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Pier Paolo Patrucco

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department of economics
"S. Cognetti de Martiis"

Via Po, 53 – 10124 Torino (Italy)
Tel. (+39) 011 6702704 - Fax (+39) 011 6702762
URL: http//www.de.unito.it

WORKING PAPER SERIES

THE EMERGENCE OF TECHNOLOGY SYSTEMS: KNOWLEDGE PRODUCTION AND DISTRIBUTION IN THE CASE OF THE EMILIAN PLASTICS DISTRICT

Pier Paolo Patrucco

Dipartimento di Economia "S. Cognetti de Martiis"

Laboratorio di Economia dell'Innovazione "Franco Momigliano"

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Università di Torino

THE EMERGENCE OF TECHNOLOGY SYSTEMS: KNOWLEDGE PRODUCTION AND DISTRIBUTION IN THE CASE OF THE EMILIAN PLASTICS DISTRICT[1]

Pier Paolo Patrucco
Laboratorio di Economia dell'Innovazione 'Franco Momigliano'
Dipartimento di Economia
Università di Torino
Via Po 53, 10124 Torino
Tel. +390116702767
Fax. +390116702762
pierpaolo.patrucco@unito.it

ABSTRACT. The emergence of technology systems is the result of interdependent dynamics of generation and diffusion of complementary bits of localised technological knowledge. Technological communication is the crucial element assessing the collective conditions under which technological knowledge is accumulated and diffused. The case study of the emerging Emilian technological system in the plastics sector shows that the synchronic and diachronic localised interactions among industrial dynamics, institutional R&D efforts and technological interrelatedness are the determinants of the systematic production, accumulation and distribution of localised technological knowledge, in turn explaining the origin and development of the technology system itself.

Keywords: Collective technological knowledge; Technological communication; Technology systems

J.E.L. classifications: O31, R00

1. INTRODUCTION

The analysis of the conditions, determinants and effects of the generation and distribution of technological knowledge has recently received increasing attention in the interdisciplinary field of the economics of innovation.

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Theoretical (Antonelli, 2001; Metcalfe, 1995 and 1998; Nelson, 1994 and 1998) and empirical (Metcalfe and James, 2000; Patrucco, 2001; Russo, 2000) contributions enquire the systemic and localised character of the dynamics of technological knowledge, appreciating the production and diffusion of technological knowledge as the result of industry-specific and region-specific interactions among technological, institutional and social factors (Clark, Gertler and Feldman, 2001; Swann, Prevezer and Stout, 1998; Storper, 1996 and 1997).

A preliminary body of understanding of the localised character of technological knowledge derives from three complementary streams in the literature on technical externalities.

Firstly, the MAR (Marshall-Arrow-Romer) externalities tradition argues that geographical concentration and specialisation in a single industry, coupled with local integration strategies, foster technical externalities to be generated, transmitted and accumulated by local firms. The emergence and growth of a local body of technological knowledge is the result of intra-industry and geographically well-defined flows of technical know-how. Secondly, the so-called Jacobs externalities tradition (Jacobs, 1969) alternatively gives prominence both to inter-industrial knowledge transfer among geographically proximate but technologically different industries, and to local economic differentiation in contrast with integration. Moreover, Jacobs stresses the role of cities and metropolitan areas as especially conducive for the effective exploitation of inter-industrial technical externalities and hence for the growth of local clusters of technological knowledge. Integrating the two approaches, Porter (1990) insisted on geographical specialisation as a factor stimulating the effective diffusion of technological externalities, hence the MAR externalities argument. However, the role of internal competition and hence of economic differentiation is seen as crucial in the growth of local technological clusters, that is the Jacobs externalities argument. Technological knowledge is now localised because of the local competitive interactions between firms in the same technical space. In this context, Porter emphasises the role of large firms as key actors in the local clustering of technological knowledge and innovation dynamics.

Although stressing different determinants of technical externalities in terms of industrial factors, such contributions make the point that the production and accumulation of technological knowledge is the result of peculiar and constrained interdependences between technical and geographical factors.

As a result of the increasing understanding of the localised nature of technological knowledge, three further sets of arguments have been underscored.

The first element stems from the analysis of the importance of external knowledge. The major achievement of this field of analysis is the recognition that firms able to establish interconnections with the plurality of relevant knowledge producers can take advantage from the complementarity between their internal knowledge base and external pieces of knowledge. Learning efforts make it possible to access and integrate different external knowledge bases even in contexts that are different from those in which they have been originally elaborated (Cohen and Levinthal, 1989; Griliches, 1992; Loasby, 1999; Richardson, 1998; Simon, 1985; Stiglitz, 1987 and 1997).

Second, and consequently, the strong collective character of the generation of technological knowledge has been appreciated. A growing field of studies in the economics, history and sociology of innovation points out that the production of technological knowledge shows the features of a process where firms are not simply involved in either isolated in-house R&D efforts or in productive relations within the supply chain. The production of technological knowledge is systematically characterised by interdependences among different, generic and idiosyncratic, bodies

of knowledge accumulated in different institutional, technological and social circumstances (Bijker, Hughes and Pinch, 1989; Gibbons et al., 1994; Latour, 1987; Stephan, 1996).

Technological knowledge is thus seen as coherent stock of fragmented pieces of information, partially owned by a variety of economic agents (Malerba, 1992). Now technological knowledge is the result of the systematic accumulation, integration and recombination of such dispersed and yet complementary, internal and external, tacit and codified, pieces of knowledge (Antonelli, 1999).

Therefore, the key role played by explicit communication opportunities and established communication channels in the build-up of such collective dynamic of technological knowledge is the third element to be stressed. The opportunities for individual actors to affect and, at the same time, capitalise on the localised base of technological knowledge rest crucially on the ability to implement and carry on effective communication channels. Geographical and technological proximity, but even institutional and social proximity favour the existence of common norms, formal rules and institutions that support interactive and collective learning among complementary actors. The variety of firms and institutions and the diverse kinds of economic and social dynamics in which they are embedded account for a communication flow that is multilateral and takes place at different (industrial, technological, institutional and social) levels. Technological communication is the crucial element when assessing the systemic conditions under which technological knowledge is generated and distributed (Antonelli, 2000 and 2001; Antonelli and Quéré, 2002; Patrucco, 2002).

The production and distribution of localised technological knowledge is now the complex result of interdependences not only among specific industrial and geographical factors, but also among them and institutional and technological ones. The localised character of technological knowledge is now understood both in terms of technical and regional factors that co-define, technically and geographically, the peculiar, technological and institutional, features affecting the systemic generation and diffusion of the specific body of technological knowledge we finally observe.

Technology systems emerge as the result of such systemic complementarities governing the production and distribution of localised technological knowledge.

Therefore, the main purpose of this paper is to provide evidence to the way in which interdependences among industrial, institutional, technological and to a certain extent also regional factors, both synchronically and diachronically, are the determinants accounting for the generation and diffusion of localised technological knowledge and for the relevant emergence of technological systems.

1.1. Working hypothesis: the social embeddedness of local interactions

The paper presents the case study of the Emilian technology system clustering in the plastics sector.

Although starting in 1951 with lower levels of technological specialisation in the plastics industry if compared with the regional and national levels, in the long-term evolution the narrow area of Correggio has shown a huge dynamic of specialisation in the plastics production. Such increasing technological specialisation and the consequent accumulation of localised technological knowledge does not benefit from the location in a metropolitan area and is more and more distributed in small and very small firms.

First, technological knowledge is here localised because of technical factors. The long-term evolution of the industry in the Correggio district reveals the huge and restless specialisation in plastics technologies. Moreover, plastics technological knowledge in the Correggio district emerges

as the blending of the specific and path-dependent accumulation of chemical and mechanics bodies of knowledge. Second, technological knowledge is also localised because of geographical factors. Plastics production is more and more concentrated in a well-defined and very narrow area around the town of Correggio, at the core of the province of Reggio Emilia. Third, and more importantly, the systemic production and distribution of such localised technological knowledge emerge as the result of the co-evolution of interactive behaviours at the industrial, institutional and inter-sectoral levels, in turn determining the origin and development of a quite coherent local technology system.

These specific interrelations and the resulting processes of generation and distribution of technological knowledge benefit at large from the social embeddedness of such industrial, institutional and technological interactions. The specific location in the Emilia Romagna regional innovation system, and hence geographical proximity, represent the condition that favours trust, confidence and the sharing of the same communication norms and channels, in turn facilitating the socialisation of the diverse knowledge bases. Geographical factors are not *per se* a determinant of the dynamics of collective technological knowledge but only because they account for the proper social and institutional conditions.

Empirical evidence from Italian regional systems of innovation (Evangelista et alii, 2001, p.16) confirms that the regional innovation system in the Emilia Romagna region is positively affected by the favourable context-specific conditions. These are represented by a plurality of collective actors and social conditions such as not only technology-transfer centres, business services, business associations, chambers of commerce and the local polity community at large; but also as the habit of co-operation among firms, the existence of long-term productive networks and an environment of trust among firms and among them and institutions. Such social and collective institutions are considered as important sources of technological information and knowledge distribution, especially in terms of informal and often personal linkages among firms and between firms and institutions. Informal contacts constitute the means through which practical and technical know-how is accumulated and spread in the region.

In other words, geographical localisation in a specific social context is a factor supporting the modes of knowledge production and distribution. The network of productive and institutional interactions governing the creation and diffusion of technological knowledge is strongly shaped by the local cultural and social climate (Brusco, 1982). Specific and localised informal norms, trust conditions, personal relationships, and the structures and processes of the political system affect the way in which economic actors share economic behaviours, more or less formal communication practices and technical and non-technical know-how (Belussi, 1999; Belussi and Gottardi, 2000).

Technological knowledge, and especially its tacit components, can be exchanged because its production and distribution rely on a territorial base of common social norms. These kinds of interactions are often informal and not fully mediated by market mechanisms, but largely based on the connections of the societal structure and on the personal communication of tacit knowledge. Localised technological knowledge emerges in turn from the contextual set of social interactions determining the dynamics of collective learning (Lawson, 1999).

1.2. The methodology for empirical assessment

The paper provides an analytical interpretation of the evolution of the technology system developing in the plastics industry in the Emilia Romagna region, coupling quantitative and qualitative information.

The analytical approach adopted is 'appreciative theorising' (Feldman, 2001; Malerba et al., 1999; Nelson, 1994 and 1998). As Nelson put it, 'appreciative theorising tends to be close to empirical work and provides both interpretation and guidance for further exploration. Mostly is expressed verbally and is the analyst's articulation of what he or she thinks really is going on. However, appreciative theory is very much an abstract body of reasoning. Certain variables and relationships are treated as important, and others are ignored. There generally is explicit causal argument. On the other hand, appreciative theorising tends to stay quite close to the empirical substance' (1994, p. 500).

This choice finds the rationale in the fact that the generation and diffusion of localised technological knowledge is a very complex process, in which private companies, public bodies, collective organisations and social norms co-interact defining the peculiar features and paths of evolution of a specific body of technological knowledge, eventually leading to the development of a relevant technological change. Moreover, appreciative theorising gains momentum in the analysis of the geography of innovation and economic clustering because of the high level of social embeddedness of the collective process of knowledge generation and distribution. This means that the process of knowledge production and distribution incorporates tacit and practical know-how embodied in productive routines and is supported by institutions building formal and informal opportunities and channels for the communication process (Breschi and Malerba, 2001).

Such social, institutional and technical interdependences are complex by definition, not fully captured by formal models and may often be expressed only in qualitative terms. First, formal models cannot reduce or express the qualitative character of local interactions among technological, institutional and social factors, severely limiting their explanatory power of the regional dynamics of collective technological knowledge. Moreover, the context-specific historical evolution of such factors is also misrepresented by formal models, which underestimate the conditions and effects of the path-dependent process that underpins the dynamics of collective technological knowledge (Martin, 1999).

An historical and in-depth approach to the understanding of the peculiar and idiosyncratic interactions that lead to the emergence and evolution of learning processes and collective knowledge dynamics seems the proper methodology. The understanding of the dynamics of collective technological knowledge will guide the empirical analysis appreciating the role, in terms of complementary interaction, of industrial dynamics, institutional R&D efforts and technological complementarities that are embedded in the local network of social relations. In this perspective, the analysis should provide strong empirical content related to theory.

Concerning the quantitative aspects of the evolution of the Emilian plastic technology system, historical series have been elaborated on data provided by official statistical sources at the national (ISTAT – Italian Institute for Statistics) and local (CCIAA Reggio Emilia – Chambers of commerce of Reggio Emilia) level. The historical analysis of such data, provided in Section 2, confirmed the need for an in-depth investigation, at a more qualitative and descriptive level, of the evolution of the Correggio district.

Such second step was based on interviews with entrepreneurs which directly contribute to that development, as well as with local policy makers, expert analysts and members of collective bodies directly involved in the implementation of local institutions and local structures of co-ordination for the developing activities of the cluster.

More precisely, reiterated focused groups of open and vis-à-vis interviews were organised, gathering in each group selected members of the 'plastics community' (namely 1 entrepreneur, 1

policy maker, 1 expert analyst from research centres and the University, and 1 member of collective bodies such as business associations and technical centres) and organising the collective discussion around the following broad issues: the origins of the district, its development path, its present characteristics in terms of industrial organisation. Interviews were guided in order to gather information on which firms did firstly locate in the district, where entrepreneurs which subsequently entered the district were prior employed, whether and which institutions co-determined the emergence of the district at any point in time, which are the vertical and horizontal linkages, especially in terms of the relevant sectors and technologies characterising the firms in the district.

Since issues such as interactive behaviours, knowledge sharing and institutional co-operation are extremely complex, only open and face-to-face interviews may allow to capture the very qualitative nature of such interdependences. Moreover, the organisation of very close interview groups of selected members of the plastics community allows the gathering of information benefiting from collective, interactive and in-depth discussion on the topics proposed in the trace of the interview, at the same time leaving room for unexpected issues emerging from the discussion, and in turn also strongly motivating the commitment of the participants in the research work.

Such set of descriptive and qualitative information gathered through interviews was complemented with the data collected in a preliminary survey[2] of the firms in the Correggio plastics district (Baldoni and Bonaduce, 2001).

2. THE EVOLUTION OF THE ITALIAN PLASTICS INDUSTRY

The plastics industry is worldwide characterised by a great variety of products and customers. Plastics products are in fact sold both in the final and intermediary markets. Table 1 illustrates that, in 1999 in Western Europe, aggregate demand for plastics is distributed across an array of sectors (APME, 2000).

INSERT TABLE 1 ABOUT HERE

The packaging sector is the major market for plastic products. In terms of products features, plastics' lightweight, flexibility and processability are particularly important for customers in this sector.

The automotive and the electronics industries are also major users of the products of plastics industry. Consumers needs in the automotive industry are a challenge for designers and engineers. Motorists want high performance cars combined with reliability, safety, comfort, fuel efficiency, style, competitive pricing and minimum environmental impact. Lightweight plastics appliances are providing the automotive industry with a wide range of solutions to many of these challenges.

In a similar way, the variety of applications in the electronics sector is clear. From microwaves, washing machines, television sets and stereo systems to fibre optic cables, computers and mobile

[2] A survey was carried out in April 2000, with the support of 'Laboratorio d'Impresa, the sole plastics R&D centre of the area, gathering information on the firms belonging to the Emilian plastics district and covering four main issues: the organisation of the productive activities of the firm; the characteristics of the market of the firm; capital investments and innovation; the competitive environment. A qualitative sample, made up by 35 firms, of the firms composing the local plastic system has been employed, surveying a the 1997-1999 period. The prevailing qualitative, and at least explorative even when quantitative, nature of the results of the survey does not allow to drawing strong conclusions, in statistical terms, on the diffusion of certain modes of industrial organisation of local plastics firms. Nevertheless, it allows to draw in qualitative terms the composite character and the importance, as sources of innovation, of user-producer relations within the productive networks of the plastics firms.

phones, plastics provide practical benefits that other materials cannot match. Many of the developments taking place today capitalise on the latest lightweight plastics.

The building and construction industry accounted for 18.36 per cent of the total consumption of plastics in Western Europe and is the second largest user after the packaging industry. In terms of product requirements, strong, durable, low maintenance and corrosion-resistant plastics products open a wide range applications in the building and construction sector, including drainage and irrigation systems, pipes, cladding, insulation, interior furnishings and pre-fabricated constructions.

Finally, in the household and domestic market, which account for 19.37 per cent of total plastics consumption, especially fashion and furniture are major customers of plastics products.

Vertical and horizontal product differentiation are therefore at the core of the strategic interplay among firms. Firms compete with a portfolio of products differentiated in terms of price, quality and destination, the characteristics of which are attuned to the needs of the diverse customers. Hence, economies of scope play an important role. The basic competitive strength is based upon the flexibility and capability to adapt to the ever changing conditions of the needs and the tastes of intermediary consumers and households respectively. Subcontracting is a typical strategy, allowing more flexibility and adequate responses to the changing demand conditions. Small firms that have the advantage of flexibility relative to large ones are major players in such niches and targeted markets, being capable to rapidly adapt and react to changes in customers' needs and supplying the small quantities of goods demanded.

Consequently, the production process is mainly characterised by low levels of fixed capital investments and in-house R&D activities, and a great variety of specialised machine tools. Skills and human capital constitute the strategic input and thus there is little room for technical economies of scale.

Specialised and targeted production and hence the shift to high added-value products, i.e. products with characteristics that meet users' specific and continually growing technological requirements of sophisticated customers such as the automobile industry, in turn characterise the evolution toward knowledge-intensive production in the plastics industry, requiring vast technological infrastructures and capabilities such as designers, engineering services, R&D facilities, services companies, public bodies. Both pre-competitive or generic research and development activities are of utmost importance to improve products and meet the constantly expanding customers' needs. They require multi-disciplinary know-how and expertise (for example, design, chemical engineering, material expertise, machinery engineering) which cannot be provided in-house by plastics processing firms since most of them are small firms. Plastics producers have to rely on external knowledge and complementary actors. Co-operation and systematic interaction are the crucial strategic behaviour leading to the implementation of technology systems where plastics manufacturers, R&D institutions, basic inputs and raw materials suppliers, services firms and clients interplay in the generation and diffusion of new knowledge in plastics technologies (Yinnon, 1996).

The variety of components provided to these industries is huge and, therefore, the market is characterised by a great variety of niches, which are nevertheless reasonably characterised by low barriers to entry and to mobility because of the opportunity to systematically implement new external relations and hence the recurrent access to new external knowledge.

Summing up, the industrial characteristics of plastics production in terms of products, processes and market competition are heavily affected by a great variety and fragmentation in terms of applications and needs on the demand side. The variety of applications and customers' needs reflect

the technological variety characterising intermediary consumers, in turn also affecting the variety and the levels of technical standards required to plastics producers. Technical and practical skills and human capital in general, coupled with the ability to understand users' needs, to interplay with them and to access an array of external sources of new knowledge are, from the supply-side viewpoint, the crucial responses to those variety and differentiation.

2.1. The progressive clustering of plastics production

In this paragraph, the evolution of the clustering of plastics production will be analysed comparing the long term dynamics (1951-1998) of specialisation[3] in plastics production in four geographical domains: Italy, the Emilia Romagna region, the Emilian plastics cluster, and the area of Correggio. The Emilian plastics cluster is a sub-regional geographical domain located at the core of the Emilia Romagna region, covering 18 municipalities in the provinces of Reggio Emilia and Modena. The area of Correggio is a very narrow area around the small town of Correggio, including three small towns (Correggio, San Martino in Rio and Rio Saliceto), it is located in the province of Reggio Emilia and it is progressively emerged as a pole in the plastics sector. (A deeper characterising of the geography of the Emilian plastics system will be provided in section 2.3).

In this perspective, the structure of the Italian plastics industry shows that the Emilia Romagna region is the second in Italy in terms of the regional concentration and specialisation in the plastics sector. In 1998, the Italian plastics industry involved 10,031 firms and 105,500 employees. The sector is strongly geographically concentrated in the northern regions: especially, more than 40 per cent of plastics components or end-goods producers are located in the Lombardia and Emilia Romagna regions. More precisely, the Emilian plastics industry covers about 12% both of the firms and employees of the national industry, the regional sector amounting to 1,176 firms and 12,562 employees.

The long term (1951-1998) evolution of the number of firms and employees in the regional plastics industry is characterised by a first period (1951-1961) of relatively slow growth in which the number of firms increased from 277 up to 310. At the same time employees in the plastics sector increased from 2,506 up to 3,197. A second period covering two decades (1961-1971 and 1971-1981) shows a huge growth in the number of firms and employees in the regional plastics industry, increasing from 310 up to 1,580 and from 3,197 up to 14,005 respectively. Subsequently, from 1981 to 1996, the number of firms decreases slowly, with the exception of the 1991-1996 period, reaching the minimum in 1991 (1,171 firms in regional plastics industry). In the same period, employees in the regional plastics sector increase up to the maximum of 15,824 in 1996 and subsequently slow down to 12,562 in 1998 (Data are provided in Table 2).

INSERT TABLE 2 ABOUT HERE

From the viewpoint of the specialisation in the plastics sector, and in a historical perspective, the Emilia Romagna region confirms an increasing position in the process of localisation of plastics technological knowledge. In fact, in 1998 the regional plastics sector represented 2.0268% and 3.1074% of the regional manufacturing firms and employees respectively, while until 1961 the plastics sector covered less than 1% of the regional manufacturers, either in terms of firms or employees.

[3] The degree of specialisation in the plastics industry characterising the diverse geographical domains is calculated as the ratio between the number of plastics firms/employees and the number of overall manufacturing firms/employees. Thus it is calculated as an index of manufacturing specialisation.

Moreover, also the analysis of the distribution of diverse degrees of specialisation in the plastics sector among Italian provinces highlights that the province of Reggio Emilia is the second for importance in Italy and the first in the region. In fact, in terms of firms, Varese (in the Lombardia region) and Reggio Emilia are the first two Italian provinces, showing in 1998 a specialisation index in the plastics sector of 5.1401 and 3.8090 respectively. From the viewpoint of the employment specialisation in the plastics sector, Reggio Emilia confirms its importance because it is the second province in Italy after Macerata (in the Marche region): the proper index of specialisation is 5.5303 and 5.0196 respectively[4].

In such a regional context, the progressive specialisation in plastics production affected a well-defined area mainly located in the province of Reggio Emilia and that has been defined as an Emilian cluster in the plastics sector.

In 1998, such cluster covers 18 municipalities and is made up by 357 firms and 3,897 employees, representing 30.3571% and 31.0221% of the regional plastics industry. In contrast with the regional evolution, the long-term (1951-1998) development of the cluster is characterised by a restless and progressive growth both in the number of firms placing in the cluster and in the relevant employment capacity. Starting in 1951 with only 4 firms and 24 employees, during the 1951-1981 period the growth of the cluster shows a rapid and uninterrupted increase in the number of firms and employees in the plastics sector, reaching a relative peak of 310 firms and 2,522 employees in 1981. Subsequently, the years from 1981 to 1998 are characterised by a slower growth both in the number of firms and in employment, even showing a relative decrease in the number of firms during the 80s (from 310 in 1981 to 268 firms in 1991) that however did not influence the growth in the employment capacity of the plastics cluster.

Moreover, and more importantly in the perspective of this paper, the historical analysis of the specialisation in the plastics technology among the diverse geographical domains shows that the Emilian plastics cluster becomes progressively more and more specialised in plastics technology than the regional and, more obviously, the national industries. In 1951, the index of manufacturing specialisation in the plastics sector of the Emilian cluster is lower than the regional and the national ones, considering both firms and employees: the former is 0.0823, while the latter is 0.1306. (National specialisation index, incidentally, is the higher among the diverse geographical domains considered in Table 2, both in terms of firms and employment). Nevertheless, the rapid growth in plastics firms and employment, especially in the first half of the period taken in examination, determinates an increasing and restless growth in the technological specialisation of the area, in turn producing a strong localisation of plastics technological knowledge. In fact, in 1998, the cluster specialisation index in the plastics technology is 3.8661 and 5.5018, considering firms and employment respectively.

Such progressive technological specialisation is even more evident when considering the narrow area around Correggio: the so-called Correggio plastics district. This area includes 3 small towns (Correggio, San Martino in Rio and Rio Saliceto) and in 1951 only 2 firms and 22 employees made up the local plastics sector. Nevertheless, the growth in the number of local firms and in local employment in the plastics sector has been even greater and more continuous than in the wider area representing the Emilian cluster. In 1951-1998, the number of plastics firms increased up to 99 (a small decrease in the number of firms characterises the 1996-1998 period; in 1996 firms were 103) and the relevant employment grew up to 1,268 units. In this context, the historical analysis of the specialisation index in the plastics industry shows the progressive and huge localisation of plastics production in such narrow area. In 1951, the local specialisation index in plastics technologies was

[4] Data from Chambers of Commerce of Reggio Emilia (CCIAA Reggio Emilia, 1998).

0.3846 when considering firms and 1.2115 when considering employees; in 1998 such index increased up to 12.9263 and 21.6975, considering firms and employees respectively.

A highly specialised technological cluster is clearly and greatly emerging in the province of Reggio Emilia and especially in the narrow area of Correggio. Indeed, since 1951, the quantitative evolution in terms of number of firms and employees within the plastics sector has been continuos and restless. More importantly, the evolution of the local plastics sector in terms of growth of the number of firms and employees also shows that such process of growth is paralleled by the progressive technological specialisation of the local industrial system in the plastics sector.

Figures 1a and 1b compare the long-term evolution (1951-1998) of the specialisation of the area of Correggio in the plastics sector with the national, regional and provincial levels, in terms of both firms and employment specialisation (Data are provided in Table 1). The progressive and uppermost specialisation of the area of Correggio in the plastics industry is most evident.

INSERT FIGURES 1a AND 1b ABOUT HERE

2.2. Is the size of firms a factor shaping plastics production?

The huge and progressive specialisation in plastics production in the Correggio area is not the result of vertical integration. In the Correggio district there are no medium and large firms with more than 100 employees, while in the wider Emilian cluster only 1 firm has more than 100 employees (123 employees) (See Table 3).

In terms of the number of firms, at the level of the Correggio district small and very small firms with less than 50 employees represent 95.14 per cent (98 firms out of 103 total plastics firms in the district) of plastics firms, while, when the wider Emilian cluster and the Emilia Romagna region are considered, the share of plastics production in small firms increases up to 96.3% (314 firms) and 96.0% (1,236 firms) respectively. At the national level, 95.7% of plastics firms are small and very small firms.

Although the fact that, in terms of firms, the share of plastics production of small firms in the Correggio district is slightly lower than the regional and Emilian cluster ones, the analysis of distribution of plastics production in terms of number of employees confirms the key role of small and very small firms at the local level. As a matter of fact, small and very small firms with less than 50 employees in the Correggio district and in the Emilian plastics cluster occupy respectively 65.8% and 75.8% of the total employment in the relevant plastics industries. At the regional and national level plastics employees in small firms are 65.4% and 61.6% of the total plastics employment.

INSERT TABLE 3 ABOUT HERE

The role of small firms in the local plastics sector is most evident. The increasing technological specialisation and localisation and hence the resulting body of localised technological knowledge in plastics technology is more and more distributed among small firms.

When considering the number of firms and employees as reasonable proxies of the specialisation and accumulation of technological knowledge, the specialisation in plastics technological knowledge is especially accumulated in small and very small firms with less than 50 employees, and it takes place at the local level in particular.

Finally, also the analysis of the evolution of the dimension of firms through the calculations of average dimensions in the 1951-1998 period confirms the persistence of very small firms as a distinctive feature of the area: average firms dimension in the 1951-1998 period is almost stable varying from about 10 employees in 1971 to about 13 employees in 1998 (excepting the 'peak' of 20 employees in 1961) (Calculations on data provided in Table 2).

2.3. The geography of the Emilian plastics system and the irrelevance of the metropolitan area issue

The Emilian plastics cluster covers a narrow area made up by 15 municipalities in the province of Reggio Emilia (Bagnolo in Piano, Bibbiano, Cadelbosco Sopra, Campagnola, Cavriago, Correggio, Gattatico, Luzzara, Novellara, Reggio Emilia, Reggiolo, Rio Saliceto, Rubiera, S. Ilario D'Enza, S. Martino in Rio), and 3 municipalities in the province of Modena (Carpi, Campogalliano, Mirandola). The progressive industrial specialisation in plastics technologies determined the emergence of a productive cluster in the plastics sector that, from the geographical viewpoint, does not coincide with the whole province of Reggio Emilia and covers an area of 18 municipalities that are very close in terms of geographical proximity.

Moreover, when looking at the distribution of the specialisation in the plastics sector among the diverse municipalities composing the cluster, such technological specialisation is much more well-defined in geographical terms. The agglomeration of the plastics sector in few municipalities is clear when looking at Table 4: plastics production is more and more concentrated in the very narrow area covering the three small towns of Correggio, San Martino in Rio and Rio Saliceto[5]. This very narrow area represents the plastics district, not only in terms of the productive importance of the plastics sector but even and more importantly because it focuses the main set of industrial dynamics, institutional efforts and technological complementarities co-determining the development of a quite coherent technology system.

INSERT TABLE 4 ABOUT HERE

As far as geographical factors are considered, it is hence very interesting to note that the Emilian plastics district does not benefit from the advantages stemming from a metropolitan location. Much economic literature has shown that metropolitan areas provide a far more positive institutional context affecting the dynamics of localised technological knowledge. Metropolitan areas account for the mix of industrial and financial conditions, endowment of scientific and technological infrastructures, and systematic communication mechanisms. The Emilian plastics district is located neither in a metropolitan area nor in a city. Together with the absence of medium and large plastics firms, this is a further element revealing the peculiarity and the strength of the local mechanisms determining the evolution of the huge technological specialisation we have observed and the relevant emergence of the technology system itself, in turn stressing the need for an in-depth case study.

3. COMPLEMENTARY INTERACTIONS IN THE EMERGENCE OF TECHNOLOGY SYSTEMS: THE CASE OF THE EMILIAN PLASTICS DISTRICT

The evolution of the Italian plastics industry confirmed that the conceptual approach articulated in the paper is relevant. In fact, the regional specialisation in plastics technologies is paramount even and mostly when considering that: 1) it is not explained in terms of advantages from cities

[5] Employment specialisation in the plastics sector in the town of S. Martino in Rio is lower if compared to other towns outside the district because of the extensive presence of very small and micro firms.

economies and from the institutional and technological endowment of a metropolitan area; 2) no medium and large firms are located in the local plastics industry and hence they are not a factor shaping the progressive specialisation and agglomeration in plastics technologies; 3) natality and entry waves of small firms emerge as the crucial industrial factor in the production and accumulation of plastics technological knowledge.

The analysis of the collective technological knowledge seems the appropriate tool to understanding the 'Correggio effect'. To do so, the following hypotheses will provide the guidelines for the empirical assessment of the complementary mechanisms determining the governance of production and distribution of localised technological knowledge and the resulting development of the local technology system.

First, start-ups, local entrepreneurship and the process of firms' spin-off provide opportunities for the accumulation and dissemination of mainly internal tacit technical know-how and practical capabilities mainly embedded in human capital (Belussi, forthcoming; Feldman, 2001; Feldman and Ronzio, 2001; Longhi, 1999; Quéré, 1997)

Second, upstream and downstream user-producer relations, namely the provision and purchase of specific and complementary intermediary inputs, and more generally the division of labour enable by-product interactions and the process of accumulation and distribution of external and firm-based knowledge embodied in specialised inputs (Lundvall, 1985; Russo, 1985; Von Hippel, 1988).

Third, the local institutional environment in terms of R&D infrastructures provides the suitable endowments to generate collective opportunities for co-localised firms to take advantage from the diversity of science-based knowledge (Audretsch and Stephan, 1996; Feldman and Audretsch, 1999; Quéré, 1994), internalising knowledge flows through formal organisations and strengthening local environments for the generation and diffusion of codified knowledge (Jaffe, Trajtenberg and Henderson, 1993; Jaffe and Trajtenberg, 1999; Patel, 1995).

Four, technological knowledge emerges also from technological interrelatedness between firms in contiguous sectors. Therefore, technological systems are the result of complementarities between production processes and product components and hence are the result of the pattern of interconnection between such processes and products (Bijker, Hughes and Pinch, 1989; Carlsson, 1997; Carlsson and Stankiewitz, 1991).

3.1. The evolution of the process of endogenous spin-off in the Correggio district (1942-1985)

This section considers the evolution of the process of endogenous spin-off in the plastics sector characterising the district in the area of Correggio. The huge and more rapid dynamic of spin-off characterised the district since the 40s until the mid of the 80s. Subsequently, the new gales of entrepreneurs in the plastics sector will be induced by the market opportunities opened with the growth of the first generation of plastics firms, which hence started to decentralise phases of production, assembling and related services. In that this paper assumes the initial process of spin-off as the crucial element in the industrial dynamics determining the emergence of a collective body of localised technological knowledge, it leaves out, in terms of an historical analysis, the second phase of the evolution of the formation of local firms. Nevertheless, the role of user-producer relationships as emerging also from the increasing decentralisation of production phases in the district is taken into account in the next section.

Three main waves of entrepreneurs could be pointed out in the historical evolution and progressive emergence of a plastics district in the area of Correggio.

The evolution of plastics firms in the area of Correggio starts since 1942, when Corrado Gianfranceschi, who was previously engineer at Fiat and Bayer, coupling his engineering-based competences in the chemical and mechanical sector, founded Gianco, firm operating in the injection plastic moulding for the agro-food industry. The second firm established in the district starts in 1954 due to the entrepreneurial initiative of Paolo Bosi, who was previously the main partner of Corrado Gianfranceschi in Gianco. The new firm, namely Pibiplast, started its production in the plastic moulding for the pharmaceutical industry and subsequently for the cosmetic industry. The earliest entrepreneurial stream is completed by three further spin-offs: the Stampotecnica and the Fratelli Mazzali companies on the one hand, and the Fratelli Pietri company on the other has been founded in the late Fifties as spin-offs from Gianco and Pibiplast respectively.

As far as the notion of 'generative relationships' has been put forward to explain peculiar positive interactions leading to the emergence and evolution of learning processes and innovation dynamics (Lane and Maxfield, 1997), the historical and in-depth analysis of entry dynamics is most important to grasp the generative relationships among firms determining the creation of a common base of technological knowledge in the local plastics sector (see Table 5). In this perspective, the historical and ethnographic approach to the understanding of generative relationships (Russo, 2000) justifies a detailed analysis of the individual paths of main entrepreneurs each of which is very specific and idiosyncratic.

INSERT TABLE 5 ABOUT HERE

In 1957, Terzino Spaggiari and Alberto Alberti established the Spal company. The former was previously a technician in the main mechanics firm (Corghi) in the area of Correggio establishing market and technical linkages with the plastics sector as a client of Gianco. Blending the original mechanics know-how of Terzino Spaggiari and the knowledge of the plastics market opportunities accumulated as client of plastics firms, Spal was the first firm in the area devoting to the plastics production of specialised components previously produced by mechanics firms as metallic artefacts.
Spal greatly determined the progressive implementation of a specific internal body of plastics technical know-how that, coupled with increasing productive and market opportunities in the local plastics industry, representing as a matter of fact one of the main sources of production and diffusion of sectoral knowledge in the area.

In fact, a second and great wave of endogenous spin-offs contributed the progressive formation of the Correggio plastics district in the 60s and the 70s. Such a new stream of entrepreneurs is characterised by the original generation from the Spal company.

The first two spin-offs from Spal dated back in 1962, when Tonino Mariani on the one hand and Rino Spaggiari on the other established the Sitoplast and the Plastmeccanica companies respectively. The former was prior shop foreman at Spal while the latter was the head of the plastic injection moulding process also at Spal. Both the entrepreneurs accumulated a kind of skill-intensive and long-term experienced practical know-how in the emerging and new plastics technologies and products. Two kinds of practices matter: first, the specific previous long-term technical experience at Spal but also, and second, the long-term interactions with client firms in the mechanics sector that emerged as the main market for Spal.

In a similar manner, in 1963 Enzo Spaggiari, who was previously a technician at Spal, founded the ATS company and, subsequently in 1972 Tiennio Bettati founded a new firm, namely Uniplast. The latter, in the first phase of his training in the plastics sector, was a technician at Spal moving subsequently at Sitoplast, where he completed his training re-joining Tonino Mariani who was in

turn the supervisor of Bettati at Spal. Such a personal relationship between Mariani and Bettati leads, in 1980, to a new start-up, namely the Mar.Bett company, which is still now one of the most important firms in the local plastics district.

In this perspective, the growing body of technological knowledge in the plastics sector is progressively the result of the blending of practical and trained competences in plastic material and productive processes and more skill-intensive know-how in the mechanics technologies, often accumulated through user-producer interactions and relations with clients. Such dynamics of accumulation of technical know-how is the result of long-term practical experience in the plastics technologies and products and is often diachronically transmitted through the personal relationships established between technicians and entrepreneurs.

The original link with the Spal company characterises also Mario Franchini, who was shop foreman at Spal and subsequently at Sitoplast, and who founded in 1971 the FM company. Moreover, a second group of minor firms is yet the result of the generative capacity of Spal, at least in two different ways: 1) a first group of firms is the result of further spin-offs directly from Spal, namely Davolio Giuseppe, CEG, TVM, SA.BE, Novastamp and B. e B., and takes place in the 60s; 2) a second group of firms spin-offs from firms that had been generated by Spal in the earlier phase of spin-offs. This second group of spin-offs occurred mainly in the 70s and includes B.F, S.B., F.G.M, with the above-mentioned F.M and Uniplast.

Such second phase of spin-offs is complemented, in terms of entry dynamics, by two important start-ups in the plastics sector. In both the cases, entrepreneurs were not prior employees of local plastics firms. Nevertheless, being technicians in the local mechanics industry, they established links and accumulated competences in plastics technologies and products as clients of local plastics firms.

In 1966, Giorgio Gaiti and Loris Ferraris founded GF, specialised firm in the production of plastic moulds. They exploited the base of skill-intensive knowledge of mechanical production processes and coupled it with the knowledge of plastics techniques and products developed as clients of plastics firms when they were technicians in the mechanics sector. In the same way, in 1967 the GS company was founded by Gobbi and Spaggiari, who were previously employed as technicians in one of the main mechanics firm in the area of Correggio. Here, the plastics injection moulding paralleled mechanical production, hence blending the two kinds of technical know-how that implement the core body of knowledge characterising the plastics sector in the area of Correggio in a peculiar way, maintaining two distinct and yet very interdependent lines of production. At the beginning of the 70s, GS generated a new company, namely Gamar.

The beginning of the third entrepreneurial wave in the Correggio plastics district could be dated in 1973, when Parmiggiani and Zagni founded the CGM company. Zagni was previously entrepreneur in the mechanics sector. He established long-term and strong relationships with the growing plastics cluster of Correggio accumulating at least three kinds of know-how and competences: entrepreneurship, mechanical technical know-how, and product and market knowledge in the plastic sector. The second important firm leading such third gale of entrepreneurs is the above mentioned Mar.Bett, a spin-off from Sitoplast and Uniplast occurred in 1980 and resulting from the long-term master-apprentice-like relationship between Tonino Mariani and Tiennio Bettati. They worked in close partnership, first, at Spal where Mariani was a shop foreman and Bettati a young technician and, second, at Sitoplast where Mariani was the entrepreneur and Bettati a skilled technician. In 1973 Tiennio Bettati founded the Uniplast company and in 1980, as the result of at least 23 years of experience in the plastics industry, he founded the Mar.Bett company, banding together with Tonino Mariani once again (whose experience in the sector was, incidentally, even longer).

In the context of the third stream of endogenous entrepreneurial spark, it is to be noted that 4 new companies has been generated from Mar.Bett and CGM in he 80s, namely Tre Bi and Vuemme from the former, and Vezzani and Scaltriti from the latter. Although the endogenous generation of new firms progressively slowed in this third period, 4 further start-ups in the plastics sector occurred, namely, Plastica Secchia at the beginning of the 70s, A.R., B.C and CRC at the beginning of the Eighties. In turn, such 4 new firms generated through spin-off mechanisms 4 further new companies, which completed the historical evolution of the endogenous formation of new firms in the plastics district: namely Isiplast in the first years of the 80s from Plastica Secchia, and Simoplast, Plastica Ognibene and CorPlast in the mid 80s from A.R., B.C and CRC respectively.

Figure 3 summarises the historical evolution of such main entry dynamics in the area of Correggio since 1942.

INSERT FIGURE 3 ABOUT HERE

Sketching out the main results of the historical analysis of the generative relationships in the plastics district of Correggio, in terms of the determinants and features of the emerging body of localised technological knowledge it is clear that the very beginning of the history of the plastics district of Correggio biased the evolution of local firms in the plastics sector at least in two ways. Firstly, the blending of technical know-how in chemicals and mechanics is a recursive element of local firms, also exploiting the increasing specialisation in the mechanics sector of the manufacturing system in the Emilia Romagna region in general and in the area of Reggio Emilia in particular. Secondly, the original spin-off through which the second plastics firm in the area was established biased the subsequent historical path of the district, being spin-off the key mechanism of reproducing for local firms, hence characterising the development of the cluster with a strong endogenous evolutionary element.

More generally, the role played by initial firms has been crucial for the subsequent development of the plastics district. As matter of fact, those firms started the generation of a common base of technical and practical know-how and its diffusion, mainly through tacit and informal channels, among at least two categories of actors.

First, such seminal know-how was diffused among technicians of the firms themselves, some of which began entrepreneurs after the initial training at Gianco, Pibiplast and Spal. Some others completed their training moving from those original firms, but even in this case subsequently they started up new firms. As a matter of fact, a first body of local entrepreneurs was prior directly involved in the technical activity of Gianco, Pibiplast and Spal, at the same time contributing to the definition of the seminal common base of technical and entrepreneurial know-how in the area and benefiting from the accumulation of such practical competences.

Second, this common base of know-how in the plastics sector was transmitted also to client firms, especially in the mechanics sector. Perhaps the most important company in the area, both in terms of market position and more importantly in terms of generative capacity, namely Spal, is indeed the result of strong market and technical relations between Gianco and client firms in the mechanics sector. A second body of entrepreneurs in the plastics district is in fact belonged to the category of prior employees, even and especially as technicians, in local mechanics firms that purchased plastics components from the plastics firms of the district. In this perspective, client-provider relations was the main mechanism favouring the access to the common base of technical know-how generated in plastics firms, which was mainly embodied in human beings and artefacts, and hence personal and tacit.

In both the cases, relations and interactions between original firms and spin-offs are persistent and reiterated not only through the personal linkages among technicians and entrepreneurs, but also through long-term market and sub-contracting interactions. Components and products are more and more sold and purchased between original firms and the relevant spin-offs, as well as the decentralisation of production phases finds in the trusted and personal relations between new and old entrepreneurs the proper conditions for long-term and privileged user-producer interactions.

In conclusion, although the variety of backgrounds characterising the various entrepreneurs in terms of prior employment positions, the common base of technical know-how blending competences in mechanical and chemical/plastic technologies is the result of long term experiences in both sectors as either specialised technicians or users of artefacts, intermediary input and technologies developed in the relevant sector.

This common base of technical know-how is mostly communicated through personal linkages and relations among individuals, which are persistent and reiterated also because of market and sub-contracting relations. Master-apprentice relationships between specialised craftsmen-like entrepreneurs and technicians, who will subsequently spin-off, impinge on learning-on-the-task mechanisms and involve implicit knowledge exchanges, in turn leading to the accumulation of two kinds of firm-based internal tacit know-how: technical and entrepreneurial expertise.

3.2. The division of labour in the Correggio district

When looking at the industrial organisation of the district, the analysis of whether user-producer relationships exist and are carriers of technological communication could benefit from the investigation of at least three phenomena: whether they established sub-contracting relations and networks; which are the characteristics of the markets, especially in terms of technological variety; which is the role of providers and clients as external sources for the introduction of innovation. Such phenomena are investigated through the information gathered in the preliminary survey carried out in Baldoni and Bonaduce (2000).

The decentralisation of production, at least of very simple phases, characterises 52% of the sample of plastics firms (Table 6). The adoption of such mode of production organisation is strongly consistent with the entrepreneurial model diffused in the Reggio Emilia area and more generally in the Emilia Romagna region, which is characterised by the systematic use of wide and very specialised sub-contracting networks. In this context, the more decentralised phase is likely the production of plastic moulders, which is externalised to mechanics firms that are widely diffused in the Reggio Emilia area. As already observed in the analysis of the evolution of endogenous spin-offs, the blending of mechanics-based, even externally accumulated, and internal plastics-based competences is at the core of the knowledge base of the district. Such competences are embodied in artefacts, process technologies and even human beings, revealing a strong tacit character.

INSERT TABLE 6 ABOUT HERE

If the decentralisation of simple production phases is more and more diffused in the sample of firms, nevertheless more complex intermediate inputs and end goods are also sub-contracted in about 30% of firms. More importantly, outsourcing of simple phases is more and more concentrated in the local/regional productive system of sub-contracting relationships (44%). Local sub-contracting is dominant in either the case of complex intermediate inputs or end products (respectively, 16% and 20%). In this perspective, the element of localisation is affected by both geographical and technological conditions. Localised sub-contracting takes place mainly in the local

area of Reggio Emilia and in the Emilia Romagna region in general, involving especially mechanics firms. Localised interactions generate a network of communication opportunities where complementary kinds of technical know-how (plastics-based and mechanics-based) are exchanged in a well-defined regional space.

From the viewpoint of the technological base of the final markets of plastics products, client firms are principally located – measuring the share of turnovers generated by selling plastics output to the relevant industry – in the mechanics sector, in the automotive, in the agro-food industry and in the biomedical sector, underscoring the technological variety of intermediary customers of plastics products (Table 7).

INSERT TABLE 7 ABOUT HERE

Nevertheless, important differences arise when considering the intensity of relationships with this variety of markets. As a matter of fact, the biomedical sector does not represent a market at all for 75% of the plastics firms of the district, its importance for the regional industrial system[6] notwithstanding.

The mechanics sector is the first in terms of importance as a final market, being a key market for 47.8% of the firms in the plastics district of Correggio. In this perspective, the importance of the automotive sector as final market for plastics products is crucial in quantitative terms: 58.4% of the plastics firms' turnovers are generated by selling plastics artefacts to the automotive sector. Moreover and more importantly, it is strongly consistent from the technological viewpoint.

In fact, the mechanics and engineering-based sectors are main technological specialisations in the Emilia Romagna region and in the province of Reggio Emilia in particular. In this perspective, the existence of a strong market interdependence between the firms in the plastics district and complementary regional productive specialisation reveals the presence of a network of relations, which are well-rooted in the geographical context and that are formalised through market transactions and yet often informal in terms of know-how exchange and distribution.

Technological proximity, especially in terms of a common body of technical know-how and also as a result of the historical evolution of the district, and, second, geographical proximity are reasonably the crucial factors explaining close interactions between plastics and mechanics firms even from the point of view of market relations.

In other word, technological proximity couples regional proximity in establishing and enforcing effective user-producer relations. Technological and regional proximity with user firms as a matter of fact favours the continuos co-definition and testing of new technical and process solutions for plastics components for the mechanics and automotive sector, and the rapid circulation of new projects and ideas, in turn leading to the explicit implementation of co-design strategies in the definition of the technical features of the plastics components that are based upon the acquisition of external tacit knowledge through the mechanism of user-producer interactions. The definition of a certain product design is the creation of the peculiar configuration and combination of features, materials and components that give a product its attributes of, for example, function, appearance and durability. Co-design strategies are developed through a team often involving users' marketing

[6] The very close geographical proximity between the plastics district of Correggio and the biomedical district of Mirandola is noteworthy here. In a similar way, the geographical proximity of the Bologna packaging district does not represent a determinant for close market and more generally user-producer relations between plastics and packaging firms.

and production specialists, a high-skilled technician or an engineer of the plastics firms, and a scientist or research chemist of the large raw-materials providers.

The analysis of the variety of sources indeed confirms and summarises the importance of such external stimuli in the generation of innovation and technological advances: product and processes are ameliorated reacting to new quality standards and changes in final users' requirements that are signalised due to the interaction with client firms (Table 8).

INSERT TABLE 8 ABOUT HERE

When developing innovations and more generally when defining the (new) technical features of a certain plastic component, plastics firms co-operate principally with client and sub-contractors. It is noteworthy that in the plastics sector, either providers and clients are also multinational firms even geographically located outside the district and able to develop autonomous formalised technological and more generally innovative efforts that generate key impulses for the more tacit and practical technological and innovative efforts in forward and backward sectors.

This determinates two important consequences in terms of knowledge production and distribution. Firstly, as far as the traditional mode of productive decentralisation appears as a mechanism for the accumulation and diffusion of tacit and practical know-how, the link with large multinational firms is a device to access a much more formalised and science-based body of knowledge. Secondly, in order to fill the gap between the tacit and practical know-how of plastics firms and the science-based and formalised body of knowledge of large firms, codification institutional efforts are necessary in the systemic generation and diffusion of diverse knowledge bases. Next section discusses these issues.

3.3. R&D institutions and the creation and distribution of codified knowledge

When analysing the role of R&D institutions in determining the evolution of the Emilian plastics technology system and their modes of interaction with complementary actors in the system, the 'Laboratorio d'Impresa', located in Correggio, is key collective centre for basic research, technology development, testing and technical training, which enhances both embodied and disembodied codified knowledge to be produced and distributed.

Laboratorio d'Impresa is a consortium of public and private bodies established in 1994 in order to meet the technological and organisational needs of small enterprises in the plastics industry and especially of those located in the Emilian district. More precisely, its main areas of intervention are the following: R&D activities, such as studies on basic inputs and raw materials and its applications in the plastics production process; the provision of technological equipment and technological services; training; and the collective promotion of the activity of the plastics district.

In the 90s, the implementation of a sectoral network involving private companies, and public and collective bodies is central to the activity of the Laboratorio, in order to exploit the advantages of relationships between bodies with different skills and know-how, especially via R&D projects funded at the regional, national and European level.

INSERT FIGURE 4 ABOUT HERE

In particular, a stable and institutional network (Figure 4) has been developed involving firms, private and academic research centres, business associations and regional public support services centres, and directly aiming at the collective generation and diffusion of new codified knowledge in

the plastic industry. More precisely, the network carries out formalised efforts in the following fields, exploiting the specific competences of the relevant partners: simulation studies, developed directly by the Laboratorio d'Impresa; studies on the characterisation and degradation of polymers, developed by both the Laboratorio and Superlab; studies on the development of new materials and on the use of rapid prototyping systems, carried out jointly by the Laboratorio, the University of Modena and Reggio Emilia, Superlab and the Democenter; the monitoring of both the diffusion of new plastics and chemicals technologies and of new production processes, carried out by both the Laboratorio and the CNR – The Italian National Centre for Scientific Research .

In turn, R&D projects have been developed by the Laboratorio, aiming at enforcing the codification of an homogeneous and coherent knowledge base of the plastics cluster, especially when trying to couple the skill-intensive knowledge base of the mechanical sector that represents the common technical background of local entrepreneurs and the science-based knowledge of the chemical sector.

The set of localised R&D institutions contributing to the definition and evolution of the Emilian plastics system is characterised also by the presence of R&D departments of private large firms in the chemical industry (namely, Du Pont, Bayer and BASF, all starting long-term interactions with the district at the beginning of the 80s), which complemented the role of public bodies. The element of localisation here is not simply geographical, but even and mostly technological. Indeed, the links between local small plastics producers and big multinationals in the chemical sector (which can have headquarters located even outside the district, but maintain strong links with the territory through R&D units and subsidiaries) affect the collective generation and diffusion of technological knowledge in two ways.

Firstly, large science-based firms supply plastic materials and basic chemical inputs to local plastics firms directly on the marketplace. Such market-based interactions affect the collective dynamic of knowledge production because they are carriers of accumulation of the results of external R&D activities, which are typically codified and yet embodied in materials and basic inputs. The embodied character of this knowledge underlines the importance and the complementarity of the codification and formal training efforts put in place by 'Laboratorio d'Impresa'.

Secondly and subsequently, large chemicals firms interact with plastics moulders producers in the mechanical sector, co-defining the technical features and technological performances of a given moulder on the base of the specific technical and technological characteristics of the plastic material chose by plastics firms in the plastics injection moulding district. A kind of triangular communication among large science-based providers of basic inputs, mechanics providers of intermediary tools and plastic processors firms seems to occur. It contributes not only to the dissemination of large firms' R&D outputs making it available for small and non science-based firms. It also favours the large science-based firms to access the body of mainly tacit and skill-intensive knowledge base of mechanics and plastics firms, in turn fostering the recombination of complementary kinds of knowledge and effectively contributing to the emergence of a system of knowledge centred upon the plastics district.

3.4. Technological complementarities and the systemic recombination of external knowledge

When considering the Emilian plastics technology systems, technological interdependences that favour the systemic recombination of the diverse knowledge bases into a common pool of localised technological knowledge are based upon interactions between the following actors in contiguous science-based and manufacturing industries and service sectors: basic chemical input producers, moulders producers in the mechanics sector, related services firms (design, technical and

commercial assistance, up-dating press technology), engineering-based and high-skilled automation machinery producers of plastic injection technology. Such variety of technological and knowledge bases is involved in backward and forward linkages with the plastics injection moulding cluster, fostering the systemic access and recombination of those diverse knowledge bases by means of complementary provisions of technologies and technology-based services (Figure 5).

INSERT FIGURE 5 ABOUT HERE

Specialised suppliers of basic plastic materials are typically large firms in the chemical sector (namely, DuPont, Bayer and to a lesser extent BASF) that establish downstream linkages in two directions, fostering the diffusion of codified and science-based knowledge often embodied in raw materials and human resources. First, they provide basic plastic materials to the firms in the plastics injection-moulding district according to the specific technical and technological features defined for a specific plastic artefact or component. Second, they interact with moulders producers in the mechanics sector in order to co-design a specific moulder responding to the technical and technological characteristics of a certain plastic material chosen by plastics moulding firms. While in the latter case science-based knowledge is mainly embodied in the specific chemical/plastic basic input and is traded on the marketplace, in the former science-based knowledge is embodied in human capital (i.e., technicians, engineers and applied scientists) and is transmitted through more personal relations and close co-operation between research chemists and mechanics designers and engineers.

While providing downstream the plastic injection moulding district with specific moulders, the moulders producers in the mechanics sector establish backward relations with the service sectors. More precisely, high-skilled and technology-based services (e.g., support for design and project activities, long-term relations of technical assistance and press up-dating, and even commercial assistance to implement market strategies) are provided by knowledge intensive service firms. Long-term interactions, even mediated by formal long-term contracts, and formal and informal partnerships especially in supporting the design and project activities of mechanics firms are the prevalent devices through which high-skilled and formal training-based knowledge is transmitted and recombined with the more tacit and practical know-how of the mechanics sector.

In parallel, technology-based service firms provide the same kinds of knowledge intensive services also to the plastics injection moulding firms, constructing formal and informal long-term interactions and partnerships, in turn recombining the high-skilled knowledge base of technology-based service firms with the kind of know-how that characterises the knowledge base in plastics firms, which is mostly tacit, practical and based on learning on the task.

Finally, the relation between plastics firms and clients in the manufacturing sectors is characterised by a threefold interaction in terms of knowledge recombination. First and more obviously, plastics firms provide specialised components embodying specific know-how in the chemical and mechanical sectors plus a body of service-based technological knowledge. Learning mechanisms (likely, learning by doing and learning by interacting) are needed in order to implement effectively such body of know-how and artefacts in the production process of client firms. Second and reversely, client firms are a key stimulus in the elaboration of technical improvements in both the moulding process and the basic chemical inputs required upstream. Practical and commercial kinds of knowledge, which are often experienced by client firms through market competition, interact with and even bias the more technical know-how and generation of new knowledge of plastics producers, but also of chemical providers of basic inputs. Third, the relation between plastics moulding firms and clients is affected by the provision of engineering-based automation technologies for the moulding productive process. Engineering-based and high-skilled knowledge

bases of automation machinery producers interacts with the technical know-how of plastics producers and the commercial know-how of clients in order to determine the peculiar technical features of the plastics component.

Such a complex set of interactions that are based on the backward and forward provisions of complementary technologies and technology-based services among contiguous sectors complements on the one hand industrial dynamics favouring the diffusion and recombination of internal and external mainly tacit know-how. On the other hand it complements institutional efforts in direct R&D activities and co-operative projects that aims at codifying the base of knowledge in the plastics district, disseminating it among plastics firms and accessing new bodies of science-based knowledge. The generation, accumulation and distribution of complementary knowledge bases are hence systemically implemented through the recombination of such diverse kinds of knowledge favoured by systematic technological complementarities among interdependent sectors and activities.

In conclusion, the emergence of a structured flow of complementary knowledge bases which are integrated at different levels (i.e., by means of different industrial, institutional and technological dynamics) and supported by complementary interactions among a variety of diverse knowledge producers and users is therefore at the basis of the development of a quite coherent technology system impinging upon a common pool of technological knowledge.

4. CONCLUSIONS

This paper provided empirical evidence for the fact that the production and distribution of localised technological knowledge and the related emergence of technological systems are the result of specific and constrained interdependences among industrial, institutional, technological and geographical factors.

As a matter of fact, the Emilian plastics technology system reveals the characteristics of an emergent and young technology system where the interdependence and co-evolution among industrial dynamics, institutional R&D efforts, and technological interrelatedness are the crucial mechanisms fostering the generation, accumulation and distribution of localised technological knowledge. Industrial dynamics is the first factor because favours tacit knowledge to be pooled in a peculiar technical space, hence accumulated and diffused. More precisely, three factors matter: 1) the cumulation of technical know-how localised in a well-defined technical space coupling chemicals and mechanics know-how generates the common and specific body of technical know-how, 2) the dynamics of entry based upon the process of local spin-offs fosters the accumulation of internal tacit know-how, 3) the interactions with specialised sub-contractors and client firms enhance the access to external tacit knowledge. Moreover, institutional technological communication and market-based knowledge trade favour the generation and acquisition of codified knowledge from the local R&D network of collective institutions as well as from R&D units of multinational firms. Finally, and also as a consequence of such productive and R&D interdependences, technological complementarities take place among firms in contiguous and interactive sectors, in turn favouring the systematic and systemic recombination of external, tacit and codified knowledge.

Small and very small firms in turn emerged as the key industrial factor governing the production and accumulation of localised technological knowledge both because of the high levels of distribution of plastics production among them and because of the progressive entry dynamics in the plastics district, in turn confirming their role as determinants in the dynamics of innovation (Audretsch, 1995). Moreover, the progressive generation of a common pool of localised

technological knowledge seemed the result of inter-sectoral flows of complementary bits of technological knowledge at least in two ways: 1) the blending of chemicals and mechanics know-how constituting the base of plastics technological knowledge is the result of systematic interactions between firms and between them and R&D institutions; 2) inter-sectoral interdependences and knowledge distribution are affected by technological interrelatedness among contiguous manufacturing and service sectors.

Technological knowledge is here localised both because of technical and geographical factors. The production and the increasing accumulation of localised technological knowledge is the result of the diachronic and synchronic interactions among industrial dynamics, institutional efforts and technological complementarities between different sectors, determining the specific body of technical know-how as the blending of knowledge in the chemical and mechanics technologies especially. Such economic interactions are supported by the social and cultural climate characterising the specific geographical location (in this case, the Emilia Romagna region) in which they are embedded, and do take place in the very narrow area around the small town of Correggio.

The social and institutional structure of the region in terms of the internal set of interactions among firms, and between them and institutions is the crucial factor creating communication opportunities and communication channels, favouring local learning and knowledge sharing, in turn determining the internal dynamics of knowledge production and distribution (Braczyk et al., 1998; Cooke, 2001; Cooke et al., 1997; Howells, 1999).

From the viewpoint of the regional institutional endowment contributing to the birth and growth of the local technology system, the fact that the Emilian plastics technology system is not located in a metropolitan area and does not benefit from the proximity of large plastics producers greatly underlines the peculiarity and the strength of the interactions determining the progressive and systemic production, accumulation and distribution of localised technological knowledge.

Therefore, when investigating the systemic nature of technological knowledge this paper underscores that the generation of technological knowledge is strongly localised because it is influenced by heterogeneous and contingent factors – industrial, technological, institutional, and even social factors – that interplay to determine the particular form of technological development we finally observe. The notion of path dependency clearly matters here because the specific innovation outcome observed, being it a new product, process, technology, institution or system, is unique and contingent resulting from an historically constrained pattern of interactions (David, 1997 and 2000).

Moreover, and consequently, such localised creation of technological knowledge has been neither only dependent on firms' internal resources nor on external institutional and public efforts. Such localised production of technological knowledge is the result of the interpolating relationships between firms' based tacit learning and the formalised acquisition of external knowledge originated in both firms and institutions. The absorption of external knowledge and also, and more importantly, the integration and recombination between the two processes and the related knowledge bases is fostered by the presence of multiple, formal and informal, interactions mechanisms (Maskell, 2001; Maskell and Malmberg, 1999; Maskell et alii, 1998).

Finally and more importantly, the generation and diffusion of localised technological knowledge appear not as intrinsic properties of isolated agents (i.e. firms), but as emergent phenomena where different actors and mechanisms are interdependent and co-evolving. The production and organisation of technological knowledge, and the birth and growth of innovation systems at large, result from the co-evolution of technology in a narrow sense and the more general institutional

framework. The specific set of economic and social interactions arises here as the crucial institutional arrangement for the governance of knowledge production and distribution (Metcalfe, 2000 and 2001).

Within our empirical context, the generation and distribution of technological knowledge are improved through the different kinds of knowledge provided by the variety of interactive actors and mechanisms. The case of the Emilian plastics district highlights that the progressive generation of a common and localised background of technological knowledge and the emergence of a relevant technological system have been promoted through a wide set of communication mechanisms established among the variety of local actors belonging to both the productive and the institutional systems.

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Figure 5. Technological complementarities in the emergence of the Plastics technology system

Table 1. Plastics consumption by industry in Western Europe (Tonnes and percent; 1999)

Sectors	Tonnes	%
Packaging	13,464,583	40.10
Automotive	2,253,098	6.71
Electronics	2,539,110	7.56
Building and construction	6,166,267	18.36
Large industry	1,803,056	5.37
Other household and domestic	6,503,759	19.37
Agriculture	848,037	2.53
Total	33,577,910	100.00

Source: APME, (2000)

Table 2. The evolution of plastics and manufacturing industries in the Correggio district compared to Italy, Emilia Romagna region and the wider Emilian plastics cluster (1951-1998; number of firms; number of employees)

	Correggio district*			Italy			Emilia Romagna region			Emilian cluster**		
	Manuf.	Plast.	Specialisation	Manuf.	Plast.	Specialisation	Manuf.	Plast.	Specialisation	Manuf.	Plast.	Specialisation
Year						Firms						
1951	520	2	0.3846	631,875	3,974	0.6289	53,328	277	0.5194	4,858	4	0.0823
1961	481	6	1.2474	609,760	2,882	0.4726	57,450	310	0.5396	5,218	65	1.2457
1971	676	24	3.5503	629,759	6,619	1.0510	63,754	948	1.4870	6,700	147	2.1940
1981	1,096	54	4.9270	784,777	12,715	1.6202	81,761	1,580	1.9325	10,694	310	2.8988
1991	1,012	75	7.4111	862,609	11,114	1.2884	80,065	1,171	1.4626	10,017	268	2.6755
1996	893	103	11.5342	757,014	12,671	1.6738	69,320	1,287	1.8566	8,922	326	3.6539
1998	766	99	12.9263	560,391	10,031	1.7900	58,022	1,176	2.0268	9,234	357	3.8661
						Employment						
1951	1,816	22	1.2115	3,498,220	53,559	1.5310	208,616	2,506	1.2013	18,378	24	0.1306
1961	3,095	121	3.9095	4,498,004	44,596	0.9915	355,354	3,197	0.8997	36,154	459	1.2696
1971	4,530	237	5.2318	5,308,587	101,485	1.9117	463,243	9,758	2.1065	51,206	1,466	2.8629
1981	6,988	571	8.1712	6,143,378	136,118	2.2157	586,133	14,005	2.3894	69,008	2,522	3.6546
1991	7,911	893	11.2881	5,784,608	131,383	2.2713	582,602	14,038	2.4095	72,606	2,950	4.0630
1996	8,414	1,231	14.6304	5,209,134	151,522	2.9088	546,207	15,824	2.8971	69,713	3,620	5.1927
1998	5,844	1,268	21.6975	3,878,676	105,500	2.7200	404,260	12,562	3.1074	70,832	3,897	5.5018

Source: elaboration on ISTAT (1951, 1961, 1971, 1981, 1991, 1996) and CCIAA Reggio Emilia (1998)
Note: The degree of specialisation in the plastics industry characterising the diverse geographical domains is calculated as the ratio between the number of plastics firms/employers and the number of overall manufacturing firms/employers. Thus it is calculated as an index of industrial specialisation.
*Towns of Correggio, San Martino in Rio, Rio Saliceto.
**Towns of Bagnolo in Piano, Bibbiano, Cadelbosco Sopra, Campagnola, Cavriago, Correggio, Gattatico, Luzzara, Novellara, Reggio Emilia, Reggiolo, Reggiolo, Rio Saliceto, Rubiera, S. Ilario D'Enza, S. Martino in Rio (Province of Reggio Emilia), and of Carpi, Campogalliano, Mirandola (Province of Modena).

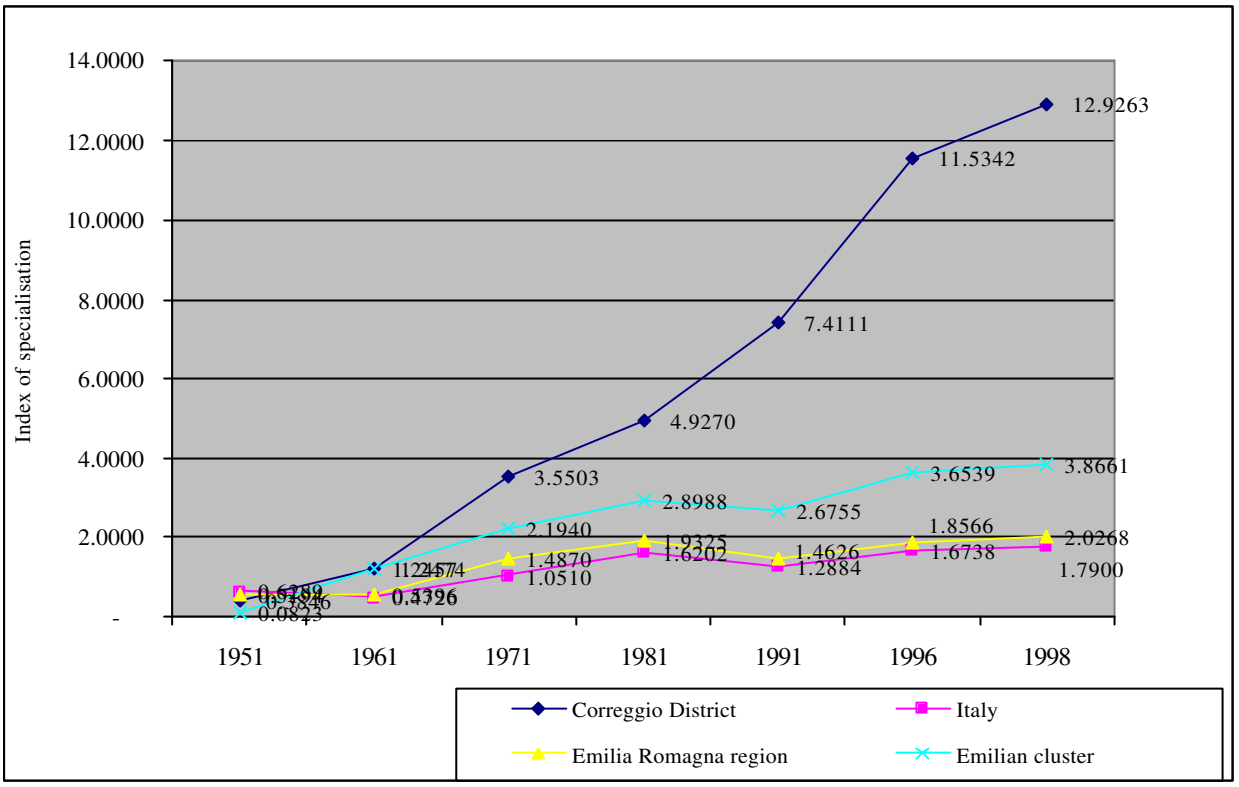
Table 3. The concentration of plastics production in small firms in the Correggio district compared to Italy, Emilia Romagna region and the wider Emilian plastics cluster (1996; number of firms; number of employees; percent in brackets)

	Dimension of firms*					
	1 - 9	10 - 19	20 - 49	50 - 99	>= 100	Total
			Firms			
Correggio district	65 (63.1)	21 (20.2)	12 (11.9)	5 (4.8)	- (0.0)	103 (100.0)
Emilian cluster	200 (61.4)	77 (23.5)	37 (11.4)	11 (3.4)	1 (0.3)	326 (100.0)
Emilia Romagna	810 (62.9)	281 (21.8)	145 (11.3)	32 (2.5)	19 (1.5)	1,287 (100.0)
Italy	8,426 (66.5)	2,268 (17.9)	1,432 (11.3)	342 (2.7)	203 (1.6)	12,671 (100.0)
			Employment			
Correggio district	192 (15.6)	255 (20.7)	363 (29.5)	421 (34.2)	- (0.0)	1,231 (100.0)
Emilian cluster	760 (21.0)	985 (27.2)	999 (27.6)	753 (20.8)	123 (3.4)	3,620 (100.0)
Emilia Romagna	2,864 (18.1)	3,608 (22.8)	3,877 (24.5)	2,168 (13.7)	3,307 (20.9)	15,824 (100.0)
Italy	26,365 (17.4)	28,335 (18.7)	38,638 (25.5)	21,668 (14.3)	36,517 (24.1)	151,522 (100.0)

Source: elaboration on ISTAT (1996)

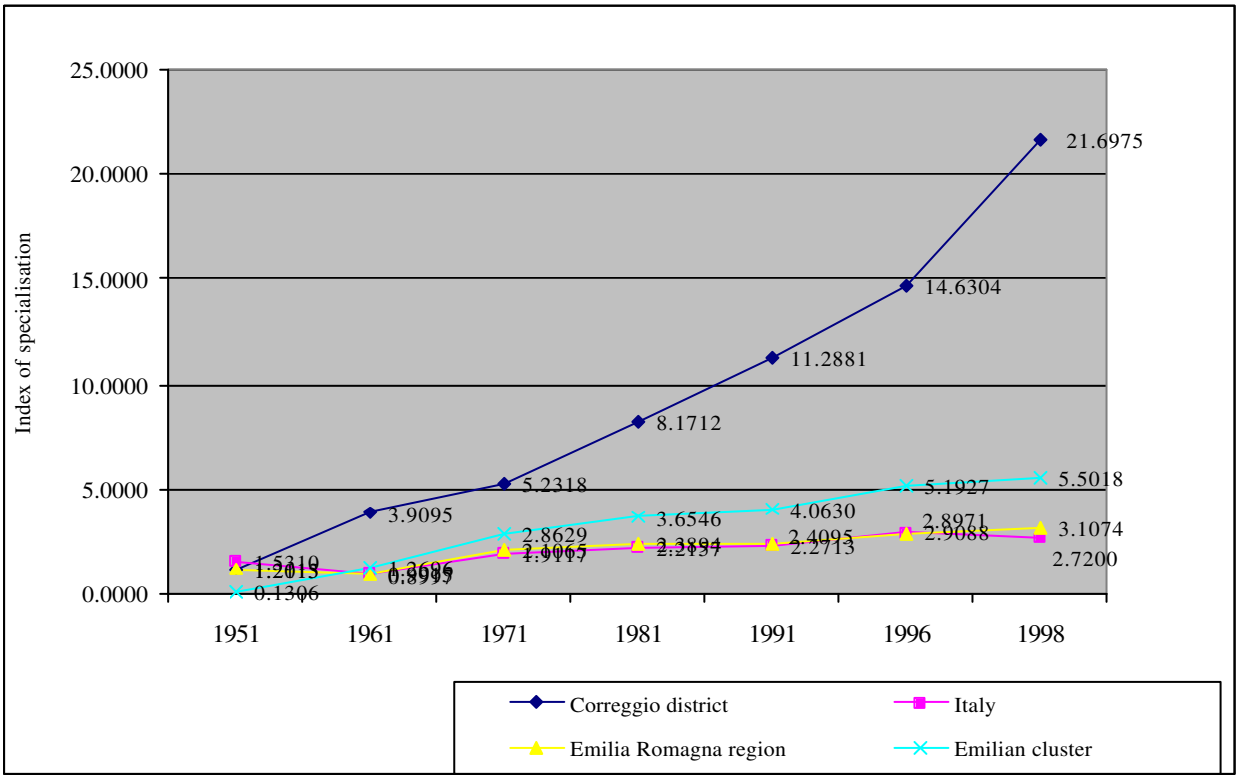
* Dimension of firms is articulated in terms of classes of employees

Figure 1a. The evolution of specialisation of the Correggio district in the plastics industry compared to Italy, Emilia Romagna and the Emilian cluster (1951-1998; firms)



Source: ISTAT (1951, 1961, 1971, 1981, 1991, 1996) and CCIAA Reggio Emilia (1998)

Figure 1b. The evolution of specialisation of the Correggio district in the plastics industry compared to Italy, Emilia Romagna and the Emilian cluster (1951-1998; employment)



Source: ISTAT (1951, 1961, 1971, 1981, 1991, 1996) and CCIAA Reggio Emilia (1998)

Table 4. The geographical concentration of plastics production in the area of Correggio (1996; firms; employment)

Municipalities	Plastics firms	Manufacturing firms	Firms specialisation	Plastics employees	Manufacturing employees	Employment specialisation
Bagnolo in Piano	8	164	4.8780	122	1453	8.3964
Bibbiano	14	209	6.6986	235	1370	17.1533
Cadelbosco Sopra	10	190	5.2632	80	1276	6.2696
Campagnola	4	131	3.0534	57	892	6.3901
Cavriago	17	295	5.7627	217	2823	7.6869
Correggio	**64**	**531**	**12.0527**	**921**	**5081**	**18.1264**
Gattatico	7	107	6.5421	65	1062	6.1205
Luzzara	9	219	4.1096	139	2624	5.2973
Novellara	18	308	5.8442	167	2073	8.0560
Reggio Emilia	51	2587	1.9714	406	19731	2.0577
Reggiolo	6	244	2.4590	27	2443	1.1052
Rio Saliceto	**22**	**168**	**13.0952**	**163**	**1098**	**14.8452**
Rubiera	12	259	4.6332	242	2846	8.5032
S. Ilario d'Enza	8	201	3.9801	135	1736	7.7765
S. Martino in Rio	**17**	**194**	**8.7629**	**147**	**2235**	**6.5772**
Carpi	44	2384	1.8456	349	13659	2.5551
Campogalliano	6	237	2.5316	59	2598	2.2710
Mirandola	9	494	1.8219	89	4713	1.8884

Source: elaboration on ISTAT (1996)

Figure 3. The core spin-off dynamics in the Emilian plastics district (1942 - 1985)

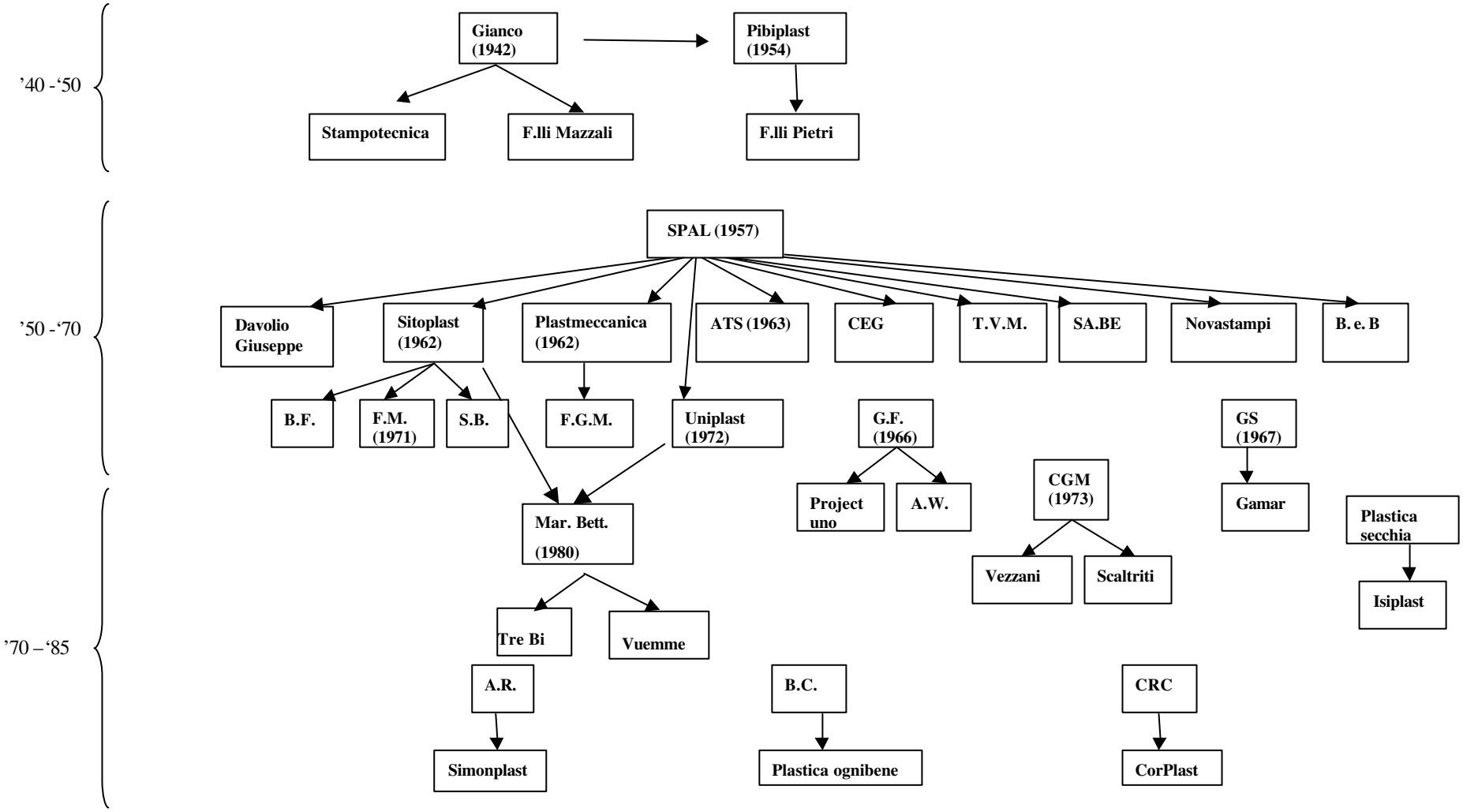


Table 5. Main entrepreneurs in the plastics district, prior employment position and relevant know-how (1942-1985)

Entrepreneur	Company	Year	Prior employment position	Know-how
Corrado Gianfranceschi	Gianco	1942	Engineer at Fiat and Bayer	Engineering-based knowledge in mechanics
Paolo Bosi	Pibiplast	1954	Engineer and main partner in Gianco	Engineering-based know-how in plastics and entrepreneurship
Terzino Spaggiari & Alberto Alberti	Spal	1957	Technician in the mechanics sector and client of plastics firms (especially Gianco)	Mechanical technical know-how
Tonino Mariani	Sitoplast	1962	Shop foreman at Spal	Skill-intensive and long-term experience based technical know-how in the plastics sector
Rino Spaggiari	Plastmeccanica	1962	Head of the plastic injection moulding process at Spal	Skill-intensive and long-term experience based technical know-how in the plastics sector
Enzo Spaggiari	ATS	1963	Technician in plastics sector at Spal	Plastics technical know-how
Tiennio Bettati	Uniplast	1972	Technician in plastics sector at Spal and Sitoplast	Plastics technical know-how
Tonino Mariani & Tiennio Bettati	Mar.Bett.	1980	Technicians at Spal, entrepreneurs with Sitoplast and Uniplast respectively	Plastics technical know-how and entrepreneurship
Mario Franchini	FM	1971	Shop foreman at Spal and Sitoplast	Skill-intensive and long-term experience based technical know-how in the plastics sector
Giorgio Gaiti & Loris Ferraris	GF	1966	Technicians in the mechanics sector and client of plastics firms	Mechanical technical know-how
Gobbi & Spaggiari	GS	1967	Technicians in the mechanics sector and client of plastics firms	Mechanical technical know-how
Parmeggiani & Zagni	CGM	1973	Entrepreneur in the mechanics sector and client of plastics firms	Mechanical technical know-how and entrepreneurship

Table 6. Outsourcing solutions by productive phase and localisation (1997-1999; percent)

Decentralised phase	%	Localisation of sub-contractors		
		Regional/ local	National	International
Simple phases	52.0	44.0	8.0	0.0
Components and intermediary inputs	32.0	16.0	12.0	4.0
End goods	28.0	20.0	4.0	4.0

Source: Baldoni and Bonaduce (2000)

Table 7. Client firms of plastics moulding producers in terms of technological variety (1997-1999; percent)

Sectors	No clients	Market shares*		Total
		<60%	>60%	
Mechanics	52.2	30.3	17.5	100.0
Automotive	41.6	37.6	20.8	100.0
Agro-food	58.3	29.2	12.5	100.0
Biomedical	75.0	16.7	8.3	100.0
Packaging	91.7	4.2	4.1	100.0
Non-food	87.1	8.6	4.3	100.0

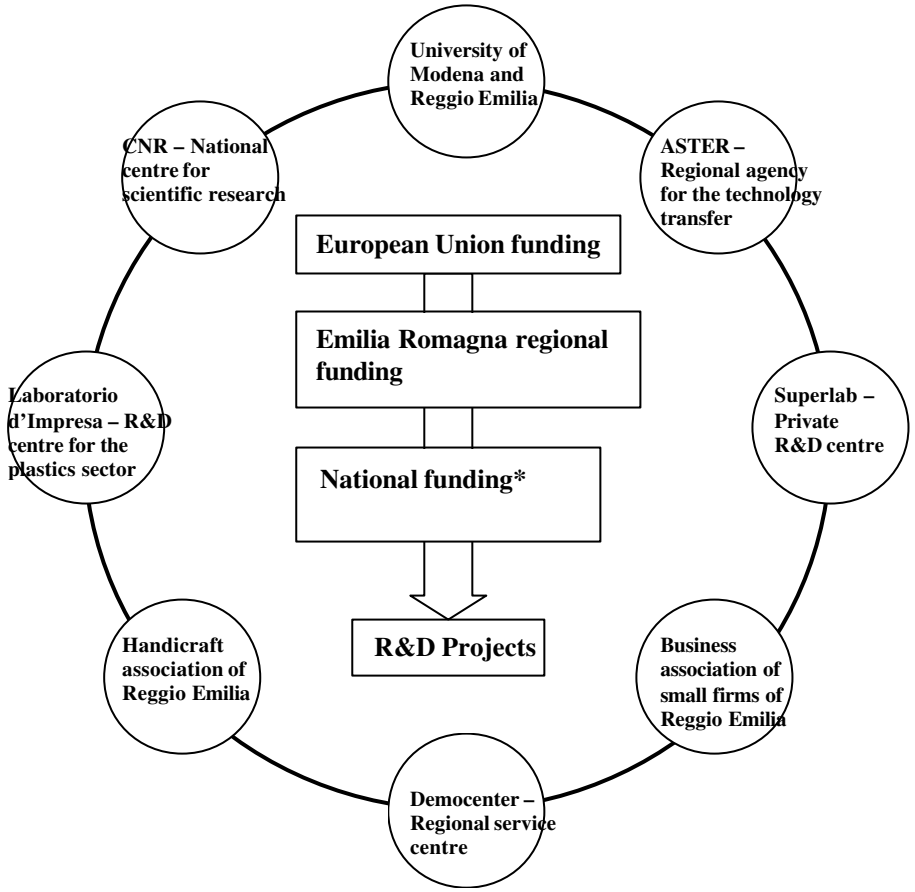
*Measured in terms of turnovers reached by plastics firms in each client industry
Source: Baldoni and Bonaduce (2000)

Table 8. The sources of innovation for plastics firms (1997-1999; percent)

Types of innovation	Sources of innovation				
	External*	Internal**	Market-oriented***	Others	Total
Process innovations	60.0	24.0	4.0	12.0	100.0
Product innovations	44.0	8.0	28.0	20.0	100.0
Organisational innovations	37.5	41.6	4.2	16.7	100.0
Commercial innovations	16.0	20.0	20.0	44.0	100.0

*External sources are: clients needs, institutional constraints including standards and quality requirements
**Internal sources are: costs reduction, process optimisation and efficiency in general
***Market-oriented sources are: entry in new markets, commercial strategies
Source: Baldoni and Bonaduce (2000)

Figure 4. The institutional R&D network in the Emilian plastics cluster in the 90s



*National funding includes also objective 2 regions-focused funds

Figure 5. Technological complementarities in the emergence of the Plastics technology system