specific character. The concept of 'industrial networks' mirrors not only the recuperation of themes approached by classical political economics - discussing the specificity of the 'division of work' among firms in an advanced capitalistic society - but also contributions from other fields of knowledge, with a basis in an interdisciplinary approach through which economics has absorbed concepts from other sciences that look functional for the understanding of economic phenomena. Network analysis tries to describe the structure of co-operative links among firms and its location into the economic environment, as well as the undercurrent of its development and evolution along time. Considering the usefulness of the concept, Axelsson stress that "*application areas can roughly de divided into two categories. First there are a number of general problems in economic life that could, as has already been demonstrated, be illuminated by means of industrial network studies, such as technological development, industrial change, economic performance, new market entry and the like. Second there are a number of a more specific industry or local market issues that could be elucidated, such as the role of activity and actor networks in high-tech versus mature industries, the role of social networks in different cultural settings, and change processes in tightly structured as opposed to loosely structured networks*" (Axelsson, 1993, p.239).

The concept of industrial networks presupposes that the nodes of the structure refer to firms with specific characteristics, while the relations which articulate them contain some tangible or intangible element of capital. We can observe the presence of firms with different characteristics inserted in these networks, which make joint investments and co-ordinate, with view to certain aims, their productive and technological activities. Those firms have asymmetrical characteristics - related to the consolidation of specific productive, technological and organisational competencies - which affect the possibilities of a mutual interaction among them. The consolidation of these arrangements implies certain investment efforts, resulting in specific sunk-costs to the relation and in rigidities that reinforce the links among firms along time.

Industrial networks consists not only of actors and relationships, but also of certain activities/resources. We can observe the integration of multiple activities (production, commercialisation, R&D etc.) at the network level, generating a functional interdependence that reinforces the cohesion of the arrangement. At this level, the analysis has to deal with the diversity of functional activities associated with network structure, involving a description of intra-network productive chains. Specifically, the interdependence between network members can be associated with a specific ‘division of work’ that connects the different activities performed by them. According to Johanson and Mattsson (1987, p.256), the internal ‘division of work’ of industrial networks performs a critical role, involving specific mechanisms of co-ordination, with the price mechanism being just one of several influencing conditions.

We can also stress the relevance of some ‘internal flows’ that connected the agents inserted in industrial networks. These flows involve two-way exchange processes which form the backbone of the networks (Easton e Lundgreen, 1993, p.90). They are responsible for the generation of internal stimulus that induce the strengthening and transformation of the structure over time. They involve not only tangible assets - associated to the transactions of inputs and products - but also intangible assets - such as information and tacit knowledge - that reinforce the connections and interdependencies between network members. We can observe the existence of recurrent transactions among network members, based on multiple contractual forms and on distinct temporal horizons. Those transactions generally involve specific assets, which, in order to be generated, require the integration of technical and organisational competencies. Considering this aspect, the analysis of the transactions established among network members can be seen as an important aim. Industrial networks also involve the consolidation of a pool of information shared among their members, requiring the assembling of language codes and communication channels, in order to transfer knowledge and competencies among them.

3 - Theoretical background: a critical view of transaction costs approach

In the theoretical level, the analysis of industrial networks can be articulated to critical revisions and attempts to sophisticate the traditional firm theory. These analyses look for capturing with greater exactitude the complexity of the firm as an economic agent, discussing its “openness” to external relationships. Evidences of industrial networks formation have been articulated to propositions made by a theoretical approach that stress the importance of transaction costs (Coase, 1937 ; Williamson, 1975, 1985, 1991, 1993) in the organisation of economic activities. This approach discuss the determinants of the process of vertical integration (related to a ‘make or buy’ dilemma), emphasising the characteristics of organisational structures which induce technical-productive efficiency in different contexts. The importance of technological aspects in transaction costs analysis is mentioned by Williamson, to whom a transaction can be defined as an operation which involves not only the transference of property rights of goods or services but also a technologically separable interface.

The analytical scheme developed by standard transaction cost economics can be associated with a distinction between the content of the transactions and the context in which they are realised. In terms of the transactions' content, the critical element to be considered is the specificity of assets involved. Different factors are usually mentioned as sources of assets' specificity. Nooteboom (1993), for instance, identifies six types of specificity: (i) investments which are specific with respect to the transaction, without being specific to the product exchanged, involving search costs, costs of marketing, investment in knowledge about the transaction partner, etc.; (ii) investments specific to the product (no alternative use for the asset) which is, in turn, specific to the buyer (no alternative demand for the product), resulting in no alternative use for the asset; (iii) situations in which the product is specific with respect to the technology used; (iv) situations of dependence linked to whether the supplier has other products and markets to fall back on, being specific with respect to the product; (v) specialised products without substitutes on which the buyer, along with other buyers, is highly dependent; (vi) situations in which the supplier may be so expert in the activity performed that buying becomes preferable to making, from the perspective of the buyer.

In transaction costs perspective, different institutional set-ups would be selected according to a cost-minimising criteria, which involves not only technical factors related to economies of scale but also an effort to reduce transaction costs usually present in market relations, which are particularly impacted by the 'specificity' of the assets involved. The original idea of an unequivocal distinction between market and hierarchy as institutional set-ups to be selected was modified to consider intermediate forms that frequently create frameworks for transactions, such as bilateral governance forms, based on mechanisms of "relational contracting", and trilateral governance forms, involving mediating third parties. The selection of an efficient 'structure of governance' would involve a minimisation of the sum of production costs and transaction costs, which are function of assets' specificity and organisational forms. Williamson assumes that assets' specificity (H) and organisational forms (O) are not mutually affected, in a way that for different levels of H assumed as given, a particular choice of O would lead to a minimisation of transaction costs.

The selection of an "efficient" form of governance could be related to a reactive behaviour of economic agents, in face of market signals that affect the conditions in which transactions are realised. If there are assets which are specific to the transaction, this will reinforce bilateral dependence between partners which yields transaction costs if there is risk of opportunism and if rationality is bounded. In a critical review of transaction cost perspective, Provan (1993, p. 841) emphasises that "*the uncertainties of market relationships coupled with bounded rationality of decision makers makes it likely that suppliers and buyers will seek to routinize their transactions by developing more established repeat relations with each other. However, such relations create mutual dependencies, based on what Williamson refers to as asset specificity and small numbers conditions. These conditions enhance the likelihood of opportunistic behaviour, or 'self-interest seeking with guile', resulting in intolerable transaction costs. When this happens, the market relationship will fail giving rise to* *a hierarchy (i.e. vertical integration). transactions then become internalised, eliminating the uncertainty of the market and protecting against opportunism through a formal governance structure*".

According to this view, industrial networks constitute "hybrid forms" of governance, localised between the integrated firm and the atomised market, which proportionate, in certain circumstances, an efficient co-ordination of economic activities (Thorelli, 1986; Jarillo, 1988; Williamson, 1991, 1993). Internal organisation ("hierarchy") is considered the best mode to co-ordinate economic activities under stable environment conditions, when there are significant internal economies of scale or scope involved. Otherwise, the market (associated to discrete arm's-length transactions) is more efficient in the case of standardised inputs and assets, since it allows a rapid adjustment to changing external conditions. However, the use of market becomes more problematic the more specific is the character of assets involved in transactions. In this perspective, industrial networks can be seen as an institutional form designed to overcome well known weaknesses of markets and hierarchies. Specifically, these networks would be associated to frequent transactions, with some degree of incertitude and which involve specific assets. Networks are assumed to be more stable than pure market relations but also more flexible than the internal organisation. Basically, they allow not only the realisation of "autonomous" adaptations - in face of suddenly changes of market signals - but also complex adaptations based on the co-ordination of different productive functions, which are divided among networks' members (Williamson, 1991; Guilloux, 1993). Network forms usually involve indefinite and sequential transactions, performed in a context of a general pattern of reciprocity. This pattern is associated to an undefined temporal horizon, more based on implicit obligations than in explicit ones. As a consequence, we can observe the consolidation of a strong interdependence among agents, distinct from the independence which prevails in commercial transactions and from the hierarchic dependence which prevails in intra-firms relationships. Along time, that inter-dependence allows the consolidation of a mutual orientation, which is manifested in a common language regarding technical matters, contracting rules and standardisation of process, products and routines.

The assembling of governance structures based on industrial networks requires an adaptation of behavioural principles which rule agents conducts. Inversely to the "opportunism" which directs the insulated firm actions, when it is inserted in those networks practices based on trust and in reciprocity of actions tend to disseminate among inter-firm relations (Ouchi, 1980). The strengthening of co-operation inside these networks would be related to the surpass of opportunism while a principle which orientates individual behaviours and to the consolidation of an intra-network environment based on socially built commitments (Williamson, 1991; Guillon, 1993). Those networks could be associated with different contractual arrangements, involving interaction and bargain processes among inter-dependent agents. These processes would result in the elaboration of "incomplete contracts" - not totally formalised - incorporating safeguards against excessively opportunistic postures, as well as adaptive mechanisms which guarantee the resolution of conflicts by negotiation. The dissemination of principles of trust in intra-network relationships could be explained by different factors: (i) the minimisation of “behavioural incertitude” associated to opportunistic postures; (ii) the reduction of costs associated to the assembling of contractual arrangements; (iii) the optimisation of the “division of work” inside the network, adjusting production scales and avoiding the duplication of efforts.

Some authors are critical about transaction cost theory interpretation of industrial networks. According to these critics, more than a “idealised” form of governance - localised between the integrated firm and the atomised market - industrial networks should be associated to different "transactional regimes" (Knorringa, 1994) and to a variety of “hybrid” forms (Menard, 1996). These forms would have its own specificity, related to a contractual basis which orients the interactions between network members and to a certain level of mutual trust that can be found in relationships. Basically, the consolidation of industrial networks could be seen as an evolution of relational contracting practices, based on inter-organisational dyads between buyers and suppliers mutually dependent. Along time, these practices would reinforce the interactions between agents and the interdependencies among dyads of relationships, conforming a structure (the network) with specific characteristics.

Despite the recognition of the importance of technological aspects as sources of assets specificity, the influence of these aspects in the creation of specific mechanisms of governance is not discussed in a systematic way by the standard view of transaction cost theory. A first aspect, particularly emphasised by Provan (1993), involves the predominant focus of transaction cost perspective on dyadic exchanges. In fact, traditional transaction cost perspective does not consider that such exchanges are often embedded in a broader network of technological links, in a way that the emergence of opportunism in anyone dyad would be based solely on the characteristics of that dyad, without considerations about technical interdependencies with other agents and activities. In the alternative perspective proposed by Provan, the structural properties of a network create incentives for co-operation and long-term commitment. According to him, the following factors related to “network embeddedness” constrain the opportunism in dyadic relationships: (1) the dependence of a supplier on the dominant buyer in a buyer dominant network; (2) the indirect connectedness of a supplier to other suppliers in the network through the dominant buyer; (3) the direct connectedness of a supplier to other suppliers in the network, associated to the concepts of density (number of ties with other suppliers as a proportion of all possible network links); multiplexity (durability of ties to any network member) and intensity (relative importance to a supplier of its links with other suppliers); (4) the overall network interdependence, based on the embeddedness of all firms in the network, excluding the focal supplier.

The second aspect to be considered involves interdependencies that are usually present between the specificity of assets and the selection of different organisational forms with basis in efficiency’s criteria. In fact, the hypothesis that assets’ specificity and organisational forms are not mutually affected can not be seen as effectively realistic. When a firm opts by a process of vertical integration or by the establishment of bi-lateral relations with suppliers, the nature of productive and technological assets involved tends to be strongly affected. Specifically, adaptations that must be done in the productive orbit, to permit the integration of internal and external competencies, alter assets' specificity in a decisive way. This process tends to assume a cumulative (*path dependent*) character along time, due to internal learning mechanisms (associated with interactions between functional activities in a verticalized firm) or to interactive learning mechanisms that emerge from systematic relations with suppliers. Three main consequences of this dynamic can be stressed: (i) a kind of customisation and adaptation of productive assets according to the necessities of agents involved in systematic interactions, that naturally occurs as a sub-product of the deepening of interactive learning mechanisms; (ii) the development of productive, technological and organisational inter-dependencies between agents involved, which strongly affects the "rationality" that orients their decisions; (iii) the development of a self-reinforcing process of (inter) organisational forms along time.

The third aspect to be considered involves the relevance of technological aspects as determinants of assets' specificity. In this sense, some interconnections between the level of assets specificity and the evolution of the technological environment in which transactions are realised must be stressed. The first is specifically related to the "complexity" of the technological environment. Basically, TCT analyses the influence of technological complexity in the more general context of 'make-or-buy' decisions. Using product complexity as a surrogate of asset specificity, TCT has related the increase of technological complexity to the generation of stimulus to processes of vertical integration. On one hand, the complexity of components would increase the cost of writing complete contracts, resulting in higher costs of market contracting compared to internal organisation. On the other hand, for transactions whose output dimensions are difficult to measure, due to problems related to technological complexity, organisations in firms would tend to be more efficient. The basic critic that must be done to that analysis is related to limitations of agents' competencies in the context of technological complexity. In fact, these limitations strongly constrain the possibilities of vertical integration. Furthermore, the more complex is the technological environment, the more strong will be the interdependencies between productive activities. These interdependencies decisively impact the "specificity" of the respective assets, creating important stimulus to the realisation of systematic transactions between the agents that retain the competencies required.

The impact of new information technologies to the reduction of transaction costs, particularly in bi-lateral relations between buyers and suppliers, is another aspect usually mentioned in the discussion of inter-firm relations. Apparently, this reduction could reinforce the governance by the "market", because of the reduction of costs related to the search of efficient suppliers. Despite this fact, the tendency to the reduction of suppliers could be explained, according to Bakos e Brynjolfsson (1993), by the investments that have to be done to sustain bi-lateral relations. In fact, these investments tend to be increasingly complex, involving aspects related to the quality, technological level, certification procedures and customisation of components produced that can be hardly specified in trivial market arrangements. In this sense, despite the possibility of reducing transaction costs, the number of suppliers tend to be reduced because of the "non contractible" character of investments that have to be made.

Another important aspect of the technological environment in which networks are inserted is related to the “dynamism” of this environment. The more this environment is dynamic - and consequently uncertain - the more difficult will be the previous (*ex-ante*) definition of assets specificity, in order to orient the realisation of transactions. In fact, the continuous incorporation of technological innovations in products and components makes extremely difficult the realisation of a rational economic calculus to select the organisational form that permit the realisation of transactions in a more efficient way. In this sense, more than an efficient way to co-ordinate transactions, the assembling of inter-organisational links can be conceived as an efficient mean to stimulate innovative efforts. Based on autonomous instances that establish sophisticated relations among them, industrial networks could promote a balance between decentralisation and cohesion required to identify technological opportunities. By one side, those networks allow the creation of new knowledge. By the other side, they guarantee a greater reversibility of the collectively mobilised resources, allowing a better facing of uncertainty inherent to the technological environment.

The limitations of transaction cost approach in the context of a dynamic technological environment - in which relevant innovations are continuously generated - is also stressed in the critic of Lundvall (1993). The main aspect of Lundvall’s critic is based on the excessive focus of transaction cost analysis in the exchange of commodities, without giving the proper attention to interactive learning mechanisms as a fundamental aspect of the processes of production. In this perspective, the reasons why users and producers - or buyers and suppliers - may be reluctant to pursue a strategy of vertical integration go beyond the minimisation of transaction costs, involving two interrelated aspects: (i) the loss of flexibility in a turbulent and dynamic environment; (ii) the limited scope of interactive learning mechanisms that characterises integrated units.

4 - Industrial Networks and technological complexity: in search of a useful typology

In the last years, a wide literature has tried create comprehensive typologies of industrial networks. These typologies are based on different analytical cuts, utilising distinct criteria with the aim of characterising various kinds of structures. Despite the problems and caveats that are usually present in the construction of these kind of typologies, they can be used as an auxiliary device, in order to get a better understanding of the institutional diversity of network forms. Having in mind those limitations, this section will present some elements that might be consider in a typology that reflects the technological diversity of the environment in which industrial networks are inserted.

The possibility of enhancing inter-firm co-operation is strongly conditioned by the characteristics of technologies employed. According to Joly and Mangematin (1995, p.38), we can identify two general trends associated with the increase of technological complexity of the environment in which firms are inserted. The first is related to the increase of the complexity of production processes in terms of the number of inputs required, which causes an increase in the utilisation of external resources. The second trend is related to an increase in the set of knowledge and skills that must be integrated to make production feasible. Considering these trends, we can suppose that the more ‘complex’ is the technological environment in which the firm is inserted, the more important will be the access to complementary assets and competencies. In a ‘dynamic’ environment, the necessity of this will be still greater, due to technological changes that could affect the competitiveness of firms.

Lundgren (1995, p.77) emphasises the interconnections between the evolution of industrial networks and the technological environment in which they are inserted, stressing the importance of the interplay between technological systems and network structure and evolution. The concept of ‘technological systems’ seems particularly useful to characterise the technological environment in which industrial networks are embedded. Carlsson and Stankiewicz (1991) correlate the concept of ‘technological systems’ to interactions of agents in a specific industrial area that can be associated to a particular institutional infrastructure or set of infrastructures, involved with the generation, diffusion and utilisation of technology. According to them, these systems should be defined in terms of knowledge/competence flows rather than flows of ordinary goods and services. We can combine the more ‘institutional’ definition of technological systems developed by Carlsson with other definitions that emphasise the intrinsic technological characteristics of those systems. Maisseu (1995), for instance, correlates the characteristics of technological systems with some properties of the product that has to be generated. Specifically, this product could be seen as a 'system product’ that may be understood as an organised complex whole, based on an assemblage or combination of parts forming a complex or unitary whole. A product is thus defined as a structured system revolving round a principle, being based on an aggregation of elements ordered with a view of fulfilling a previously defined objective. According to this view, a ‘system-product’ can be broken down into subsets defined with basis in a ‘functional’ classification. Considering their degree of complexity, these subsystems can also be broken down into components which are made up of elementary technical objects, defined according to a technological classification.

Considering the complexity of ‘system products’, Maisseu identifies three elements to differentiate the components and their embodied technologies: (i) the relevance (relative share) of the components in terms of the overall cost of production; (ii) the degree of maturity of technology embodied in components; (iii) the relevance of the component in terms of some criteria of functional performance (related to the utility and quality associated with it). According to these elements, four kind of components could be identified. First, we can identify *trivial* components, with little influence on the properties and quality of the product and to which the cost is relatively small compared with the total cost of the product. Trivial components are also based on mature technologies, widely available and hence commonplace. Second, it is possible to identify *basic* components with a considerable influence on the product. The total cost associated to these components plays an important place in setting product’s cost. They are also based on mature technologies mastered by a number of other competitors. Due to the standardisation of these components, any inefficiency in the provision of them negatively affect the performance of the product. Third, we can identify *critical* components, to which the function performed is extremely important to define product characteristics, properties and its final quality, without the cost of the component being necessarily dominant in the total cost. The embodied technologies in these components are usually in their early or fast growth stage, strongly affecting the performance of the product. Finally, a fourth kind of component, called the *key* component, can be identified, combining the different characteristics previously mentioned: its cost may be relatively high in the make up of total costs, its characteristics may be a determining factor in the functional performance of the product, and the distribution of its constituent technologies may still be limited because they are in their early or fast growth stage or because they are protected by patents.

Another important contribution to the understanding of technological systems can be found in the analysis of Lundgreen (1995, p.94). He uses concepts originally developed by David (1987) to associate these systems with the idea of ‘technical connectedness’ and with prospects of economic benefits from ‘system integration’. This definition stress not only some aspects traditionally associated to the performance of industrial activities - such as the presence of scale and scope economies in the production of inputs and goods and the relevance of different learning mechanisms - but also two other key-concepts: (i) technological interrelatedness, when the functioning of the parts is contingent upon the functioning of the whole system, creating a kind of ‘system’s indivisibility’; (ii) network externalities related to situations in which the value of a technology is dependent upon the total numbers of adopters.

The concept of “technological interrelatedness” can be directly linked to the ‘complexity’ of technological systems. Despite the difficulty to find a generally accepted definition of “technological complexity” in the literature, we may consider the relevant contributions of some authors. According to Singh (1997), three characteristics can be extracted from these contributions. The first is related to the ‘systemic character’ of complex technologies, which means that a complex product or technology comprises elemental units or components, usually organised in hierarchies of subsystems, in a way that the performance of the system is strongly dependent on the performance of its subsystems and components. The second characteristic involves ‘multiple interactions’ among system’s components, associated with feedback mechanisms in terms of technical performance - between components within subsystems, between components across subsystems and between subsystems at various hierarchical levels. The third characteristic is related to the ‘non-decomposable’ character of complex technologies, which can be found in situations where the product cannot be separated into its components without affect its performance.

According to Kline (1991), it would be possible to estimate an index of complexity of technologies and ‘sociotechnical systems’ by the aggregation of three measures: (1) the number of ways changes can occur within technological systems; (2) the number of items which must be decided to design the technological system; (3) the number of control modes in the technological system plus those that connect the system to its surrounding environment. The third measure seems particularly important, being associated with feedback mechanisms that result in system modification or adaptation. Henderson and Clark (1990), in an important work, deal with the same subject, using the concept of ‘product’s design architecture’ to define the patterns through which components and sub-systems interact with each other. Basically, they discuss the differences between four types of innovation associated with the morphology of industrial systems: (1) incremental innovations that introduce relatively minor changes to existing product, exploiting the potential of established design and reinforcing the competencies in both product architecture and component technologies; (2) modular innovations based on the introduction of a new component technology inserted within an essentially unchanged product architecture; (3) architectural innovations based on the reconfiguration of an established system to link together existing components in a new way, often triggered by a change in some components that creates new interactions and linkages with other components in the established product; (4) radical innovations that establish a new dominant design and, hence, a new set of core design concepts, embodied in components that are linked together in a new architecture.

Another interesting contribution to the characterisation of the ‘complexity’ of industrial systems can be found in a recent work of Sanchez and Mahoney (1996, p.66). Using the concept of ‘nearly decomposable system’ originally formulated by Simon (1962), they emphasise that product designs differ fundamentally in the degree to which they can be decomposed into ‘loosely coupled’ vs. ‘tightly coupled’ components. In this sense, ‘modularity’ would be a special form of design which intentionally creates a high degree of interdependence or ‘loose coupling’ between components, by standardising component interface specifications. Connecting the concept of ‘modularity’ which the notion of ‘product architecture’, Sanches and Mahoney define a ‘modular product architecture’ as a special form of product design that uses standardised interfaces between components to create a flexible product architecture. In terms of industrial networks, two analytical unfoldings can be identified in this perspective: (1) the standardised component interfaces in a modular product architecture provide a form of embedded co-ordination that greatly reduces the need of managerial authority to achieve co-ordination of productive flows and development processes; (2) the possibility of increase productive flexibility through different combination of new or existing modular components results in the need to co-ordinate a network of component developers and suppliers.

Based on this preliminary systematisation, some ‘stylised models’ of industrial networks can be characterised. Our hypothesis is that the complexity of ‘technological systems’ in which networks are inserted, particularly in terms of the architecture of products generated and of the interconnectedness of productive activities, performs a critical role, affecting the institutional form of the arrangement in a decisive way. Three types of industrial networks can be characterised: (i) *traditional products’ networks***,** involving non-complex products that can be produced in small-scale units, with a limited number of components integrated in a ‘non-complex’ architecture; (ii) *modular products’ networks* with a complex hierarchy of components and sub-systems, produced through mass-production processes; (iii) *complex products' networks*, oriented to the production of high-cost, engineering intensive capital goods that are produced as one-off items or in tailored batches - usually on a project basis - for individual customers.

5 - Mapping the institutional diversity of industrial networks

5.1 - Traditional Products' Networks

These networks involve productive chains with dense sub-contracting relations between assemblers and suppliers, being based on the principles of "flexible specialisation" (Piore and Sabel, 1984; Best, 1990). The functional specialisation of suppliers in different stages of the production cycle can be stressed as the main characteristic of this kind of arrangement. They are often associated with processes of vertical disintegration of firms located in specific points of the productive chain, which tend to induce the strengthening of interactions with suppliers. These networks usually involve three main actors: specialised suppliers (usually small firms), assembly firms (with different sizes and different levels of vertical integration) and dealers (which often act as co-ordinators of productive activities performed by small firms in the network). From a spatial point of view, they are usually associated with the traditional concept of 'industrial districts' (Marshall, 1920), which emphasises the potential benefits of a productive specialisation between firms located in the same geographical region. Specifically, the territorial agglomeration of small and medium-sized firms - through the formation of 'industrial clusters' - permits the exploitation of 'locational externalities' associated with technical services and facilitate the interchange of information between them. Examples of these kind of arrangement have been related to different industries, such as textile, shoes, furniture, metal craft and food. The model of 'Third Italy' industrial districts has been recurrently mentioned as an example of this kind of arrangement.

In a broader sense, these networks can be characterised by the low technical complexity of products generated (which can be produced in small-scale units) and by the simplicity of the knowledge that has to be mattered to generate a product accepted by the market. In fact, products generated through this kind of arrangement have usually low value, low volume and a simple design. They are usually associated with industries that do not deal with complex technologies and in which the main font of technical progress come from outside, involving the supply of equipment and other inputs. Products tend to present a high variety, based on different combinations of components, and are associated with high tolerance margins in terms of productive procedures and quality level. The high tolerance margins reflects the heterogeneity of products in terms of their technological level. Thus, situations in which products completely different in terms of technological level are obtained in the same industry are very common. Despite these differences, the products generated usually involve a limited number of components and are based on relatively simple ‘architectures’.

The ‘division of work’ inside these networks is usually based on the generation of economies of specialisation in the production of inputs, parts and components, in order to reduce production costs and to facilitate adaptations in the face of a volatile demand. Despite the possibility of others gains, the reduction of production costs tends to perform a critical role in the establishment of these networks. Specifically, they usually involve the generation of productivity gains in the production of components, associated with the technical specialisation of suppliers. The provision of technical services at the local level - seen as positive externalities that increase productive efficiency - tend also to be developed as a consequence of co-operative links between network members. We can also mention the generation of scope economies and productive flexibility at the level of assembly firms, due to the intensification of their interactions with a net of specialised suppliers.

The inter-organisational basis of these networks reflects the characteristics of the process of ‘flexible specialisation’. They typically involve relations between assemblers of non-complex products (shoes, textiles, etc.) and a network of firms responsible by the production of inputs, components, parts or by specific tasks in the productive chain. The possibility of separating the different technical tasks in these industries - due to the simplicity of product architecture - make easier the establishment of systematic relationships between network members. Sometimes, the emergence of these networks has been associated not only with strictly economic factors but also to specific conditions of the socio-economic environment around them. The embeddedness of these networks in localities with a specific industrial atmosphere generates a lot of benefits - such as the exchange of ideas, information, resources and goods and also the accumulation of technical skills and capabilities - making easier the generation of productivity gains and the adoption of collective actions that increase the efficiency of the arrangement.

These networks usually involve dispersed structures of ‘governance’ with low level of hierarchisation. They can be characterised as polycentric networks, in which the actors co-operate or compete with each other on a voluntary basis, through a set of vertical and horizontal relations that conform a particular interaction environment. They can be seen as an evolution of the traditional ‘putting out’ system, involving interactions mediated by pre-definition of orders that might be attended by suppliers. The co-ordination of internal flows involve two main alternatives. The first is based on a co-ordination promoted by external agents (dealers) through the definition of new designs that must be attended by suppliers. The second would be based on a co-ordination promoted by assembly firms at the end of productive chains, through the definition of orders. However, the two alternatives are usually based on short-term contracts that hardly include incentive mechanisms oriented to the generation of technical-productive gains in the orbit of the supply chain. As a general tendency, informational flows between assembler firms, dealers, retailers and distributors tend to be more relevant than the flows connecting these agents with the net of suppliers, which involve a non-systematic interchange of information about performance and quality of components. Informational flows usually assume a one-way direction in these networks, coming from dealers and assembly firms in the direction of a diverse net of suppliers. These flows also involve the previous definition of design and others products' attributes that must be attended by suppliers. Despite that, the volatility of market tendencies often impose the need for an efficient communication between assemblers (or dealers) and suppliers, in order to adapt some attributes of the components produced according to those tendencies.

5.2 - Modular Products' Networks

These networks involve a variety of actors that interact in productive chains, reflecting the sophistication of sub-contracting arrangements in mass-production environments. The main actors of these networks are large assembly firms, suppliers of sub-systems to be integrated in the final product (that are usually also large firms), suppliers of components and raw materials. Competitive gains associated to these networks involve not only the reduction of costs of components but also the increase of the variability of the range of products due to changes in the components integrated in a 'modular architecture'. As a consequence, relations between suppliers and assemblers have suffered important qualitative changes, inducing productive and technological co-operation. Examples of this kind of arrangement have been associated with changes that can be observed in the automobile industry and other assembly industries (computers, electronic equipment etc.), related to the incorporation of principles of modularity in the organisation of production and in the relations between assemblers and suppliers.

Products generated by this kind of arrangement have high value, high volume, high variety and technical complexity. They usually involve a complex design, based on a diversity of components and sub-systems integrated through linear-linked mechanisms. The integration of components is usually based on 'modular architectures' that permit different combinations of them in similar platforms, generating a large variety of products and attending the principles of 'mass customisation' (Pine, Victor and Boynton, 1993). The concept of mass customisation involves the production of varied and often individually customised products at the low cost of standardised, mass produced goods. Mass customisation could be seen as a more advanced stage of a continuous improvement process, linked to an architecture based on different modules, which can be rapidly integrated in the best combination or sequence required to tailor products.

Technical-productive gains that can be obtained in these networks are usually linked to the simultaneously generation of economies of scale and scope in the productive chain. According to Noori (1990), the concept of 'economies of integration' could be related to synergies whose dependence relies on the co-existence of scale and scope economies. To obtain these gains, it is necessary to focus on total value chain improvement, as well as substantial investments in productive co-ordination mechanisms and dedicated assets. Three aspects seem particularly important to achieve this kind of gain: (i) a sophisticated level of automation which allows for operation of CIM (computer-integrated manufacturing) systems; (ii) technological developments in product design, based on the increase of modularity of components; (iii) the sophistication of the manufacturing of sub-assemblies and parts.

The increase of reactivity in face of market changes is also an important aspect of technical gains obtained in these networks, being based on a productive flexibility associated with the diffusion of just-in-time practices in inter-firm relations and with the generation of a wide range of products with basis in the principles of modularity. This point is particularly emphasised by Coriat (1995, p.224-225) in a characterisation of 'regimes of variety', seen as flexible mass production systems that combine economies of scale and differentiation in such a way that they can manage both flexibility of demand and strategies of differentiated supply. The implementation of total quality control systems between assembler and suppliers is also a pre-requisite of the consolidation of this kind of regime. As a consequence, the performance of suppliers tends to be evaluated with basis in complex mechanisms, involving certification practices, carried out in accord with specific protocols that try to built new routines in the inter-firm relationships.

The *governance* structure of this kind of network is based on the central role performed by a core assembler positioned in the apex of the network. It is also very common that we find a hierarchisation of suppliers of sub-systems and components in different levels - first-tied suppliers, second-tied suppliers, etc - according to their technical expertise and to the intensity of their interaction with the core assembler. We can also identify different patterns of co-ordination of productive links according to the position of suppliers in different levels of the network. In fact, the closer of the core assembler they are in the *governance* structure, more intense and multidimensional will be the character of the process of co-ordination. When the process of exchange between suppliers and assembler gains a multidimensional dimension, the responses to inter-firm problems tend to become based on mechanisms of negotiation, oriented to a long-term logic of co-operation. We can also observe a tendency to a spatial agglomeration of assembler and suppliers, in order to facilitate the co-ordination of productive activities in the supply chain.

In these networks the mechanisms mobilised to co-ordinate the actions of firms (assembler and suppliers) are very complex. At the productive orbit, these mechanisms involve sophisticated methods of production planning and a widespread use of protocols based on just-in-time principles, with the subcontractor being perfectly integrated into the manufacture's production cycle (Coriat, 1995, p.218). The mechanisms of intra-network co-ordination also involve specific projects oriented to the co-development of new components and sub-systems between assembler and suppliers, as well as the management of the modular architecture used to generate a large variety of products. In terms of their contractual basis, the mechanisms of co-ordination are strongly based on long-term contracts with specific incentive mechanisms to stimulate the increase of productivity-quality of components generated.

These networks can be related to informational flows extremely sophisticated. Specifically, informational feedbacks from suppliers tend to be encouraged. Some aspects of this process might be emphasised. First, we can mention a continuous interchange of information about performance and quality of components and sub-systems between assemblers and suppliers. This interchange can be related to the consolidation of specific learning mechanisms at the architectural level that facilitate the improvement of existing products and the generation of new models with a basis on adjustments in the modular architecture. The co-development of new components and sub-systems results in an intensification of informational flows between assemblers and suppliers. Informational flows assume a two-way character, making use of a sophisticated informational infra-structure and being associated with the development of specific codes of communication.

5.3 - Complex Products' Networks

These networks involve productive relationships associated with the generation of single-customised 'complex products' through a process of systems integration. They are usually organised in a temporary project basis, involving a diversity of agents and institutions and being oriented to the production of high-cost, engineering intensive capital goods that are produced as one-off items or in tailored batches for individual customers (Hobday, 1997). The products generated present a high level of technical complexity, demanding the integration of different sub-systems and a integration of hardware and software. They are also extremely engineering intensive, involving a diversity of technical skills and complex interfaces between a hierarchy of sub-systems. The 'complexity' of products involves the integration of semi-autonomous sub-systems, sometimes based on very different technologies. Due to the diversity of sub-systems that must be integrated at the product level, these networks are usually associated with non-linear proprieties of architectures, with several points in which relevant innovations can be incorporated. Products generated also involve very low tolerance margins because they have to satisfy very demanding customers in terms of technical performance. Among the examples of this kind of product described in the literature, we can mention air-traffic control systems, aircraft engines, flight simulators, flexible intelligent buildings, manufacturing systems, mainframe computers, nuclear power plants, offshore platforms, robotics equipment and satellite systems.

These networks are created with the objective of integrating components, subsystems and software, in order to generate customised products that attend specific demands in terms of performance, capacity and reliability. Competitive gains are usually associated with high performance customised solutions that attend specific demands of sophisticated buyers. Among the technical-productive gains that can be obtained, we can mention: (i) the reduction of cost and lead-time of complex projects with the use of parallel engineering; (ii) specialisation gains in the production of sub-systems, due to the specialisation of suppliers; (iii) the increase of functional performance of products generated, through the integration of hardware and software; (iv) customisation gains based on a process of technical co-ordination promoted by 'systems integrators'. The productivity and efficiency of this kind of production are strongly linked to a experience in the management of complex projects, being based on the integration of multiple competencies and in horizontal interactions that permit a continual readjustment and redefinition of tasks. To make these adjustments feasible, the deepening of productive and technological co-operation between ‘systems integrators’ and an extensive network of suppliers of components and sub-systems seems to be crucial.

The ‘complexity’ of products tends to be reflected in the ‘institutional’ form of these networks. In fact, we can identify a diversity of actors that must be mobilised to make the production feasible. The main actors are firms that act as ‘systems integrators’, responsible for the integration of multiple competencies and for the co-ordination of the internal flows (tangible and intangible) of the network. The presence of a temporary network of suppliers of sub-systems, components and software is also an important characteristic of the arrangement. As the final aim of the network is to attend demands of sophisticated buyers, they also perform an important role in the network. We can also mention two other actors that, according to the circumstances, perform an important role in these networks. First, we can identify the presence of engineering firms that sometimes act not only in the co-ordination of specific phases of the process, but also as ‘systems integrators’ themselves. Second, there are government regulators that, in some circumstances, influence the management of projects, affecting important aspects of network *modus-operandi*.

The typical relations in these networks involve firms that act as ‘systems integrators’ and a network of suppliers of sub-systems. The ‘governance structure’ is relatively ‘fluid’, being based on specific projects with a transitory character, in which we can observe a previous definition of tasks to be performed by network members We can also observe a hierarchization of the ‘governance structure’ of the network, according to the diversity of components and sub-systems that must be integrated at the project level. Contrasting to others networks, the ‘governance structure’ tends also to be more ‘concentric’, with the suppliers of sub-systems directly linked to ‘systems integrators’. We can also observe a lot of horizontal interactions between technologies used in different points of the network. Despite the transitory character of the projects, firms inserted in these networks are supposed to establish systematic relationships among themselves in order to permit the mobilisation of resources as soon as it seems necessary. Specifically, these networks could be seen as ‘virtual’ task-forces that could be activated by systems integrators to realise new projects or to correct some aspect of projects already finished, due to specific demands of the buyers.

The co-ordination of internal flows is the main function of ‘systems integrators’. This co-ordination is strongly based on the use of project management techniques. The process of co-ordination usually involves few large transaction between ‘systems integrators’ and a net of sub-systems suppliers. Transactions tend to be based on incomplete contracts between the parts, involving negotiated prices that often act as ‘incentive mechanisms’ to the increase of productivity. In the process of co-ordination, we can also observe an intense use of information technologies and new software techniques, as well as techniques of ‘parallel engineering’ that increase the performance of the network as a whole. Contrasting with others networks, the importance of co-ordination processes goes beyond the improvement of the technical performance. In these networks, the process of co-ordination involves the establishment of productive and technological links that progressively induce the consolidation of a ‘new’ market, specifically related to the ‘complex product’ generated. In this sense, non-market mechanisms play an important role in the co-ordination of economic activities, which is based on inter-firm *ex-ante* co-operation, agreement and negotiation of technical issues related to the stages of design, development and manufacture.

The ‘complex’ character of products generated through these networks requires an intensification of informational flows between network members in order to permit an integration of multiple competencies and skills. Some characteristics of those flows may be pointed out. First, we can observe an intense involvement with the users of these products in order to define their needs and to customise the system. This involvement should start in early stages of the definition of the project and be maintained and deepened in the next stages. Second, we can mention the intense interchange of information about sub-system proprieties in the implementation of projects, which induces many horizontal links between ‘systems integrators’ and the net of suppliers. Third, there are informational flows with a two-way character specifically associated with project management techniques. These flows are particularly important to integrate some ‘intangible’ technologies at the network level. Finally, we can mention informational flows related to a sophisticated technical assistance developed between users and ‘systems integrators’, related not only to adaptations that permit an increase of products’ performance (incorporating a new software, for example) but also to an eventual replacement of the product by a new model.

6 - Conclusions: some analytical unfoldings

Some lines of investigation to be deepened in subsequent steps of analysis can be identified. The first involves a more theoretical discussion, emphasising how some concepts originally formulated in the transaction cost approach - such as the concepts of asset specificity, opportunism, relational contracting - can be used to describe characteristics of the ‘stylised models’ of industrial networks previously identified. The second line refers to the possibility of correlating the institutional changes of industrial networks to the evolution of the technological environment in which those structures are inserted. In fact, the possibility of industrial networks generating competitive gains for their members depends on the evolution of technologies that define the ‘best practices’ in each industrial context. The increase of the ‘complexity’ associated with the technological environment can result in relevant changes in the manner how systematic relations between firms are organised in these environments. To capture these changes, the deepening of empirical studies seems to be an important task.

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