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Knowledge codification and the geography of innovation: the case of Brescia mechanical cluster

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Abstract

The paper re-examines the twin concepts of knowledge "tacitness" and "codification", which both the literature on (broadly defined) industrial districts, and some recent econometric literature on "localized knowledge spillovers" have possibly mis-handled. Even within specialized local small and medium enterprises (SMEs) clusters, knowledge may be highly codified and firm-specific. The case study on Brescia mechanical firms shows that knowledge, rather than flowing freely within the cluster boundaries, circulates within a few smaller "epistemic communities", each centered around the mechanical engineers of individual machine producers, and spanning to a selected number of suppliers' and customers' technicians. Physical distance among members of each community vary a lot, but even local messages may be highly codified.

Keywords: Knowledge tacitness; Codification; Epistemic community; Machinery; Industrial districts

1. Introduction

In the past few years, regional economics and the economics of knowledge have multiplied their links and exchanges. On the one hand, an increasing number of researchers in regional science and economic geography have suggested that one of the key competitive assets of many manufacturing clusters in traditional industries, such as Italian industrial districts, is their capability to introduce and diffuse innovations at a much faster rate than their organizational counterparts (such as large companies, possibly vertically integrated). Many researchers in the same fields have also provided detailed accounts of the outstanding innovation capabilities of hi-tech SME clusters, possibly located nearby top-rate academic facilities. In both cases, explanations of the observed phenomena have suggested that knowledge generated by cluster-based firms spreads rapidly *within* the cluster itself, but very slowly *outside* it. Concepts such as "tacitness" or "codification" have been borrowed from the economics and sociology of knowledge, and used widely to explain how physical distance may affect innovation patterns.

On the other hand, researchers in the economics of knowledge have started exploring the geographical implications of their conceptualization of knowledge activities. In addition, some of them have explored the consequences of the diffusion of ITs, a most valuable tool for knowledge codification, for the geography of innovation.

Overall, this cross-fertilization appears to be very stimulating, but also extremely confusing. Different definitions of the same concepts (above all, "tacitness" and "codification") abound, and many of them seem very far from having reached an operational status. As a consequence, empirical research appears to be, from

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a methodological viewpoint, very heterogeneous and highly fragmented.

The purpose of this paper is to test the usefulness of a number of concepts, which have been recently proposed by leading researchers in the economics of knowledge, for describing the innovation activities in a well-established local system of production, namely the mechanical cluster of Brescia (east Lombardy). This exercise will allow us both to de-bug those concepts, thus proposing changes and improvements, and to use them to better define the sort of knowledge activities that take place in a district-like area such as the one we have selected.

In order to do so, we first discuss some recent literature on the economics of knowledge codification, and show what implications one can derive for the study of local systems of production and innovation (Section 2). Then we move on to present the key features of three selected group of machinery producers in Brescia, namely the producers of hosiery machinery, metal molding presses and molding presses for thermoplastics. We describe their design activities, which involve both a high degree of knowledge creation and dissemination, and also represent the key channels for introducing innovations (Section 3). In doing so, we use the conceptual categories discussed in Section 2. Finally, in Section 4, we put forward a few conclusions, and suggest a number of policy implications.

2. Tacit knowledge and the geography of innovation

2.1. Recent fortunes of tacit knowledge in economic geography

Recent developments in the theory of industrial districts have increasingly emphasized the role of knowledge diffusion in supporting the districts competitive advantages. Concepts such as “tacit” and “codified” knowledge have been called in to explain what kind of innovation industrial districts are good at producing, and why. Codified knowledge is described as general and abstract: understanding it may require high education levels, and also some personal contacts, but no common social background. Codified knowledge, that is, can be easily transferred outside its context of generation. On the contrary, tacit knowledge can be understood only by people who have shared the same personal experiences, and possibly contributed actively to its generation. Therefore, the existence and diffusion of tacit knowledge requires the pre-existence of a community of people, rich of social links and endowed with a common cultural background.

While codified knowledge is implicitly seen as responsible for major technological and scientific breakthroughs, tacit knowledge is described as the necessary tool for translating them into economically viable innovations. That is, the two are seen as complementary. However, exploiting this complementarity requires tacit skills.

Thus, industrial districts, which, by definition, rely upon long-established and homogeneous social networks, are best placed to diffuse and produce tacit knowledge. In addition, as long as they manage to gain access to codified knowledge, they will be well positioned for combining the latter with their own, and appropriate the results. The following quotations from Brusco (1996), and Becattini and Rullani (1996) are enlightening:

> The underlying idea [behind the industrial district theory] is that the decisive factor in determining development [. . .] is knowledge in its various forms [. . .].
>
> The first of these two [forms] is that of *codified* knowledge [. . .] The site of this knowledge is the scientific community, whose members are able to exchange this culture and knowledge with relative ease.
>
> The second type of knowledge is *local* [. . .] This local know-how is passed on by doing things and seeing how other people do things, through informal chit-chat [. . .] Above all, this form of knowledge is necessarily rooted in a specific area in which people are linked by the bonds of a shared history or values, where specific institutions work to the benefit of people and where codes of behaviour, lifestyles, employment patterns and expectations are inextricably implicated in productive activity. (Brusco, 1996, pp. 149–150)

> [In] each local system an integration between “codified knowledge” and “contextual knowledge” is realized [. . .] (Becattini and Rullani, 1996, p. 162)

> [The] coding and decoding of knowledge often involves a set of skills which cannot be set out in a simple standardized code. Rather, it is a matter of complex and often indefinite, and not rarely "indescribable" skills which can be acquired only by direct experience, by repeated practice, or by the process of "seeing at work" [. . .] (Becattini and Rullani, 1996, p. 164)

> The local systems [. . .] employ their contextual knowledge [. . .] to filter, take possession of, elaborate and orient that [codified] transferable knowledge [. . .] (Becattini and Rullani, 1996, p. 169)

Tacit knowledge is given even a greater role in some recent econometric studies on the geography of innovation.[1] Here, it is assumed that the geographical concentration of innovation activities is necessarily due to the existence of (vaguely defined) "network effects", which we understand to imply word-of-mouth processes of knowledge exchange. These are likely to be spatially bounded. Many authors measure the "propensity for innovative activity to cluster spatially" by means of econometric estimates based upon the concept of innovation production function. Then, they relate their findings to what they call the "considerable evidence supporting the existence of knowledge spillovers", which consists both of their own previous work, and a number of well-known case studies on hi-tech clusters, the most heavily quoted being possibly Saxenian (1994).[2]

However, their findings can be also explained by different sets of agglomeration forces (such as Marshallian externalities in the labor market and the market for intermediate inputs), which have nothing to do with knowledge-sharing.[3]

Even more strikingly, many of these findings are referred to very broad geographical units (such as individual states within the US) and even broader industries (3- if not 2-digit codes). A key example is provided by Feldman and Florida (1994):

> Concentrations or agglomerations of firms in related industries provide a pool of technical knowledge and expertise and a potential base of suppliers and users of innovations. These networks play an especially important role when technological knowledge is informal or tacit in nature [. . .] Concentrations of these firms foster important synergies in the innovation process, as for example when innovations in semiconductors spill over into electrical, consumer electronics, and computers industries (Feldman and Florida, 1994, p. 220)

Work by Acs et al. (1992, 1994), and Audretsch and Feldman (1996) goes even further, and extends the same line of reasoning from pure inter-firm relationships to the interplay between business and academic R&D. In this case, tacit knowledge is given a big role even within universities, or at least in their relationship with the outside world.

2.2. Knowledge tacitness revisited, and the role of epistemic communities

Both the industrial district theory and the more recent research on innovation clusters seem to fall squarely in that category of studies which Cowan and Foray (1997), and Cowan et al. (2000) (from now on, CF97 and CDF00) target as guilty of having possibly overestimated the role of tacit knowledge in promoting technological change, and possibly mis-interpreted the meaning of "tacit" versus "codified" knowledge in Polany's (1962) original contribution.

CF97 and CDF00 observe that all knowledge for which a "codebook" is available can be classified as codified. Moreover, as suggested by Steinmueller (2000), CF97's and CDF00's definition of codebook goes very near to that of "language". Language rules, whether written or not, certainly exist and are acknowledged by all those who speak that language. Moreover, one can presume that the better and more widely the codebook is known, the less is the need to refer to it explicitly. This happens both within individual firms, inter-firm relationships inside and outside industrial districts, as well as in academic discussions.

At the same time, codebooks/languages may well serve as means of appropriation, since codified messages cannot be understood outside the realm of those who have access to the codebook. The possibility, for those who did not participate to the creation of the codebook, to access such a codified knowledge depend

[1] For a more detailed survey of this literature, see Breschi and Lissoni (2001b).

[2] Quotations from Audretsch and Feldman (1996).

[3] On this point, see the *Conclusions* by Glaeser et al. (1992).

on the rule of access to the codebook (whether to put the latter down in written form also depends on those rules). That is, to use CDF00's own words, the two issues of "codification" and "manifestation" have to be distinguished and, possibly, dealt with separately.

These remarks reduce tacit knowledge to "unvoiced" or "unarticulated" knowledge, which may be so for two reasons:

1. There is no (foreseeable) way to articulate it, i.e. to work out a common set of rules for talking or writing about it, either by means of common language or scientific formulas or even drawings and the likes. This is what CDF00 call "unarticulable knowledge".
2. Although codification is a possibility, this has not (yet) been undertaken, possibly for economic reasons, i.e. lack of incentives or too high costs.

Conversely, knowledge codification is portrayed as a complex process, which impinge upon economic considerations and calls for further conceptual work, as well as empirical studies. In particular, one can look at it as a three-stage activity: (i) codebook creation (which requires the joint effort of building up a model for understanding and a language for communication); (ii) creation of messages (for all those who share the same language and understand the model); (iii) extension of both the model and the language, when required to improve the content of messages. [4]

From this reformulation it follows that the *logical room* given to "intrinsically" tacit (i.e. unarticulable) knowledge is dramatically reduced. To go back to the quotation from Brusco (1996) we reported above, we must distinguish between knowledge which is passed on "by doing things and seeing how other people do things" (which can be unarticulable, as long as there is no other way to transmit it) and knowledge that is transmitted "through informal chit-chat", which is necessarily codified (otherwise it could not be articulated), no matter whether the code is displaced, written down, hidden to outsiders or difficult to understand without a full immersion in the local community. [5]

This, in turn, imposes a new entry in the research agenda, which has to do with identification of the size and social composition of those groups of people which share one or more codebooks, as well as the extension and disclosure rules they follow. Here, we are suggested to focus first and foremost on the so-called "epistemic communities", which are defined as:

> [. . .] *Small* working groups that work on a mutually recognized subset of knowledge issues, and who at the very least accept some commonly understood procedural authority as essential to the success of their collective knowledge-building activities [. . .] (CDF00; italics are mine)

A well-known example of an epistemic community is given by US steel minimills' engineers, as described in von Hippel's (1987) analysis of informal know-how trading. Here, we have a group of people who can rely upon mutual understanding (which implies, at least, some common jargon if not a full-developed language), a few procedural agreements about how to conduct research or design and project activities, and some norms for the identification of what kind of knowledge ought to be shared, and with whom.

When it comes to extending or building up new models and languages, epistemic communities of this kind are in a better position than loose groups of researchers and technicians. As for the benefits they can reap from codification, CDF00 list a number of them, which Steinmueller (2000) comments upon critically and connects to similar analysis by Nightingale (1997), and Arora and Gambardella (1994), to which one could add Arora and Gambardella (1997).

From a joint reading of this literature, it becomes evident that much of the discussion about the benefits of codification originates from the intuition that the latter is a necessary requirement for the exploita-

[4] Activity (i) represents a fixed cost, while the cost of the other activities are variable (i.e. they are a function of the number of messages produced). Whenever codebooks already exist, codification is reduced to activities (ii) and (iii). If there is no codebook, activity (i) has to be undertaken, which increases codification costs dramatically.

[5] However, one should notice that the *weight* assigned to tacit knowledge in diffusing and generating innovation is *not* reduced. CDF00 say nothing about the size and importance of "unarticulable" knowledge versus the "codifiable" one. Moreover, their assimilation of codebooks to language leaves open the possibility that understanding and being capable to use the codebook may depend upon tacit skills (as well explained by Steinmueller, 2000).

tion of information technologies in the processes of knowledge storage, transmission and generation.

In particular, it emerges that codifying knowledge, in order to store and transmit it by IT means, becomes attractive whenever innovation activities:

- are based upon team work, where the team can be described as an "epistemic community" (see above);
- depend heavily on re-combination and re-use of components, parts and modules of any kind (e.g. mechanical components or software routines);
- require detailed memory of past innovation efforts and outcomes;
- take place in a rather stable technological environment.

At the same time, Steinmueller (2000) emphasizes that, for codification to be successful, a number of complementary investments have to be undertaken, such as those strengthening *appropriability means*, or improving *the freedom of access to members of the epistemic community*. The former have to be made in order to avoid dispersion of innovation rents. They may consist both in dedicated encoding activities (e.g. the selection or creation of terms which are informative enough for insiders, but obscure to outsiders) and in tutorial activities, i.e. codebook transmission to newly recruited insiders. The latter require purchases of hardware memories, the development of appropriate software, and the provision of logistic services.

2.3. Research implications

By counterpoising this re-examination of the concepts of tacitness and codification to the use of the same words within the geographical literature we discussed above, we come to share in CDF00's invitation to:

> [...] re-examine many empirical studies, which have been done in the near past and whose main conclusions are that tacit knowledge remains key in many activities. This is perhaps true, but difficult to document convincingly; all these studies fail to prove that what is observed is true 'tacitness' rather than highly codified knowledge without explicit reference to the codebook [...] Differentiating among the various cases certainly requires deep and careful case studies. By definition a codebook which is not manifest is not observable in that context, and there is a high risk that various situations can be confused.

These statements are particularly convincing when referred to industrial districts. These are often specialized in industries whose products are largely mature ones, and whose processes lend themselves to extreme vertical dis-integration. They often host specialized suppliers of machinery or mechanical components, sometimes alongside significant groups of users. Innovations are very likely to be incremental ones, often derived from persistent efforts of product differentiation or repeated requests of customization, and highly focused on a few key parameters or components. In both cases, inter-firm coordination, system memory and continuous recombination of parts and modules are most likely to play a prominent role in the innovation process (on this point see also Foray, 1991). That is, they deal with knowledge activities that look very much like those identified by Steinmueller (2000) as most likely to benefit from codification.

Thus, we have the paradoxical result that an organizational form such as the district, which has often been depicted as the reign of tacit (unarticulable) knowledge, and informal sharing or uncontrolled leaking out of it, now appears, in the light of the proposed re-conceptualization, very likely to engage in codification efforts, and in investing in the related appropriability measures. This forces us to view they key knowledge assets of districts no more as a sort of local public good (unavailable to outsiders, but accessible to all members of the broad social community), but as the endowment of a number of epistemic communities, whose size, composition (above all, inter-firm distribution), knowledge-sharing rules, and communication patterns have to be properly investigated.

In the following section, we build upon this intuition and propose a re-examination of the innovative process in a typical Italian clusters of small and medium enterprises, which encompasses producers of hosiery machinery alongside with producers of molding presses for both metals and thermoplastics. Although belonging to two different industries (thus forming not just a district, but possibly two of them) and to be so old that industrial concentration has been recently rising well above usual district-standard, this cluster presents many district-like features. In particular, most subcontracting and supply relationships are highly localized, as it is the relevant labor market. Many users of mechanical equipment are also located nearby their suppliers, which in turn were often founded as spin-offs of other producers or pre-existing large users. Finally, firms located within these clusters are highly export-oriented and, in some cases, world leaders in their market niche.

Overall, such features make our case study comparable to similar ones from the Italian literature on industrial districts (especially if focused on a critical re-assessment of the economics of knowledge therein, such as Balconi, 1999; Russo, 2000) or from its broader international counterpart on local innovation systems.[6] From such a comparison, a more detailed portrait of localized knowledge activities should come out, with highlights on the boundaries between different epistemic communities within individual districts, as well as on the codification strategies of each community.

3. Codification and innovation in a SME-based area: the case of Brescia

The research addresses the three top sectors within the Italian operating machine industry, respectively:

- Textile machinery.
- Metalworking machine tools.
- Plastic-processing machinery.

In particular, it focuses on three key subsectors wherein firms located within the province of Brescia (east Lombardy) hold a clear national or international leadership:

- Hosiery machinery.
- Metal molding presses.
- Molding presses for thermoplastics.

As many other sectors within east Lombardy, these are characterized by the dominance of small and medium enterprises (SMEs), as well as by a blend of historical links with local users and aggressive export-orientation.

Hosiery is a key niche of Italian textile industry. In particular, two industrial districts, both localized nearby Brescia, dominate production and commercialization: CastelGoffredo (north of Mantua, world leader in the production of panty-hoses) and Botticino (southeast of Brescia, European leader in the production of socks).

The production of hosiery machinery in Brescia was originally spurred by the combination of the highly traditional mechanical skills of the province with the request of capital goods coming from both districts. Nowadays, the hosiery machinery producers in the area of Brescia are eight: Lonati (world leader in this sector), Sangiacomo, Rumi, Colosio, Busi, Santoni (owned by Lonati), Nuova MarcTex, and IrmacTex. There are only two other producers of some relevance outside Brescia, namely Nagata (Japan) and Matec, which is located nearby Florence, and has been recently acquired by Lonati (after many years under state control). For all these firms, export is responsible for no less than 80% of sales.

The Brescia producers are the only survivors of a large number of spin-offs from a local textile producer, which failed back into the 1950s. Most of the original spin-offs failed or were bought-off before the late 1960s–early 1970s. During the same years, and even more throughout the 1980s, Lonati outgrew both the local and the more distant competitors. Nowadays, Lonati heads a medium-size conglomerate company, which spans from vertically integrated activities in the textile machinery production to some metalworking and a few financial activities.

Table 1
Top world producers of die-cast molding presses, by country; 1997[a]

Italy	Other countries
Ardi Srl[b,c]	Prince (US)
Colosio Srl[b]	HPN (Japan)
Idra Presse Spa[b,c]	Toio (Japan)
Irmi Srl[b]	UBE (Japan)
Italpresse Industrie Srl[b,c]	Toshiba (Japan)
MaicoPresse Spa[b,c]	Muller–Weingarten Ag (Germany)
Oleopress Srl[b]	Fondarex S.A. (Switzerland)
Realpres Srl[b]	Urpemaka (Spain)
STP Presse Srl[b,c]	
Agrati AEE Srl	
Frech Italia Srl	
Buhler Spa	
TCS Molding System Spa	

[a] EDIMET, as in Ottaviani (1999).
[b] Producer from province of Brescia.
[c] Interviews/questionnaires provided.

[6] See references in Breschi and Lissoni (2001a).

Table 2
Italian producers of injection molding presses and other equipment for thermoplastics, Lombardy vs. other regions; 1997[a]

Region	Injection molding presses		Other plastic-working equipment	
	Number of producers	Percentage over Italy	Number of producers	Percentage over Italy
Lombardy	23	65.7	292	67.7
Milan	11	31.4	126	29.2
Brescia[b]	7	20.0	34	7.9
Other provinces	6	17.1	132	30.6
Other regions	11	31.4	139	32.3
Italy	35	100	431	100

[a] ASSOCOMAPLAST, as in Filippini and Scaini (1999), and Zanardelli (2000).
[b] Brescia producers in 1997 were: Mir, Pip, Bmb, Italtech, MaicoPresse, Realpres, and Remu. Remu closed down in 1999.

The metal working industry is the most important manufacturing sector of the province of Brescia, as well as its most traditional one. Through time, it has encouraged the birth of a number of machine tools and operating machine producers, among which the producers of metal molding machines have acquired a very high technological status. Since the late 1970s, technological change has had to do with the introduction of new materials for the molds, in particular new metals or metallic alloys, and thermoplastics.

Nowadays the province of Brescia hosts 10 out of the 14 leading Italian producers of die-casting molds (which in turn are the majority of world producers; see Table 1) as well as most of the producers of a particular kind of molds for thermoplastics, namely injection molds (see Table 2). All the producers of molding machines for metal alloys in the area were born as spin-offs, either from the local pioneer in the field (IdraPresse, still a leading firm) or from its own spin-offs (the most important one being ItalPresse). Similarly, producers of molds for thermoplastics are the outcome of diversification efforts by local producers of metal molds, or the outcome of entrepreneurial efforts of the latter's former employees; in a few cases, the same firms are active in both markets.

A characteristic of Brescia mold producers, when compared to their competitors from other Italian areas (mainly northwest Lombardy) as well as from the rest of Europe and Japan, is their specialization in large, customized machines. That is, typical customers are scale-intensive producers of assembled products such as cars and large household appliances. Buyers of mass-produced, multi-purpose smaller machines, such as producers of simpler and smaller die-cast products or components, are less likely to be found among typical customers of Brescia manufacturers of molding presses.

No organized statistics are available at the local level. Therefore, mixed qualitative/quantitative interviews have been the key tool of our research. First and foremost, the interviewees were asked to help us reproducing in detail both the production and the design activities of their companies, in order to allow us to identify clearly both the key actors and their knowledge activities. The interviews were then followed by the distribution of a short questionnaire, aimed at getting some quantitative information from engineers (and a few users) engaged in design, prototyping, and testing activities. The ultimate objective was here to define the boundaries of the various epistemic communities within the cluster, and the means employed for exchanging knowledge among local actors.[7]

The basic strengths of this research approach come first and foremost from the detailed reproduction of the design and production work-flow for each company in our sample. By asking interviewees to check and revise a few draft schemes, and to provide complementary information on the actors listed therein, we managed to learn and share much of the

[7] All Brescia producers in the hosiery machinery area, with the only exception IrmacTex, have been interviewed, along with their local suppliers of electronic components. As for the producers of molding presses for thermoplastics, all but Pip and Realpres were contacted and interviewed, while five out of nine producers of die-cast metal molding presses allowed us to interview their managers and/or engineers.

interviewees' language, as well as to avoid the trap of too generic questions and answers. This was of great help in setting up the following questionnaires, which allowed us to collect factual information about knowledge exchanges and knowledge codification activities, rather than the interviewees' opinions about our own views of the latter. By pointing at specific portions of the work-flows, we also managed to identify the interviewees' specific competencies, so that both our questions and their answers could be strictly referred to their own personal experience.

As for the limitations, they have mostly to do with the lack of data on the *indirect* links between the interviewees: while we managed to submit our questionnaires to almost all of the technicians of local suppliers, we did not interview those technicians' contacts within foreign suppliers and distant users.[8] It should also be noticed that most firms turned out to be very secretive about their technicians and opposed our efforts for contacting them directly, as well as forcing us to limit severely the contents of the questionnaire.[9]

3.1. Mechanical versus electronic knowledge: the core competencies of Brescia operating machine producers

Since the 1970s, innovations in the operating machine industry have been coming from two different technological fields, namely electronics and mechanics (and, in the molding machine sector, hydraulics). However, our interviews reveal that local producers' core competencies rest firmly in the mechanical field. Similarly, their interactions and information exchanges with most customers refer mainly to the mechanical parts of their machines. This is due to the different ways electronics and mechanics have affected, and still affect, the innovation process.

Up to the late 1970s, electronics was totally absent from both textile machines and molding presses. The former already required sophisticated programming and control tools, but all of them were based on mechanical principles and components. The latter, apart from a few instruments for controlling temperature and viscosity, relied heavily on expert blue-collars' ability to check the outcome of the molding process and to fine-tune it as needed.

Later on, imitation of Japanese rivals brought in electronic controls, which at first consisted in simple programming devices, and nowadays span to sophisticated systems for tele-monitoring. It is important to notice that the introduction of electronics, despite being recalled by all of the interviewees as a radical breakthrough, did not bring about radical changes in the structure of the local industry. Most firms adapted well to the new technology, as witnessed by the fact that no major selection effects can be associated with its diffusion (for example, all Brescia producers of hosiery machinery survived to it). However, the strategy employed by local firms to adjust to the era of micro-electronics was mainly based upon searching for new and reliable suppliers of control systems for increasingly specialized and/or customized machines. After an initial search-and-learning experience with Japanese suppliers, all of the Brescia machine producers turned as soon as possible to a few local companies that had appeared in the mean-time. They invested heavily in setting up stable relationships with this new breed of suppliers, which in turn specialized in assembling and programming control devices for mechanical systems, often based upon standard components, but adapted to their customers' special needs.

With this respect, the case of hosiery producers is enlightening. The local leader, Lonati, decided quite early to acquire full control of a new-born supplier, Dinema, which became its exclusive supplier (although maintaining a high degree of managerial independence). This acquisition led to the exit from Dinema of one of its founders, who set up Deimo, which is now the main supplier of electronic controls for all of the local producers of hosiery machinery (with the exception of Sangiacomo, which is the only case of vertical integration). Similar arrangements can be also found among the producers of metal- and plastic-molding machines, where inputs from

[8] While our results (see below) will point at the existence of severe limitations in inter-firm knowledge sharing within the cluster, the lack of data on indirect links prevents us from the checking for the existence of knowledge flows mediated by lead users and suppliers, whose engineers and technicians have contacts with many, if not all, their colleagues working for Brescia companies.

[9] With a few exceptions, local firms refused to give us the names of their engineers and forbade any direct interview within the firms' premises. Our survey questionnaires were collected by the firm managers, most of whom asked the respondents to remain anonymous.

electronics play even a bigger role thanks to the greater scope for automation and remote control.

These remarks allow us to conclude that local producers of both textile and molding machines, and their local environment, have managed to gain access to electronic technologies, but still are, and will be for a long while, *mechanical* firms. They are asked by their customers to introduce essentially mechanical improvements, such as new labor-saving automation devices [10] or new machine layouts (as it is the case of molding presses which are designed for producing new large-size or complex components), or improved capabilities of dealing with new materials (as it often happens with thermoplastics). On the contrary, improvements in electronics are either perceived, by the machine users, as imposed or offered "from top" by the machine producers (as it happens with tele-diagnosis for molding machines, which the machine producers see as a means for saving on assistance and maintenance costs), or come from users' generic requests of improved performance, at most coupled with information on innovations recently introduced by some competitors. Besides, the introduction of electronic innovations, although marked a major technological change in the industry, has never been quoted as a key determinant of competitive positioning, as it happens, on the contrary, with mechanical innovations.

3.2. The incremental nature of mechanical innovations: recombination and the need for system memory and personal contact management

As suggested by Rosenberg (1963), mechanical innovations are largely incremental. They often arise from the need to satisfy new requests from what Pavitt (1984) calls large, possibly "scale-intensive" customers, and are then transferred onto machines that will be bought by smaller users. Most often, the early customers are extremely competent users, which can afford to sustain high development costs, either directly or by supporting their specialized suppliers' efforts.

This general framework fits particularly well the case of Brescia machine producers, whose innovations, in the recent and less recent past, have been almost always originated by design efforts directed at meeting some key customers' specific requests, and from the feedbacks obtained from those customers after testing the new machine.

Innovations of this kind largely consist of new or improved components, sometimes linked to a new layout of the machine. Technicians charged with the task of developing them will first re-examine existing machine models, retrieve from the firm's archives drawings and calculations for specific components, and recombine them in a creative way. They will introduce entirely new components only when needed. Notice that this retrieval-and-design process involves a parallel bargaining process, during which the machine producers' marketing men try to persuade the customers of the soundness of the proposed solutions, thus limiting the requests for too radical and costly innovations. Therefore, technical meetings and informal contacts between user's and producer's technical staff are frequent and important. [11]

These observations have three fundamental implications for our research:

1. They put at center stage of the innovative process the machine producers' need to store and retrieve information on their own past and current products, at a very detailed level (individual components, their use and performance). This is especially true for mechanical components, which we have seen to incorporate the distinctive competencies of our firms.
2. They highlight the need to dialogue with customers both to define the innovative contents of the machines and to get feedback information on their performance. Such a dialogue involves both the commercial staff and the technical staff of the machine producers.

[10] This the case with the "punta chiusa" project which is currently engaging many producers in the hosiery industry. The project aims at automating the last production phase, which consists in knitting the toes of socks and stockings, an operation that so far has been performed separately.

[11] Machine suppliers will insist upon introducing new components or layouts in new machine models only after having designed and successfully introduced them for previous models. In this case, it will be the turn of (possibly small) users to resist them. But even in this case, any possible compromise will see the machine producer trying to limit its efforts to the recombination of components and layout it has already developed and tested.

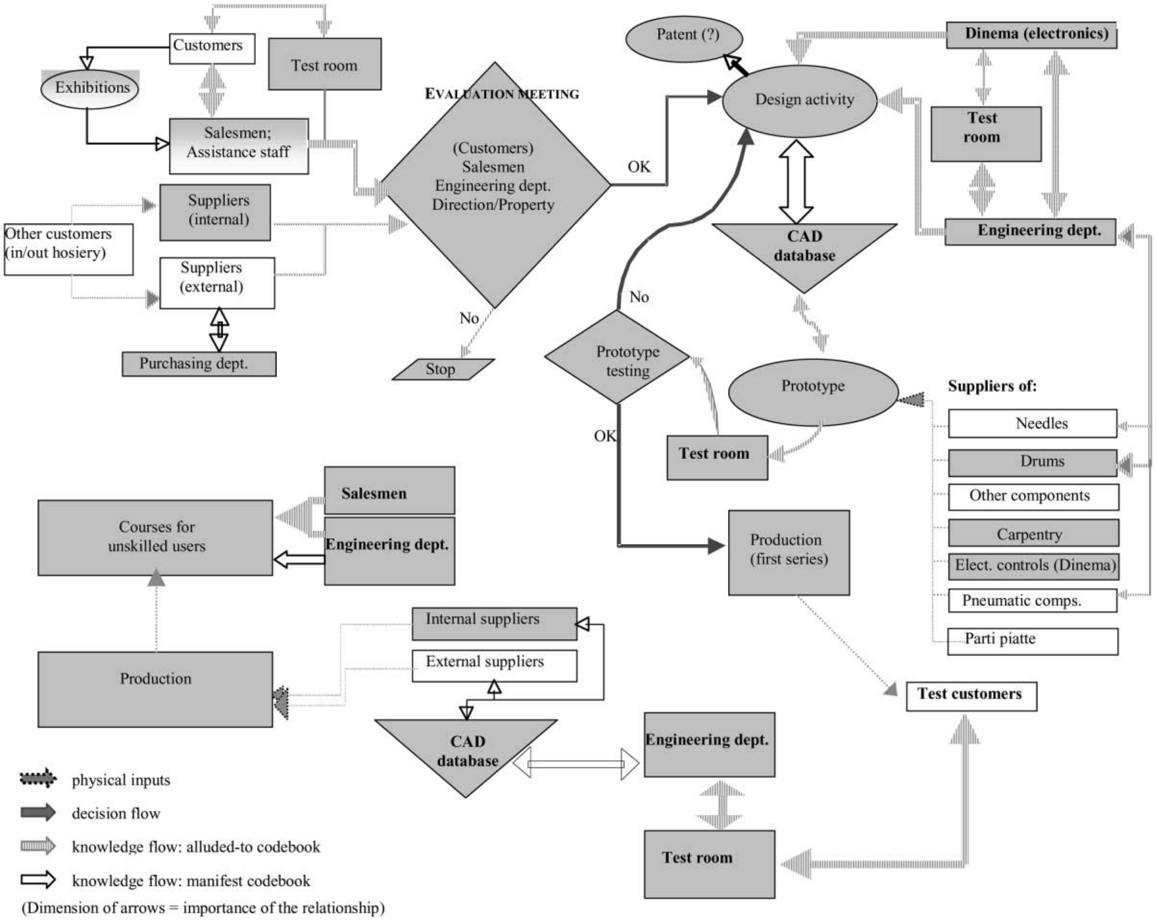

Fig. 1. Project, design and testing activities: Lonati's work-flow (1999), adapted from Pagani (1999).

3. They suggest that design engineers are also required to manage technical relationships with the suppliers of components. In fact, the Brescia district hosts very few fully integrated operating machine producers: most firms limit themselves to design and assembly, while buying almost all of their components from (mainly local) suppliers. [12]

The need for system memory and the role of design engineers can be highlighted by examining the overall work-flow of design activities leading to the production of a new machine.

[12] For example, Nuova MarcTex, a producer of hosiery machines with no more than 10 employees, deals with no less that 100 suppliers of components and parts.

Fig. 1 illustrates the case of Lonati, the leading manufacturer of hosiery machinery. [13] The first information inputs to be considered are the suggestions for

[13] Similar work-flows have been put together for all the firms mentioned in Section 2. Due to Lonati's large size, its work-flow shows a degree a complexity which may not be found elsewhere. In particular, smaller producers of hosiery machines and producers of large and highly customized molding presses may have more limited interactions with the so-called "test customers" (we will come back to this point below). In addition, smaller producers of both kinds of machines may not have a dedicated "testing room", its functions being performed by the engineering department. However, Lonati's work-flow is quite a useful reference case, since it hosts all the possible information and knowledge flows affecting the machine producers' design activities.

innovations, which may come from different sources; namely:

- Suppliers of new or improved components (both internal and external to the group).
- Large customers who require specific adaptations or put some generic pressure for the solution of long-standing problems and bottlenecks.
- Small customers, whose needs are monitored by surveys conducted by local representatives of the machine producers.
- Competitors, whose new models, which are presented at fairs and exhibitions, may set new quality standards or signal new directions of change.

At this kick-off stage, the most senior salesmen are the key actors that connect customers to the firm. They have a strong technical background largely built within the firm, either by indirect experience within the commercial staff or as former experience as design engineers. They are called in to deal with all customers who have placed an order with the sale representatives, [14] visit regularly the largest customers all around the world, and, if available, read survey data coming from the representatives. [15] Above all, they are asked to provide a first, possibly rough technical specification of the customers' needs. To do so they either pass on some highly codified information (i.e. well-specified technical parameters) coming from large and/or expert customers from western Europe and the US, or translate more vague requests coming from less technically literate customers in other countries (Fig. 1, top-left corner).

When customers' requests are particularly sophisticated, or the customers are very important, senior technicians from the engineering department may be called in to participate to meetings hosted by the firm, as well as to visit to the customers' production sites. Some requests or suggestions from so-called "test customers" (see below) may also be collected directly from engineers working for the so-called testing room.

Salesmen also play an important role in the evaluation meetings held by the firm to decide about the adoption of new externally-supplied components or the design of new internally-produced ones, [16] as well as about the launch of any project for a radically new machine. Other participants are always the executive managers of the firm (who are almost always the key shareholders) and the senior technicians from the engineering department and the testing room. The meeting produces a decision about the possibility to go on with the adoption of the new component, the customization of the machine, or the launch of a new project (Fig. 1, top-center).

If the decision is to go on, design activities begin. Center-stage is now taken by one class of actors and a key artifact. The actors are the engineers from the engineering department; the artifact is the CAD database (which nowadays substitutes old paper files as a working tool, but it has not led to their disappearance, due to the operators' fear of unrecoverable computer crashes). The latter is heavily used by the engineers to retrieve sketches and technical information about all the components which were already designed for older models and that will be used, unaltered, on the new one (Fig. 1, top-right). Additional technical information is retrieved from fellow engineers, such as:

- Mechanical engineers from the testing room, who may know or recollect useful information on the performance of one or more components, which are not available in the database.
- Electronic engineers from the supplier of control and automation devices. [17]
- Hydraulic engineers, for metal- and plastic-molding presses.

Following CDF00, information exchanges of this kind can be either classified as totally or partially codified.

[14] Representatives are unlikely to be employed directly by the firm. Most often, they are independent agents who deals exclusively for a machine producer, but offer a range of complementary products and other kinds of machines for the relevant industry. Representatives play a bigger role in markets that host mainly small, possibly unsophisticated users, such as those in new developed countries.

[15] Survey data are more likely to be collected within the hosiery machinery sector, and in particular by the largest firm within it (i.e. Lonati Spa).

[16] Although the production of almost all the components is outsourced, a few critical components may be either produced internally or by a controlled company , as it is the case with feeding screws in the metal- and plastic-molding presses, or drums for the hosiery machines.

[17] In the case of Lonati, the supplier is Dinema, a controlled firm; in other cases may be either an independent supplier or an in-house department.

They are fully codified to the extent that references are constantly made to components in the CAD database, and to the layout of existing models: references may be explicit (some engineers are asked by others to go and retrieve information from the database) or implicit, in the sense that discussion refers to components which are well-known to everybody (that is, the codebook is displaced).

However, some knowledge resists full codification, as it is the case with personal memories of the performance and "history" of some components and layouts (typically held by engineers in the testing room), which may help speeding up information retrieval and choice from the CAD database. In addition, dialogue between engineers are more likely to be based upon jargon and standard concepts, than rigorous scientific language (see below on the engineers' educational level). It is important to notice that information stored in the CAD database, and even more the complementary knowledge which is required to handle with it, are highly firm-specific. Codes assigned to components often remind of the name of those users they were first designed for, while names and nicknames of most-often used components are in many cases immediately intelligible only to insiders (this is a typical case of displaced codebook).

Suppliers' access to this kind of knowledge is limited to the kind of components they are called to produce, and, in any case, not immediately transferable to other parties. This is because standard components are not jointly designed by the firm and its suppliers, and do not require, from the supplier, any knowledge about the ongoing project; while critical components are most often produced by suppliers who deal exclusively with the firm, and develop quite specific knowledge and jargon.

Once the machine has been designed, a prototype is assembled, by means of standard components coming from the firm's stock, or new components produced on purpose, either internally or by some critical supplier. Engineers in the testing room apply the machine to small production batches and record its performance. If any problem arises they go back to engineers from the engineering department, or from the component supplier. Discussions refer again to specific components, and the CAD database can be again used to retrieve and modify those components, or to retrieve other ones which may suit better the new machine (Fig. 1, center-right).

Small producers of (small-batch) hosiery machines and all of the producers of large, customized molding presses seldom produce prototypes. However, the former test and check thoroughly the first exemplar of any new machine they have designed within their assembly department,[18] while the latter test each of their customized items before delivery. In this case, the testing activity does not only produce the kind of feedbacks we have just described, but also helps filling in the warranty forms required by the standard contracts.[19]

As soon as the prototype passes the internal examination, production series are started. More testing is needed here, because the materials used by customers (metals or thermoplastics for the presses, yarns for the hosiery machines) may differ, or be more heterogeneous, than those used in the testing room. Also working conditions (speed, intensity of use, environmental conditions) may differ. Here, a crucial role is played by the so-called *test customers* (Fig. 1, bottom-right). These may be either:

- Local users of medium or small size, whose machines come almost invariably from the same producer, and are willing to exchange their "testing services" (on-site facilities and expertise) for a prompter and faster maintenance service from the producer.
- Large and/or technically sophisticated users (local and non-local), which agree to host the first specimen of the new machine because they consider buying it, if not because the latter was explicitly designed to meet their requests.

In both cases contacts between producers and test customers are largely informal (contract specifications

[18] Small producers of hosiery machines are often unable to afford the costs of maintaining a dedicated testing room.

[19] Molding presses, especially the biggest ones, are actually tested twice, since after their assembly within the producer's facilities, they have to be dis-assembled in order to ease their transport. Therefore, once re-assembled on the user's premises, they have to be tested once more, this time by the assistance staff. This second test differs from the first one because the users' inputs are employed, which may differ from those used by the machine producer, and produce the same kind of feedbacks coming to hosiery producers from the so-called test customers (see below).

are minimal) and handled directly by the engineers of both firms. That is, reports on the performance of the machine are exchanged directly between engineers from the testing room (or the engineering department) and engineers from the users' workshop. These reports are both verbal (codebook displaced) and written (almost invariably, forms with quantitative information have to be filled in by the customer). Disclosing both kinds of reports and showing the machine to third parties are strictly forbidden.[20]

It has to be stressed that in most cases the attention of test customers is drawn to specific components of the machine, or the performance parameters which the supplier know to be influenced by those components. Thus, the user-producer relationship does not require the user's full understanding of the machine working principles (not even their complete awareness of the number of novelties which have been inserted), but simply a common jargon on a few specific topics.

Above all, however, the relationship requires long-standing acquaintance and mutual trust, which can be achieved only through personal, rather than purely inter-organizational, links. Reciprocal convenience in cultivating the relationship helps engineers from both firms (user and producer) to transmit information very fast (testing never lasts more than 90 days) and by a variety of means, above all phone calls, faxes, and, more recently, e-mails.[21]

Once testing is over, definitive information on the new components or layout details will be stored in the CAD database, and then used to send away to all the suppliers of parts and components the exact drawings and technical parameters they need to fulfill their task (Fig. 1, bottom-left).

Finally, courses and training services will be offered, and user manuals will be written.

As for courses, it should be noticed that most of them are offered to non-expert users (e.g. those from newly industrialized countries), and that many machine producers have recently set up on-site facilities for the purpose, such as demonstration centers and guest rooms. Salesmen are usually in charge of the organization of such activities, and engineers, from both the engineering department and the testing room, are called in as teaching staff.

As for manuals, we stress that writing them is up to the technicians from the engineering department, who will comply with this obligation once again by cutting and pasting sections from earlier manuals, as well as adding some new parts. Manuals will be particularly useful for non-expert users, although more as reference books, rather than as self-teaching material. With this respect, by pointing at the user manual, the producers' maintenance staff may solve the most trivial problems over the phone, and avoid delivering time-consuming on-site services.

Our description of the knowledge-generating activities of each producer's mechanical engineers, suggests that such knowledge is not likely to spill over very easily to the other firms of the district, despite being (partially) shared with people in other firms (either suppliers or, as in this case, test customers). Far from being purely "technical" (know-how and know-why), the mechanical engineers' knowledge is also of a relational kind (know-who), the latter component being crucial both for them as individuals (it helps them solving their design problems and contributes to build up their reputation and career) and for their company (that counts upon their *overall* skills in handling the design activity).[22]

In addition, our description lends support to the observation that mechanical engineers (along with textile engineers, working in the hosiery machine producers' testing rooms) play a more prominent role than electronic and hydraulic ones. Mechanical engineers' relationships with external suppliers involve much more joint design, or tight requests for customized products, than mere choice from catalogues. That is, their contribution looks much more creative than the efforts by other members of the engineering department staff, which are mainly directed at keeping in touch with novelties coming from technical fields outside the key competencies of the firm (i.e. from electronics and hydraulics), than at contributing to the latter. In addition,

[20] For more detailed descriptions on this point, see Fenaroli, 1999, and Cinelli, 2000.

[21] With regard to this, it is interesting to notice that engineers from as large a supplier as Lonati did not know all the test customers of their firm, since every engineer dealt exclusively with a subgroup of this kind of customers, and precisely with those wherein he could count upon personal ties.

[22] The distinction between technical and relational knowledge, as well terms such as 'know-why' and 'know-how', are derived from Lundvall and Johnson (1994).

it is the mechanical engineers who have to sum up all the components into the machine layout.

3.3. Mechanical engineers as the core "epistemic community": firm boundaries and knowledge exchanges

From the previous section, it has emerged clearly that knowledge activities within the operating machine industry of Brescia revolve first around each firm's assets, such as the CAD database, and the salesmen's and engineers' personal memories and contacts. In particular, the design engineers and their colleagues in the testing room seem to play a central role in the creation and management of *firm-centered epistemic communities*, which comprise also technicians from each firm's users and suppliers.

In this section we discuss further the boundaries of such communities. In particular, we check whether such boundaries may or may not be seen to go beyond each firm, and encompass the whole set of local producers, as suggested by the traditional literature on industrial districts.

In order to do so, we explore two mechanisms which are often said to help pushing knowledge exchanges beyond the limits of each firm, and at the same time keeping it within tightly-defined space boundaries:

1. Localized labor mobility, to which one can add high firm natality rates (since most firms in the districts arise from self-employment decisions coupled with subcontracting activities).
2. Knowledge socialization.

While the latter is a straightforward externality, labor mobility may or may not imply any localized knowledge spillover, depending on the share of each worker's knowledge that can be fruitfully transferred from the firm that contributed to create it to the new employer. [23]

Strong social ties are seen as the pre-condition for both mechanisms to be viable: they create a common cultural background which allow human capital to be at the same time district-specific, but not firm-specific (on this point, see also Foray, 1991). However, as we have already said in Section 2, envisaging this double mechanism hides a contradiction: if labor mobility is the key means for knowledge diffusion, this may suggest that knowledge is not much codified (CDF00 and CF97). Therefore, knowledge socialization can hardly take place outside the firm boundaries, because it requires learning-by-doing, practical demonstrations, as well as trial-and-error efforts.

Our short survey on 200 technicians actually cast some doubts on the existence of inter-firm knowledge spillovers (mediated by individual engineers' social ties) that would go beyond the exchange of generic information. As showed in Table 3, we polled 200 electronic and mechanical engineers working for four kinds of firms: hosiery machinery producers, their local suppliers of electronic controls, producers of die-cast metal molding presses, and producers of injection presses for thermoplastics.

Table 4 shows that no more than 36% of the respondents, within each industry, admitted any contact with engineers from other firms, while no more than 21% signaled "strong ties" such as friendship or kinship. [24]

In addition, no more than 18% of respondents (63% of those with social ties) indicated technical discussion as a topic of conversation with their acquaintances outside the firm, and no more than 4.5% (15% of those with social ties) admitted to talk about current projects or to give/receive specific suggestions. Therefore, we can conclude that the existing firm-based communities of engineers may certainly be connected by a number of "weak ties", which are apt at diffusing information and rumors about new technologies to be adopted or imitated. At the same time, though, those ties do not appear to vehicle the amount of technical information which is necessary to develop any commercially viable innovation. [25]

Evidence on labor mobility as a knowledge carrier is more mixed. All the interviewees hinted at a recent "tacit" agreement among competing firms in the area not to "steal" any more their rivals' best engineers, as it used to happen in the 1980s. This would suggest

[23] The absence of localized knowledge spillovers linked to labor mobility, however, does not exclude other externalities related to the labor markets, especially of the pecuniary kind.

[24] Overall, just seven engineers belong to any technical association (i.e. 3.5% of respondents; not in the table).

[25] "Weak tie" ought to be intended here as much as possible as in Granovetter's (1973) original paper, i.e. as low-intensity social bonds which are nonetheless apt at providing the only bridge, or the shortest way between distinct networks, such as epistemic communities.

Table 3
Survey on the Brescia machine producers' engineers: sample structure

Line of business	Project area				
	Electronic	Mechanical	Others	Total	Rate of response (by firm)[a,b]
Electronic controls for textile machinery	33	0	0	33	2/2
Hosiery machinery	14	53	6	73	6/8
Die-cast metal presses	15	29	20	64	5/9
Presses for thermoplastics	12	19	12	43	3/7
Total	71	96	33	213 (200)[c]	–

[a] Number of firms which accepted the questionnaires per number of local firms.

[b] No rate of response could be calculated for technicians, since no firm provided separate figures on the number of technicians they employ. However, with the only exception of one hosiery machine producer, all firms declared that all of their technicians had answered the questionnaire.

[c] Number of respondents is 200, but 13 engineers working for MaicoPresse, which produces both presses for metal alloys and presses for thermoplastics, are listed twice.

Table 4
Social and parental ties, and technical contents of information exchanges

Holding a relationship with other firms' engineers	Number of engineers	Engineers (%)[a]
Any kind of relationship	60	30.0
Friendship/kinship	41	20.5
Involving technical discussions	36	18.0
Involving discussions of current projects	9	4.5
Involving asking/giving generic suggestions	16	8.0
Involving asking/giving bibliographical references	7	3.5
Involving asking/giving names of suppliers/consultants	8	4.0

[a] Number of respondents is 200.

that firms actually perceive the departure of one of their engineers as a serious loss. However, it is not clear whether this loss consists merely of unrecoverable training costs or, more seriously, of firm-specific knowledge (details of innovation projects, contact names and so-forth). If the second interpretation is correct, we need also to understand whether such firm-specific knowledge goes lost or the engineer who leaves one firm can successfully transfer it to the new employer.

Above all, many engineers who reported to have changed job more than once, did not indicate the name of their past employers, so we do not know whether for "change-of-job" they also meant "change-of-employer". Table 5 reports our (limited) findings on this point: about 60% of the respondents revealed to have worked for another

Table 5
Engineers' career outside the firm: jobs taken

	Number of engineers	Engineers (%)
Number of jobs taken with former employers		
0	81	40.5
1	63	31.5
>1	56	28.0
Total	200	–
	Number of jobs[a]	Jobs (%)
Tasks in previous vs. present job		
Same tasks	92	41.8
Different tasks	128	58.2
Total	220	–

[a] Sum of jobs taken by all engineers who changed job at least once.

Table 6
Engineers' career outside the firm: job spells

Total working years (w.y.)	Average job spells for other employers (S.D.)	Number of observations	Working year for other employees/ total working year (S.D.)	Number of observation
Up to 10	1.8 (1.68)	51	0.50 (0.28)	30
11–20	4.0 (3.70)	62	0.44 (0.27)	37
More than 20	7.4 (5.92)	100	0.51 (0.27)	49
Total	–	213[a]	–	116[b]

[a] Observations are individual job spells (1 or more for each engineers), for 116 engineers.
[b] Observations are individual engineers.

firm, but only about 30% changed job more than once.[26]

Less than half (42%) of the job changes[27] occurred between similar kinds of jobs, thus allowing the employee, in principle, to transfer his skills from one firm to the other. No major differences emerge between project areas, i.e. between mechanical versus electronic engineers:[28] this may be seen either as a piece of evidence against CF97's and CDF00's suggestion that labor mobility is a substitute for codification (electronics being certainly a more codified field than mechanics) or as the confirmation that the electronic engineers of the mechanical district of Brescia, who work mainly on the interfaces between electronic controls and mechanical devices, do not deal with highly codified R&D issues.

Finally, up to 27% of the jobs which were changed lasted only 1 year or less, while 61% lasted less than 5 years. This suggests that the interviewees mostly changed job at an early stage of their working life, while searching for the right place to start a career, well before having acquired valuable technical competencies or industrial secrets to carry around. This is confirmed by the observation that the average respondent, among those with at least 10 years of working experience, has been working for his present employer for half of his working life (the value goes up to 80% for younger engineers, see Table 6). Therefore, it seems that most of the losses inflicted to firms by the departure of one of their employees had more to do with unrecoverable training costs than with key knowledge assets.

Coming to the nature of intra-firm knowledge exchanges, we have already noticed that they take place with few explicit references to any codebook. Here, though, important differences emerge between electronic and mechanical engineers.

All firms in our sample, but one, have an internal library, but only 40% of the respondents make any use of it. Such use is discontinuous and mainly for the solution of specific problems encountered during the project activities (Table 7). That is, books and jour-

[26] We also do not know whether the various employers one engineer may have worked for were both localized in the Brescia district or not.
[27] Since 56 out of the 119 respondents who changed job did so more than once, the overall number of job changes is 220.
[28] Data are not reported here, but are available on request.

Table 7
Use of internal library

Use of the library	Number of engineers	Engineers (%)
No	123	61.5
Yes	77	38.5
Frequency of use		
Almost never	4	5.2
Occasionally	43	55.8
Often	23	29.9
No answer	7	9.1
Purpose of use		
Generic updating	17	22.1
Problem-solving	58	75.3
No answer	2	2.6
By industry		
Hosiery machinery	21	28.8
Electronic controls	28	84.8
Metal molding presses	18	28.1
Plastic molding presses	13	30.2
By project area		
Mechanics	29	30.2
Electronics	41	57.7
Other	7	21.2

nals in the library can be seen as complementary to the firm's own CAD database, since they store codified knowledge that belongs to the wider epistemic community of all engineers (not just those in the firm or the district), to be matched with the firm-specific codified knowledge.

Well over 80% of the engineers working for electronic control producers make use of the library, against no more than 31% in the other sectors. Similarly, the disaggregation by project area shows that 57% of the electronic engineers visit the library, against only 30% of the mechanical engineers.

Much more often than using the library, however, engineers try to solve project problems by talking to each other. More than 80% of the respondents admitted to do so, and stated that most common feedbacks to request of suggestions were "oral explanations", followed by "practical demonstrations", "references to a written standard procedure or CAD database", "references to a non-written standard procedure", and "references to any technical handbook". The only exception were, once again, the engineers working for electronic control producers, who ranked second and third "references to a non-written standard procedure", and "references to any technical handbook", respectively (with a comparatively lower score for oral explanations; Table 8).

We notice immediately that the (possibly) superior degree of codification for "electronic knowledge" does not eliminate the need for personal interaction, since the design of electronic controls require as much interaction as the design of mechanical components or machines. Moreover, these results suggest that electronic knowledge, at least within the area we are studying, may not be much "more codified" than mechanical knowledge: rather, it is the codification means and the extent of the relevant epistemic communities that seem to differ.

The rank correlation for average scores assigned to knowledge exchange means is very high when comparing machine-dedicated engineers, but much smaller when it involves electronic component engineers (Table 8). The latter assign a relatively high ranking to technical handbooks, i.e. to codes that are well known to the wider community of practitioners in the field, as opposed to more firm-specific codebooks and jargon used by mechanical engineers. In addition, they do not discriminate as much as their colleagues in the mechanical field among the various means of knowledge exchange (lower variance of average scores in Table 8).

It is tempting to suggest that these differences may be explained by the fact that Brescia machine producers' core competencies lie firmly within the mechanical field. Therefore, explicit efforts to

Table 8
Intra-firm personal knowledge exchanges for the solution of project problems

	All	Hosiery machinery	Electronic controls	Metal molding presses	Plastic molding presses
Scores					
Number of engineers asking suggestions	172	64	31	50	38
Respondents (%)	86.0	87.7	93.9	78.1	88.4
Average score of answers[a]					
Reference to technical handbook	3.89	4.19	3.13	4.14	3.74
Reference to written procedure or CAD	3.07	3.22	3.26	2.60	3.16
Reference to non-written procedure	3.31	3.34	2.87	3.20	3.66
Oral explanation	2.24	2.02	2.65	2.40	2.26
Practical demonstration	2.80	2.48	3.16	3.02	2.74
Variance of average scores	0.37	0.70	0.06	0.46	0.39
Rank correlation, by industry					
Hosiery machinery	–	0.2	0.9	1	–
Electronic controls	–	–	0.1	0.2	–
Metal molding presses	–	–	–	0.9	–
Plastic molding presses	–	–	–	–	–

[a] 1 = most important → 5 = least important.

Table 9
Geographical distribution, size, and age of test customers

	Size (number of employees)			Age (foundation year)				Total
Location	≤100	101–500	>500	n.a.	≤1980	>1980	n.a.	–
Brescia province	6	3	0	0	5	3	1	9
Rest of Italy	4	3	1	3	7	1	3	11
Abroad	2	1	4	1	7	0	1	8
Total	12	7	5	4	19	4	5	28
Test/buy from other suppliers	3	3	5					

codify, as well open references to existing codebooks, would be more limited when it comes to mechanical knowledge, as opposed to (less original, and therefore less strategic) knowledge in electronics. However, we have no elements, so far, to provide strong support to this thesis. Thus, Brescia firms would be particularly cautious when it comes to codify their key knowledge asset, i.e. mechanical knowledge.

3.4. The role of customers: testing versus customization

When commenting upon the design work-flow of Section 3.2, we stressed the important role played by the so-called *test customers* in supporting the machine producers' testing activity, as well as in providing the necessary feedbacks for optimizing the design of new machines or components.

As a result of our interviews we ended up with a portrait of the "typical test customer" and its activities, which we tried to test against some hard data. Unfortunately, test customers are a rare breed (just a few of them are needed by the machine producers, and all of them have to be extremely trustworthy), so that we managed to collect data about only 28 of them (22 for the hosiery machine sector, 6 for producers of the thermoplastics molding presses, and none for the producers of metal molding presses). Such data come from twin questionnaires submitted to the staff of both suppliers and their test customers.

Despite these small numbers, it is worth looking at the data, albeit just in a descriptive way. They may strengthen the propositions derived from the interviews, and suggest further data collection and testing activity.

We first checked size and geographical location of test customers. Table 9 roughly confirms the existence of two kinds of test customers: either small-medium ones, possibly located nearby the machine producers, or a few larger ones, which may be located elsewhere in Italy, if not abroad (notice that no test customer located in the province of Brescia has more than 500 employees, while more than half of the foreign ones go beyond that threshold, with test customers located elsewhere in Italy standing in the middle). With a few exception for the small firms of Brescia, all test customers have more than 20 years of experience in their sector, i.e. they hold suitable technical competencies for being reliable technical partners.

Table 9 shows that such reliability has to do also with confidentiality: apart from the large firms, only a small minority of test customer use or test the machines of more than one producer. That confidentiality matters is confirmed by the fact that 18 out 28 test customers stated they had been explicitly forbidden to show the test-machines to their supplier's rivals, and that only one (out of 28) ever dared to do so. [29]

Our data also confirm that knowledge flows between suppliers and test customers are largely informal and channeled through personal relationships tying individual technicians from both firms. Only 10 out of 28 firms provided us with data on the time length of testing activities, suggesting an average duration of 3 months. Table 10 shows that during that time, test customers are hardly asked to perform any formal (codified) data collection, a task which is left to the suppliers' technicians, if carried out at all.

[29] Data available on request.

Table 10
Feedback transmission means from test customers to machine suppliers[a]

	Number	%
Formal data collection		
Regular inspections by the supplier's technicians, for formal data collection	18	64.3
Test customer fills in standard forms for notification of a breakdown	6	21.4
Test customer fills in special form for testing activities	1	3.6
Meetings		
Frequent informal meetings between technicians	28	100
Frequent informal contacts between technicians, by phone and fax	22	78.6
Regular inspections from the supplier's technicians, for informal discussion with users	20	71.4
Regular meetings between technicians from both firms, for discussing test results	10	35.7
Final meeting between technicians from both firms, for general evaluation of test results	13	46.4
Ongoing modifications on the machine		
Test customer suggests necessary modifications	17	60.7
Test customer modifies the machine	16	57.1

[a] Multiple answers were allowed.

On the contrary, informal meetings and phone/fax contacts come top of the agenda. Those meetings and contacts seem more likely to be arranged on the spot, that is whenever any problem arises, rather than on a regular basis.

Finally, test customers have a big say in the introduction of modifications, either by suggesting them to the suppliers' technicians, or by intervening themselves onto the machine (Table 11). Feedbacks from test customers mainly affect specific parts and components of the machines, which are, in most cases, the only novelties in the prototypes that test customers are asked to host (radical novelties, as we said above, are a rare exception in the innovation strategies of the machine suppliers). Information from test customers may stop at the level of the test room (whose staff record them just to know more about the machine characteristics), or go straight to the engineering department, where they lead to changes in the machine design. In a few cases, the test room operators forward the customers' feedbacks to the maintenance service staff, to inform fitters and repairers about typical faults of the machine, or exploit them to improve the contents of the user manuals and courses.

Table 11
Feedbacks' destination[a]

	Number	%
Engineering department		
Revision of the design of parts and components	17	60.7
Re-evaluation of the technical characteristics of parts and components	11	39.3
Full revision of the machine design	0	–
Test room		
Data on performance of specific components	11	39.3
General data on machine performance	8	28.6
Data on machine performance in specific conditions (intensity of use, materials, etc.)	5	17.9
Maintenance service		
Information for users' courses	9	32.1
Information for fitters and repairers	7	25.0
Information for users' manuals	4	14.3

[a] Multiple answers were allowed.

Table 12
Test customers' incentives and agreements with the suppliers[a]

	Number	%
Incentives for testing		
Improvement of personal relationships with supplier's technicians and management	21	75.0
Continuous technical updating	20	71.4
Influence on the machine development	19	67.9
Technological advantage over competitors	19	67.9
Generic improving of bargaining power, for purchase price, accessory conditions etc.	16	57.1
Discount on all machines	10	35.7
Own technicians gain experience	11	39.3
Discount on purchase of tested machines	9	32.1
Test activity is paid for	0	–
Agreement with the supplier		
Purchase promise/contract	20	71.4
Informal exchange of courtesies	8	28.6

[a] Multiple answers were allowed.

As for the customers' gains from the relationship, Table 12 shows that none of the 28 test customers we polled has ever been paid for its activities, and just a minority of them claimed a discount on the machines they tested, or other machines from the favored supplier. Rather, testing activities serve the main purpose of keeping in touch with the ongoing technological advances (possibly gaining a lead over direct competitors), as well as that of strengthening the social ties with suppliers' technical staff and management, and gaining their trust and goodwill. In addition, many customers hope to exert some influence on the technical development of the machine: this is why, in the majority of cases, testing activities go on with a promise to purchase the machine, if not a formal purchase contract.

4. Conclusions

The results of our enquiry suggest that the reappraisal of the twin concepts of "tacitness" and "codification" we outlined in Section 2 can be fruitfully applied to the study of geographical clusters of manufacturers that shares many common traits with typical Italian industrial districts.

The empirical findings of the paper help distinguishing between tacit knowledge and codified knowledge *cum* displaced codebook. By relating codebooks, and rules for accessing it, to individual firms' boundaries and vertical relationships, those findings also go against the common description of many geographical clusters as homogenous cultural settings, wherein technological findings are quasi-public goods. Rather than flowing freely within the cluster boundaries, knowledge circulates within a few smaller "epistemic communities", each centered around the mechanical engineers of a single machine producer in the district, and involving a number of other technicians from both suppliers and customers. We then observe that:

- Those communities are better seen as made of people, linked together by personal ties of trust and reputation, rather than from inter-firm arrangements, although they arise from successful commercial partnerships and deals, and respect firms' appropriation strategies.
- The localization of members of the epistemic communities is affected by the frequency of contacts required for transmitting information effectively, as well as from the size of the members' companies.
- Public labs and universities seem almost totally absent from those communities. Nevertheless, codification efforts, especially in the design phases, have been pursued incessantly by all firms, and such efforts have served well the purpose to store knowledge for future use. They have been accompanied by a number of measures for limiting access to it.

We have suggested that, contrarily to more typical accounts of industrial districts as an homogenous knowledge community, firm boundaries matter a lot. This is because the most typical innovation activities deal with mechanical technologies, and therefore rely heavily on recombination and incremental innovations, which in turn require reliable and sophisticated system memory. Much of this memory is stored in each firm's CAD database, as well as in the necessary fluency with the technical jargon and the individual memories about past project activities, which help using that database fast and efficiently. While senior technicians working for the machine producer master both the database and the jargon completely, bits and pieces of both are strategically distributed to their relevant counterparts in the supplier and client firms, thus allowing the dialogue among them to be fast, frequent, and efficient.

Inter-firm labor mobility may disseminate the jargon and some personal knowledge on useful social ties, but not *all* the firm-specific knowledge, despite this being codified. It is not by chance that firms in the district, with a few exceptions, tend to specialize in very narrow market niches (and customized products therein). Outside those niches, much of the firm's knowledge is not immediately useful.

The kind of knowledge that resists more clearly to codification efforts is of the "know-who", i.e. knowledge of some key suppliers and of the so-called "test customers" or, better, of the competencies and reliability of individual technicians therein. This helps very much to speed up the development, and even more, the production of critical components and to test their reliability. In this case, geographical boundaries have been historically important, but do not seem to matter as much as they did in the pioneering phase of the district, since time and intergenerational changes have allowed new social ties to be built around trust-based long-standing business relationships outside the district. At this stage of our research, however, we have not yet been able to test whether these new relationships call for significant investments to reduce the "stickiness" of information at the users' location, as suggested by von Hippel (1994).

From these observations it follows that epistemic communities can be a better policy and management target than either individual firms or geographical clusters as such.

Allowing technicians within a community to communicate more frequently, exchange more data, and access technical knowledge from outside the local cluster could help the latter to survive future technical shocks. The measures to be adopted could be better specified by interviewing and collecting data from senior technicians, rather than firm managers. It may well be that generic requests for lowering transport costs and improving TLC systems will be put forward: in both cases they should not be dismissed as irrelevant from the technological policy viewpoint, since they would allow, respectively, more frequent face-to-face contacts with distant community members and greater ease of data exchange.

New firms may arise from community members seizing some technological opportunity, as it had happened when many SMEs clusters were born. Allowing members of the various communities to access knowledge from other sectors, or from academic research would help, although policy measures in this direction (e.g. grants for seminar and conference organization/participation; grants for study leaves and further training, etc.) may be in contrast with local employers' appropriability strategies and staff management practices. Notice that many technology transfer actions which currently target existing SMEs as potential innovators, could be instead directed at giving some members of local epistemic communities the chance to found their own start-up.

More generally, technology transfer policies which focus upon specific sectors and locations, but do not arise from an agreement with local members of the existing epistemic communities, are very likely to end up offering very generic, and possibly irrelevant services (as many assessment of technology transfer policies actually show). Since knowledge is not 'in the air', but circulates within a number of relatively close networks, any policy initiative which disregard the latter will fail to:

1. Access those portions of knowledge which are the necessary complements to the technologies or the services that the initiative aims to promote.
2. Access those inter-personal networks which are crucial for diffusing news regarding the initiative and the opportunities it offers, as well as for getting feedbacks and gaining legitimization.
3. Understand the degree of geographical dispersion of the relevant epistemic community, which can be much higher than suggested by the co-localization of those firms composing the district or cluster.
4. Understand which portions of knowledge can be considered 'public' (i.e. shared by different communities) or 'private' (i.e. circulating only within one community), thus generating conflicts with local firms' and community members' appropriation strategies.

Finally, it should be observed that some of the links between SMEs and larger firms which many fashionable technology transfer policies try to set in motion, are already in place within the existing epistemic communities, as long as they include personnel from large suppliers of standardized (especially electronic) components and materials. Actions that disregard those existing ties may fail to be gain legitimization among industry practitioners.

As for future research, more case studies as well more general efforts of data collection could be fruitfully addressed to identifying existing epistemic communities within a number of sectors, their inter-firm distribution and geographical structure. This will require focusing on individuals (shop-floor workers, technicians or researchers), their company or institutional affiliations, as well as their personal links and communication means.

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