Stepping-up innovation in manufacturing firms: Knowledge combinations in an Italian local production system

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Abstract:

Industry 4.0 requires from manufacturing firms to become more innovative in order to remain relevant and competitive. To step-up firm innovation, several studies in Innovation and Economic Geography foreground that firms need to combine knowledge in novel ways either within local industrial structures or over distance. The contribution of this paper is to investigate in-depth how manufacturing firms with traditional roots combine new generative knowledge in and beyond a local production system (LPS), what enables them to access and integrate such knowledge from external sources, and how this relates to the firms' innovation performance, with a focus on radical and varied forms of innovation. The contribution of this paper lies also in a mixed-methods research approach, which combines a population-based survey of mechatronics firms in an Italian LPS, with in-depth interviews. This allows for a qualitative interpretation of the causes of the identified distributions and correlations. The main finding of the paper is that firms generating radical innovations and varied forms of innovation combine unrelated types of knowledge in-house and through external sources. The pattern is that the traditional manufacturing knowledge of mechatronics firms still prevails but that firms increasingly complement this with new knowledge, in particular science-based analytical knowledge. Firms that have acquired complementary knowledge in-house are able to access new knowledge nationally or internationally. Even though firms source knowledge relatively frequently within the local production system, the firms who access new knowledge nationally and internationally stand out in terms of their innovation performance.

Keywords: Industry 4.0; knowledge bases; local productive system; innovation; manufacturing firms

1. Introduction

In recent years, several empirical studies have provided evidence that the combination of different types of knowledge is positively related to firms' performance and the transformation of regional paths (Asheim et al., 2017; Asheim and Coenen, 2005; Bellandi et al., 2020a; Grillitsch et al., 2017; 2019; Martin, 2012; Martin and Moodysooon, 2011; 2013). In addition to a number of case studies, Grillitsch et al. (2017) has recently provided quantitative evidence based on large-scale data that firms tend to have a higher innovation performance if they combine different knowledge bases and are located in a system with a balanced mix of different knowledge bases. While the general argument about the importance of combining different types of knowledge is well established and supported by empirical evidence, this paper zooms in on the knowledge and innovation dynamics of a manufacturing industry with traditional roots. This is important because manufacturing industries, particularly those traditionally organized in local productive systems (LPS)[1], face specific challenges brought by globalization and industry 4.0 (Bellandi et al., 2020a).

The empirical study is about firms in the Vicenza mechatronics LPS, located in the Veneto Region. The Veneto Region is a typical Italian region with 'moderate' innovative capacity, a strong industrial heritage in manufacturing sectors and a large presence of local productive systems such as clusters or districts (Apa et al., 2020). The region faces similar challenges as other traditional manufacturing regions in Italy and elsewhere in Europe. Globalization and the development of Industry 4.0 have increased the need to combine the existing synthetic knowledge base resting on largely tacit technical and engineering skills, with analytical knowledge based on scientific discoveries, and symbolic knowledge bases relating to design and art. As some scholars argue, this can sustain both the development of digital skills as well as the development of new 'generative' contextual knowledge relaying on intangible assets (Bellandi et al., 2020; Castellani et al., 2017; McCaffrey, 2013). However, traditional manufacturing regions such as Veneto are often not well-equipped with analytical and symbolic knowledge bases, the latter linked to the contextualized cultural heritage, which would allow for more radical innovation in products, processes, markets or business models. In that case, firms may lever various mechanisms at different geographical scales that allow them to access the complementary knowledge bases available in other contextual settings (Bellandi et al., 2020a; Trippl et al. 2018). As most case studies about knowledge

[1] A local productive system (LPS) is an identified place that is associated to specific productive specialisations well rooted in the local community (Bellandi et al., 2021, p. 1).

combinations and innovation concern growing industries such as ICT, new media or biotech, a focus on manufacturing firms in a traditional industrial context addresses a relevant and important research gap.

The empirical study also provides new insights due to the combination of quantitative and qualitative analysis. The study has collected survey data from 85 firms in the Vicenza mechatronics LPS, which allows for a representative depiction of firm knowledge bases and how they correlate with the innovation performance of firms. In addition, we use the information from 8 in-depth interviews to understand the knowledge and innovation dynamics in firms and explain the correlations observed in the quantitative data. We consider that this approach has helped to combine some advantage of quantitative and qualitative methods. The limitation compared to large-scale quantitative analysis (e.g. Grillitsch et al., 2017; 2019) is that we cannot provide a general picture about the overall economy. However, the advantage is that we gain an in-depth understanding how manufacturing firms in traditional industrial locations combine knowledge in innovation processes. As compared to case studies (e.g. Bellandi et al., 2020a), the advantage is that we can validate our findings by comparing the relative frequency and importance of certain types of knowledge and knowledge sourcing activities with the narrative collective from expert interviews in the field.

Through recent data collected about the mechatronics LPS in Veneto Region, this paper addresses the following questions:

- Which knowledge bases are used and combined in innovation processes of mechatronics firms and why?
    - To what extent and how do mechatronic firms in Veneto Region combine different knowledge bases in-house?
    - To what extent and how do mechatronics combine in-house knowledge with external knowledge in innovation processes?
- How does the combinations of different types of firm-internal and firm-external knowledge relate to firms' innovation performance?

Section two is dedicated to the theoretical framework discussing the relation, on the one hand between knowledge bases combination and knowledge bases multi-scalarity, and on the other hand, firms' innovation. Section three presents the empirical case and methodology. Section four discusses the findings and presents the econometric models that relate knowledge base combinations in-house and from external sources to different types and degree of firms' innovation. Section 5 concludes.

2. Theoretical framework

In innovation studies, there has been a long debate about what type of knowledge promotes innovation and the growth of firms. One key argument has been that combining existing knowledge with related knowledge is most conducive to innovation. Even though there is no uniform definition of relatedness, most define it in terms of technological similarity (Content and Frenken, 2016). For instance, in the ground-breaking article on related diversification, Frenken et al. (2007) provide the example where firms use their existing knowledge to branch into other industries with a relatively similar knowledge base. Overall, there is also a lot of empirical evidence that related diversification is most common (Hidalgo et al., 2018). Grillitsch et al. (2018) argue in contrast that unrelated knowledge holds untapped potential for innovation. They argue that unrelated knowledge – even though less frequent – is the source for more radical innovation with a high potential to renew existing industrial pathways. In the context of this study, this is important because traditional manufacturing regions are in the process of a radical transformation towards industry 4.0. Hence, the study investigates the importance of unrelated knowledge combinations for firms generating radical innovations or a wide scope of innovations.

One way to capture unrelated knowledge combinations is through the concept of knowledge bases. Asheim and colleagues developed a typology of knowledge bases differentiating between analytical, synthetic and symbolic knowledge (Asheim and Coenen, 2005; Coenen et al., 2006; Moodysoon et al., 2008). The reason why the knowledge bases can in principle be considered unrelated is that they differ substantially in nature, the way knowledge is produced, including the epistemic communities in which the respective knowledge bases are embedded (Martin, 2012, Asheim et al., 2017). Synthetic knowledge is defined as having originated by the application of -or through the new combination of- existing knowledge. It is often triggered by the need to solve specific problems, or to answer the specific needs of customers or suppliers. This type of knowledge can be prevalently found in traditional manufacturing industries, where the concentration of technical and engineering skills is high, and tacit knowledge plays a key role. Analytical knowledge is instead characterized by scientific knowledge and processes of knowledge generation. Analytical knowledge is highly codified and can be embedded in goods or formal documents (Bellandi et al., 2020a). Knowledge embedded in highly sophisticated and technological advanced machinery and equipment, or licenses and patents can be considered analytical knowledge acquired through market mechanisms. Analytical knowledge is also devoted to the discovery and application of scientific laws. It represents strategic knowledge in high-tech sectors such as biotechnologies and nanotechnologies. Symbolic knowledge is instead principally built on aesthetic and design attributes, the creation of meanings and on the symbolic value of the products and services (Asheim et al., 2007). Symbolic knowledge strongly characterizes industries such as New Media (Martin and Moodysoon, 2011; 2013), but also many fashion productions and industries und the label "Made in Italy" (Bellandi et al., 2020b). Today, symbolic knowledge is also generating new meaning to industries related to socio-technical and green challenges (Strambach, 2017).

Many industries draw upon a combination of synthetic, symbolic and analytical knowledge bases. However, if and how firms access and combine the different knowledge bases for innovation is critical for their growth (Manniche et al., 2017). For example, in firms strongly characterized by a core of synthetic knowledge, incremental innovation can derive from the access to new synthetic knowledge or symbolic knowledge bases. At the same time, different studies demonstrate that the knowledge key for innovation is mainly of analytical nature (Plum and Hassink, 2011). Thus, we expect that the combination between synthetic and analytical knowledge can lead to a higher degree of innovation (Grillitsch et al. 2017.) with respect to firms that prevalently use synthetic knowledge bases for innovation, or that in general do not rely on mixed knowledge bases. In addition, we expect that knowledge combinations are also important to enlarge the scope of innovation. This is important because for firms belonging to traditional Italian LPSs, for example, what matters today is the 're-generative' knowledge that supports different types of innovation related to service, logistic, the renewal of the business model, new marketing, new business approaches, and so on. Promoting innovation with high degree of novelty and enlarging the scope of firms' innovation is becoming key to stimulate diversification of local systems towards different niches of specializations or towards processes of '*servitization*' where the development of innovative service activities requires to move from traditional synthetic knowledge-base routes and support processes to organizational challenges within analytical and intangible activities (Bellandi et al., 2020b; Bustinza et al., 2017; Lafuente et al., 2017).

To be sure, if a firm combines several knowledge bases, these are still distinct in terms of their nature, way of producing knowledge, and epistemic communities. For instance, the artistic designer, product technician, and data scientist will still draw on very different types of knowledge even if they together work on creating a new product that may have a superior value proposition both in terms of technology and aesthetic value.

In order to innovate, firms combine internal and external knowledge (Chesbrough, 2003). The literature on knowledge bases has also made a contribution to understand the geography of innovation, this is to say at what spatial scales different types of knowledge are acquired. The argument is that analytical knowledge is normally less sensitive to geographic distance and social interaction, as it is more prone to codification processes through, for example, the sharing of formal models. Consequently, interaction at different spatial scale for innovation are usually possible (Asheim and Gertler, 2005; Moodysson et al., 2008). On the contrary, knowledge characterized by a less codified and more contextualized nature – as it is often the case for synthetic and symbolic knowledge – may be more difficult for firms to acquire over larger geographical distance. Some studies show that face-to-face interaction among customers and suppliers, crucial to exchange tacit knowledge and practical experiences, are usually more important for synthetic and symbolic knowledge-based activities, than for analytical knowledge (Asheim and Coenen, 2005; Coenen et al., 2006; Moodysson et al., 2008; Martin and Moodysson, 2013). Since a consistent amount of tacit knowledge and practical experiences are exchanged in traditional LPS in those ways, it may be more difficult to rely on long distance interactions for innovation[2].

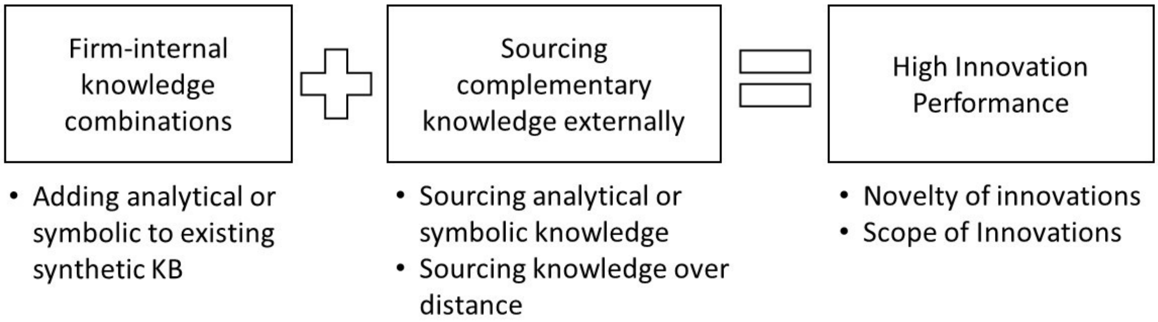
However, when linking access to knowledge to the novelty and scope of innovation processes, other mechanisms may come into play. Most importantly, the knowledge available in LPSs may be of lesser novelty than knowledge that could potentially be accessed over larger distance. This is because LPSs are characterized by strong social networks and learning between local actors, which over time leads to a more homogeneous knowledge base (Menzel and Fornahl, 2010). Additionally, LPSs are typically specialized providing a lower variety of potential knowledge sources compared to more diversified city regions or metropolitan areas. Hence, accessing knowledge beyond the LPS is expected to be important for firms generating radical innovation and a larger scope of innovations (Bellandi et al., 2020a; Trippl et al., 2018).

To be sure, even though accessing knowledge beyond LPS may promote high innovativeness; this does not mean that firms have the ability to do so. In connection with the argument presented above that the knowledge bases are substantially different in nature, and thus in principle unrelated, accessing knowledge bases, which firms do not have in-house, will be difficult over distance. When accessing complementary knowledge bases, firms may use geographic proximity to compensate for the cognitive and institutional distance of knowledge bases they do not have in-house (Boschma, 2005). This also resonates with the argument that firms need to build absorptive capacity to access firm-external knowledge (Cohen and Levinthal, 1990, Zahra and George, 2002). In relation to the current paper, this

[2] Recently some studies have identified different mechanisms at firm level (e.g. foreign direct investments to short geographical distance) that can be put in in place to access and combine different knowledge bases with synthetic and symbolic nature. These mechanisms seem to overcome some of the obstacle to knowledge-base transferability and lack of knowledge local availability (Bellandi et al., 2020a; Martin et al, 2018).

means that firms need to combine knowledge bases in-house to source easily different knowledge bases externally. As regards manufacturing industries, which are typically characterized by a strong synthetic knowledge base, firm-internal knowledge combinations imply adding analytical or symbolic knowledge to the existing synthetic knowledge base. Sourcing complementary knowledge externally, in such contexts, relates to either accessing analytical or symbolic knowledge, or accessing knowledge over larger geographical distance. These causal relationships are presented in the analytical framework (Figure 1) and will be illustrated through the empirical study presented next.

Figure 1: Analytical Framework



3. Empirical study

3.1 Introduction to the case study region: the Mechatronics LPS in the Veneto Region

The Mechatronics industry combines different knowledge domains (mechanics, electronics and ICT). In Italy LPSs, which are specialized in mechatronics products, are mainly placed in the most developed regions such as Veneto, Lombardia, Trentino Alto Adige, Emilia Romagna. Veneto, as other Italian regions located in the North-Eastern area of Italy, possesses specific industrial characteristics such as a large base of small and medium enterprises (SMEs) active in manufacturing activities; cognitive industrial structures leveraging production skills of traditional crafts; and technical and creative capabilities embedded in local social capital (Becattini, 2001). Thus, it is common in those regions to find industrial specializations organized territorially in clusters and industrial districts.[3] The focus of the paper is a Mechatronics LPS, particularly interested in the recent evolution towards Industry 4.0 located

[3] The Veneto region industrial structure has numerous LPSs anchored to traditional low and medium tech sectors of made in Italy specializations, such are those ones linked to fashion, furniture, agro-food, sport equipment and mechanics; all having quite dynamic international markets and contributing largely (more than 40%) of the value added of the region. See also: https://ec.europa.eu/growth/tools-databases/regional-innovation-monitor/base-profile/veneto.

in Vicenza, one of the Veneto provinces. The mechatronics LPS, although technologically more advanced than other traditional sectors, maintains still its core in the historical local specialization in mechanics and for this reason the industry has still strong roots in the synthetic knowledge base. A large part of the Mechatronics local specialization is aimed to the production of tailored industrial machineries, related appliances and automation processes. The production supplies functional goods and services both to the other firms present in the province and belonging to other core local industrial productions (e.g. textile, leader goods, gold jewelry, marble goods), as well as to customers in the global value chains (GVCs) to which many of those territorial specialized firms belong[4].

3.2 Research methodology and data

Our empirical investigation is driven by the need to understand how manufacturing firms step-up their innovation performance in the context of being embedded in a LPS with roots in traditional manufacturing and anchored in an industrial district capitalism model. In order to enhance our understanding of firms' knowledge and innovation processes in such a context, we collected primary data using a mixed method research design combining and integrating the collection of quantitative with qualitative data (Creswell et al., 2003).

In 2017, we conducted an online survey targeting the population of mechatronics firms in the LPS (460 firms, almost all SMEs). The survey contained a series of semi-structured questions to be answered by the firms' entrepreneurs or qualified managers focused on the understanding of the recent development of the industry. In particular, the survey investigated the degree and the geography of firms' innovation linkages during the period 2014-2016, and the nature and level of firms' in-house knowledge. The survey was inspired by some questions in the Community Innovation Survey (CIS) and other similar questionnaires[5]. Before launching the survey, to validate the questions and adapting them to the specific context, we run a pilot targeted to different local experts.

In order to increase the response rate, firms were contacted by phone. A total number of 86 firms responded to the survey and 85 provided valid answers for this paper, reaching a response rate of approximately 18.5%.. We used the results from the survey to analyze how firms combined knowledge in-house and from external sources, to identify correlations between innovation performances and knowledge base combinations, and to build the multivariate model illustrated in the next section.

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[4] The mechatronics specializations present at local level are still partly based on technical skills resembling almost 'artisan work'. The production of tailored machineries is particularly suitable for responding to the incremental adaptation of products and services and peculiar clients' needs which find correspondence in the 'Made in Italy' typology of production as well as in similar niches productions in GVCs.

[5] E.g. Plechero and Chaminade (2013); Martin et al. (2018).

We complemented the survey with 8 in-depth interviews with the aim of assisting the interpretation of the quantitative findings and better understand the local aspects of the industry. Six interviews have been conducted with entrepreneurs and key managers of local companies. The other two interviews have been conducted with representatives of the main entrepreneurial association of the province, experts of the LPS. All the interviews lasted at least one hour and have been conducted, recorded and transcribed by one of the co-authors of the present paper, the same researcher who designed the main framework of the survey, thus ensuring the highest coherence in the validation and interpretation of the results. The researcher was also in charge of the analysis of the results, extracting concepts and quotes aiming at supporting the explanation of the correlations detected in the quantitative analysis.

4. Findings

4.1 Knowledge bases in the Mechatronics sector in Vicenza

Mechatronics in Vicenza strongly relies on engineering/technical knowledge. The results of the survey show that the average profile of employees specifically involved in innovation activities is mainly linked to technical and engineering studies (around 79% of firms declared having such employees involved in innovation activities). This type of profile is particularly suitable for synthetizing existing knowledge and for activities emerging from doing, using, and interacting learning forms (DUI) (Jensen et al., 2007). As highlighted in various interviews, the presence of historical technical professional schools -such as the Industrial Technical Institute “Rossi”-, with strong linkages to local manufacturing industries, have contributed substantially to the development of a large pool of human resources endowed with synthetic knowledge to be employed in the local mechatronics industry.

Around 18% of firms have also employees supporting internal innovation without any educational background, also consistent with the DUI form of learning still characterizing the sector and the core of the mechanics specialization in the LPS. These resources without any educational background are mainly the elder employees -often middle age workers possessing more traditional and artisan skills derived mainly from learning by doing. One of the founders of a medium mechatronics company producing machineries for the leather industry explained in the interview that workers in their forties and fifties without educational background find it difficult to operate with the new technologies introduced by the recent 4.0 industrial revolution.

However, as some interviews revealed, in recent years, local firms have started to employ human resources with science-based educational profiles or with highest education degrees (doctoral degrees) aimed at supporting more scientific and theoretical modes of learning. This may help firms to strengthen their analytical knowledge base to respond to Industry 4.0 challenges. The need to employ personnel able to elaborate new data and understand new analytical problems related to the new wave of digitalization processes emerged clearly from the conducted interviews.

The CEO of a medium company specialized in integrated mechatronics solutions for automation processes discussed the mentality of local firms saying specifically:

> *'We don't have here [locally] the culture to analyze data, to read the most analytical part of things, from where they come and why'* (English translation from Italian)

In line with this, the CTO of one of the most important local mechatronics companies highlighted that local firms have to grow professionally to understand new methodologies and apply cross-sectorial competences. In general, the majority of the entrepreneurs who have been interviewed made clear that today relying on employees who know how to study and elaborate on the increased complexity of products is strategic. Products that in the past relied on simple mechanics are now sophisticated electronic products incorporating complex software features. Indeed, the Doctoral Programme in Mechatronics and Product Innovation Engineering of the University of Padua - held in Vicenza- is increasingly important[6]. Local companies, as interviews showed, still have mental barriers and find it difficult to link to the universities for research purposes.

The survey and interview data about the firms' educational profiles of employees engaged in innovation, suggest that innovation capabilities of mechatronic firms in Veneto are strongly rooted in synthetic knowledge. However, firms indicate increasing efforts to complement the internal synthetic knowledge base with analytical knowledge in order to respond to challenges of industry 4.0. This picture is corroborated by the survey data about which type of knowledge firms consider to be of strategic importance for the pursuit of their innovation activities.[7]

Most of the local firms (71) declared that mainly engineering and technical knowledge (i.e. synthetic knowledge) was strategic for pursuing their innovation activities. The scientific knowledge (i.e. analytical knowledge) was considered key by 22 firms, while artistic/creative knowledge (i.e. symbolic)

[6] One of the main aims of the local Ph.D. programme is to strengthen the scientific training of future human resources for the research activity related to the local industry.

[7] Firms were asked to judge on a scale ranging from 0 (not at all important) to 5 (very important) the presence within the company of different types of knowledge base (a. scientific, b. technical/engineering and 3. creative knowledge) supporting innovation activities. We considered the knowledge base of strategic importance only when firms provided values 4 or 5.

was considered key only for very few firms (10 firms). Importantly, all those firms that considered relevant symbolic and/or analytical knowledge bases have considered relevant synthetic knowledge base as well. This means that almost one third of mechatronic firms combine today existing synthetic knowledge with novel analytical or symbolic knowledge (see table 1).

Table 1 – Internal knowledge-base (KB) types supporting firms' innovation

	N. of firms (N): 85	Percent
None	14	16.47
Synthetic KB only	43	50.59
KB combination	28	32.94

4.2 Sourcing of knowledge in the Vicenza Mechatronics LPS

In innovation processes, firms combine internal and external knowledge. Having established that mechatronics firms have a core in-house strength in synthetic knowledge, this section investigates, which types of knowledge firms source externally and from what geographical scales. The survey shows that around 64% of firms in the sample have sourced synthetic knowledge externally, 54% analytical knowledge and 26% symbolic knowledge. These percentages change when considering the type of internal knowledge base firms rely on when they innovate: table 2 shows that firms having strategically combined in-house knowledge bases are also able to access more easily other knowledge from external sources, which is perfectly in line with the literature on absorptive capacity.

Table 2 – Access to external KB types according to the internal KB combination

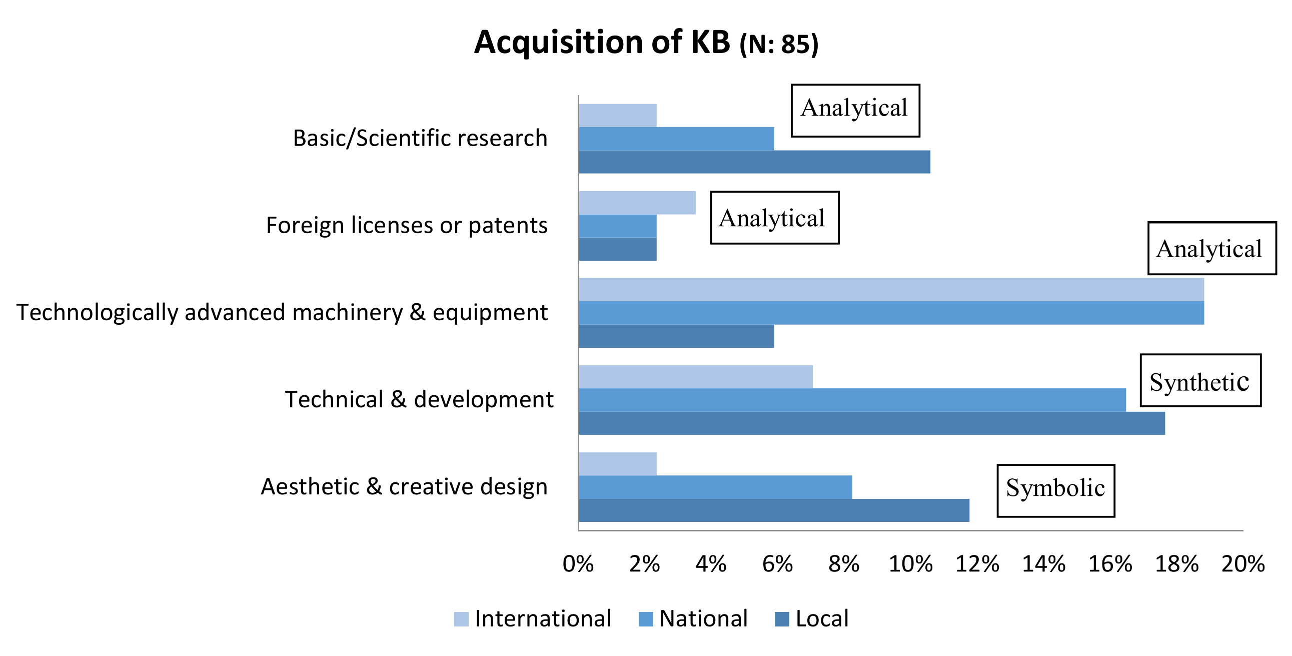
	External access of knowledge		
Internal knowledge base	Synthetic KB	Analytical KB	Symbolic KB
None (% of 14 firms)	36%	29%	14%
Synthetic KB (% of 43 firms)	70%	53%	26%
KB combination (% of 28 firms)	68%	68%	32%
% of the overall firm sample (85 firms)	64%	54%	26%

Figures 2 and 3 depict the results for different types of knowledge accessed externally (acquired from partners or accessed through external collaboration activities) considering the geographical location of firms' sources and associating them to one of the three knowledge bases. We also zoomed in on knowledge sources accessed by firms that have synthetic knowledge base and that combine knowledge bases in-house, respectively.

Overall, as figure 2 depicts, the importance of the local scale for sourcing knowledge is striking, which may be a particular attribute of the thick LPS in Italy. Furthermore, the data suggests that the local scale is dominating in particular for the sourcing of basic/scientific research and aesthetic creative design for new products and services, which represent the purest forms of analytical and symbolic knowledge respectively. This finding goes against some research suggesting that analytical knowledge is most easily to transfer over distance because it is to a larger extent codified than synthetic and symbolic knowledge (Martin and Moodysson, 2013). However, it would corroborate the idea that the three types of knowledge are in principle unrelated and combining them is difficult if the firm has not built up the respective absorptive capacity in-house. Firms in the mechatronics sector whose in-house knowledge base is mainly synthetic would thus rely on geographic proximity to overcome the cognitive and institutional distance associated with the different knowledge bases (Boschma 2005). Continuing on this line of reasoning, firms that combine their traditional synthetic knowledge base with analytical or synthetic knowledge in-house should find it easier to acquire such knowledge over distance. This is exactly what we find in our data as shown in the appendix A In fact, of the firms that source analytical knowledge internationally, all have analytical knowledge in-house.

Most frequently, however, firms source knowledge through the purchase of technologically advanced machinery and equipment. We interpret this to be an acquisition of analytical knowledge, which, however, becomes embedded in the machinery and equipment. From the perspective of the mechatronic firm, the question is then to what extent the application of the machinery and equipment requires analytical skills. This does not necessarily be the case but the interviews suggest that increasingly using sophisticated machinery and equipment also requires employees to have at least some academic training or programming skills. Such sourcing happens most frequently at the international and national scale, which is on the one hand possible due to the embedded nature of knowledge in the machinery and equipment, and, on the other hand, necessary because typically the world markets are dominated by few suppliers. Indeed, the interviews showed how important it is for firms' competitiveness to acquire those machines and equipment on leading international markets, i.e., from German suppliers.

Figure 2 – Access by type of knowledge base



Source: own data elaboration. The data refers to firms' knowledge acquisition.

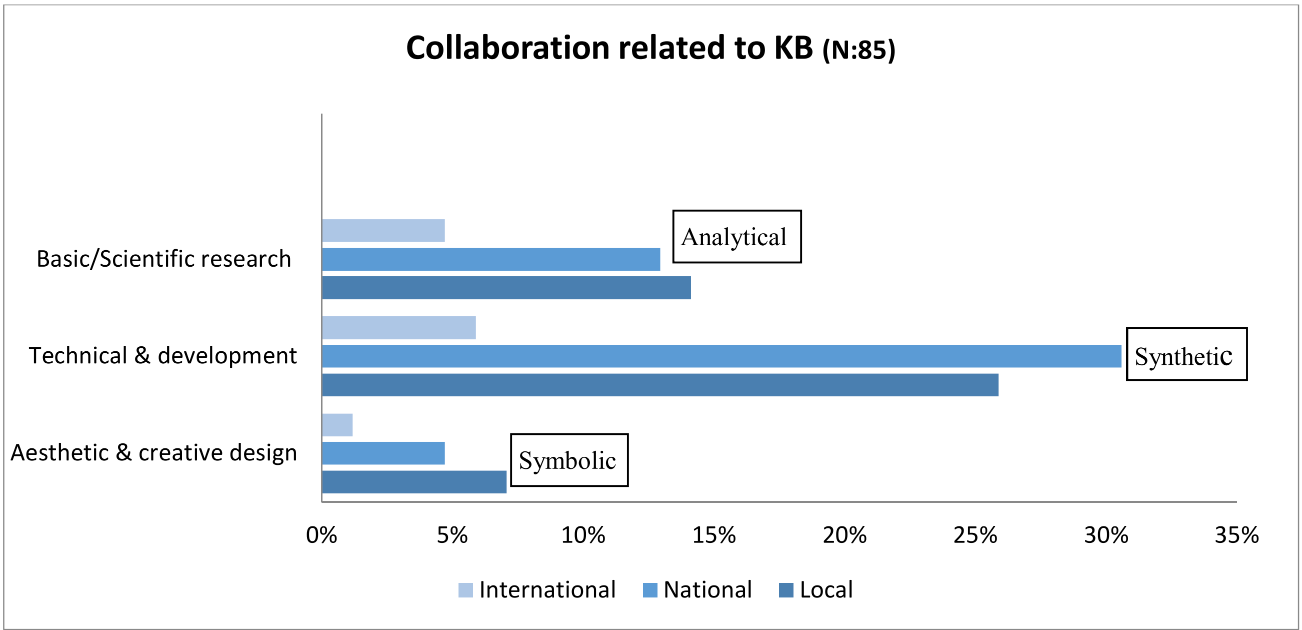
For basic/scientific research, technical development, and aesthetic and creative design, the survey also investigated if and how firms engaged in collaborations, which goes beyond the mere acquisition of knowledge and implies a reciprocal exchange of knowledge (see figure 3).[8]

Overall, we find that the local and national spatial scales were clearly dominating over the international scale, even though the importance of the local scale was less pronounced for the collaboration in aesthetic and creative design as compared to the acquisition of knowledge. This is probably due to the fact that when collaborating for symbolic knowledge some local spillover effects may take place threatening the firms' local competitiveness, particularly if the strategic in-house knowledge is mainly based on local advantages. Firms that combine in-house knowledge bases (see appendix A) collaborate more not only locally but also nationally with respect to the other firms. Interestingly, when firms externally sourced knowledge for research or for technical development, they did so more frequently in a collaborative mode than in a one-way knowledge acquisition mode. As interviews highlighted, this may be related to the fact that accessing external knowledge needs to be linked to peculiar production aspects or specific

[8] Concretely, in the survey question related to sourcing we asked firms if in the years 2014-2016 the company had purchased externally (and at which geographical level) from other companies/organizations factors and activities related to the different knowledge bases reported in figure 2. In a subsequential question, we asked if the company had (within the same time frame and in relation to the three activities of basic/scientific research; technical and development and aesthetic and creative design) some active collaborations (also at informal level) with external partners.

standardization processes bounded to specific firms' operational modes. In relation to research activities, firms having in-house combined knowledge bases collaborate more both at national and international level.

Figure 3 – External collaboration related to the three knowledge bases types



Source: own data elaboration.

4.3 Innovation and combination of knowledge bases from internal and external sources in the Vicenza Mechatronics LPS

To capture the relation between innovation and the combination of knowledge bases from internal and external sources, we have conducted a series of statistical and econometric analyses using different dependent variables: product innovation, top innovation, and innovation index, the latter measuring the strength of firm's innovation capacity:

- Product Innovation: Dummy variable equals 1 if the firm has developed a product innovation that in terms of novelty is above the average innovations in the sector, 0 otherwise.
- Top innovation: Dummy variable equals 1 if the firm has developed an innovation at the forefront in the sector, this means the firms is the only one/one among very few firms globally to have developed such an innovation in their sector, 0 otherwise.

- Innovation Index: Count variable indicating the overall span and degree of innovativeness. This composite indicator has been built by weighting the different types of innovations (product, service, process, organizational and marketing) introduced and degree of innovativeness (below, on the average, above and vanguard with respect the average sectorial standard).[9]

The models aim to investigate associations between innovation and knowledge base combinations from firm-internal knowledge bases and firm-external knowledge-base sources. As regards the firm-internal knowledge base, we distinguish between three groups of firms:

- Firms that, within the company, do not possess knowledge bases supporting innovation
- Firms that, within the company, possess synthetic knowledge supporting innovation (synthetic KB)
- Firms that, within the company, possess a combination of different knowledge bases supporting innovation (KB combination)

Table 3 provides a cross-tabulation between the innovation type and the firm-internal knowledge bases. First, as expected, we find that the relative frequency of having a synthetic knowledge base or even a knowledge base combination increases substantially for firms having product or top innovation or firms scoring high on the innovation index. The numbers also suggest that the overrepresentation is particularly striking for knowledge base combinations. In relative terms, knowledge combinations are most frequent for firms with top innovation, and firms scoring highest in the innovation index. Yet, as there are only very few firms with top innovations, this is no statistical proof.

[9] We gave value 1 to each degree of innovation for any of the 5 different introduced types of innovation activities during 2014-2016, and summed up the values.

Table 3: Firm innovation and internal knowledge bases

	Firms with product innovation	Firms with no product innovation	Firms with top innovation	Firms without top innovation	Firms with innovation index above 67th quantile	Firms with innovation index between 33rd and 67th quantiles	Firms with innovation index below 33rd quantile
Number of observations	42	43	11	74	17	38	30
None	10%	23%	0%	19%	0%	13%	30%
Synthetic KB	43%	58%	36%	53%	35%	53%	57%
KB combination	48%	19%	64%	28%	65%	34%	13%
Chi2-Test	p=0.012**		p=0.045**		p=0.004***		

As regards firm external knowledge, we associate the typical ways firms in the mechatronic sector access external knowledge with specific knowledge bases as shown in Figure 1. The results shown in Table 4 are based on whether firms access external knowledge through either the one-way acquisition or collaboration mode. Differentiating between the two modes of accessing external knowledge did not yield further insights. The table differentiates between firms that i) do not source knowledge externally, ii) source only synthetic knowledge externally, and iii) source either analytical or symbolic knowledge externally. The table shows that top innovators and firms scoring high in the innovation index very frequently complement in-house knowledge with either analytical or symbolic knowledge from external sources.

Table 4: Firm innovation and external knowledge sourcing

	Firms with product innovation	Firms with no product innovation	Firms with top innovation	Firms without top innovation	Firms with innovation index above 67th quantile	Firms with innovation index between 33rd and 67th quantiles	Firms with innovation index below 33rd quantile
Number of observations	42	43	11	74	17	38	30
None	17%	33%	0%	28%	6%	21%	40%
Only synthetic KB	14%	14%	0%	16%	6%	8%	27%
Either analytical or symbolic KB	69%	53%	100%	55%	88%	71%	33%
Chi2-Test	p=0.222		p=0.018**		p=0.002***		

Table 5 goes a step further, testing for statistical significant relationships between internal and external knowledge base combinations and firm innovativeness. We used multivariate regressions to control for confounding variables, and assess the simultaneous effect of the different variables of interest. The control variables capture, the size of the firm, and if the firm was part of a group or not. We controlled also for the presence of human resources dedicated to innovation trained on the job (without higher education) that in LPS represents 'artisan' knowledge acquired on the job through learning-by-doing and interacting, and represents synthetic knowledge[10]. Model A, Model B and Model C refer to the three different dependent variables that specify the type and degree of firms' innovativeness. Column 1 of each model considers knowledge sourcing overall, disregarding the geographical distance. Column 2 of each model captures knowledge sourcing beyond the borders of the LPS. Column 3 captures knowledge sourcing at the international level.

We find that there is a strong, significant and positive relation between combining different knowledge bases internally and firm innovativeness. As mentioned previously, in the sample of our firms this always refers to the combination of synthetic knowledge with another knowledge base. This is an important finding, which our interviews corroborate: mechatronics firms have traditionally had a strong synthetic knowledge base. Yet, to remain innovative and competitive today in a period of transition to industry 4.0, firms need to combine and integrate new knowledge bases. The result that synthetic knowledge acquired on the job is positively related to product innovation with a relatively low threshold as regards novelty but slightly negative (only weakly significant in Column 3) to top innovation reinforces the argument that traditional learning by doing is not enough to support more radical innovation that may help firms to find new business models.

Turning to the relation between the access to external knowledge and firm innovation, the results indicate the high importance of analytical knowledge for top innovators and firms scoring high on the innovation index. Indeed, the interviews corroborate that human resources with high educational profiles have been key to identify new market or technological opportunities and develop strategies for grasping these opportunities.

The multivariate analysis adds one important additional insight as compared to the descriptive statistics presented above: Even though firms source analytical knowledge more frequently at the local level, the positive correlation with firm innovativeness is mainly due to sourcing this type of knowledge outside

[10] The description of the variables and related correlations are reported in Appendix B.

the LPS, in particular at the international scale. In connection with the findings that firms need to possess a combination of knowledge bases in-house to access analytical knowledge over distance, this provides a very clear picture about the preconditions for firms to innovate in the area of industry 4.0. For example, it is necessary to build analytical and synthetic absorptive capacity for understanding and exploiting the potential of 4.0 technologies such as data analytics or sensor tools for the mechatronics business (e.g. new ways of elaborating and using customer data, scaling positions within GVC through digital platforms, using correctly devices and digital tools for maintenance of remote services). Firms that complement their synthetic knowledge base with analytical knowledge in-house are able to access complementary knowledge beyond the LPS, which in turn is highly related to the ability of firms to create top innovation and score high on the innovation index.

We also find some (but statistically weak) evidence that accessing symbolic knowledge matters for top innovation and scoring high on the innovation index. For top innovations, the relation rests mainly on accessing symbolic knowledge beyond the LPS and mainly nationally, where it is still possible to link to the 'Made in Italy' cultural heritage. As regards scoring high on the innovation index the LPS appears to play a stronger role. Our interviews suggest that this relates to sourcing such knowledge from local partners who, thanks to the deep knowledge of the context of operations, may support firms in downstream innovation, and in the creation of contextualized service and oriented experiences for customers.

We also find weak statistical evidence that accessing synthetic knowledge is positively correlated with product innovation with a relatively low novelty threshold. These patterns are also consistent with the interpretation that high innovativeness is mainly related to combining complementary knowledge and beyond the local system.

Table 5 – Regression results

Dependent variable	Logit Model A Product Innovation			Logit Model B Top innovation			Poisson Model C Innovation Index		
	(1)	(2)	(3)	(1)	(2)	(3)	(1)	(2)	(3)
Size	0.914	1.112	1.046	0.064	0.294	0.760	**0.181****	**0.205****	**0.224*****
	(0.693)	(0.691)	(0.707)	(1.102)	(1.406)	(1.002)	(0.080)	(0.088)	(0.085)
Group	-0.697	-0.665	-0.607	-1.242	-1.539	-1.448	-0.129	-0.120	-0.085
	(0.645)	(0.634)	(0.623)	(0.973)	(1.124)	(0.924)	(0.085)	(0.095)	(0.087)
Synthetic: trained on the job	**3.425*****	**3.064*****	**3.210*****	-1.424	-1.546	**-1.593***	0.054	0.087	0.093
	(1.204)	(1.125)	(0.869)	(1.498)	(1.042)	(0.832)	(0.093)	(0.088)	(0.082)
In-house knowledge base combination	**1.486****	**1.403****	**1.447****	**1.673****	**1.784****	**1.931****	**0.248*****	**0.250*****	**0.284*****
	(0.641)	(0.610)	(0.595)	(0.817)	(0.830)	(0.785)	(0.070)	(0.073)	(0.071)
Source synthetic KB	**1.081***			1.623			0.082		
	(0.649)			(1.070)			(0.108)		
Source analytic KB	0.618			**1.857***			**0.198****		
	(0.587)			(1.113)			(0.100)		
Source symbolic KB	-1.000			-0.285			**0.148***		
	(0.704)			(0.835)			(0.076)		
Synthetic KB (beyond LPS)		0.970			-0.246			0.026	
		(0.616)			(0.912)			(0.097)	
Analytical KB (beyond LPS)		0.386			1.650			**0.187***	
		(0.578)			(1.028)			(0.098)	
Symbolic KB (beyond LPS)		-1.039			**1.699***			0.123	
		(0.946)			(0.920)			(0.081)	
Synthetic KB (International)			-0.617			0.109			-0.041
			(1.156)			(1.000)			(0.160)
Analytical KB (International)			0.880			**1.671****			**0.186****
			(0.660)			(0.753)			(0.084)
Symbolic KB (International)			1.360			1.255			0.113
			(1.612)			(1.476)			(0.181)
_cons	-1.754***	-1.416***	-1.175***	-4.738***	-3.502***	-3.150***	1.951***	2.023***	2.071***
	(0.505)	(0.405)	(0.401)	(0.897)	(0.845)	(0.607)	(0.096)	(0.084)	(0.079)
Obs.	85	85	85	85	85	85	85	85	85
R-squared	0.2731	0.2537	0.2428	0.2658	0.2341	0.2234	0.0816	0.0693	0.0608
P	0.0195	0.0153	0.0003	0.0013	0.0233	0.0016	0.0000	0.0000	0.0001

Robust standard errors are in parenthesis. *** p<0.01, ** p<0.05, * p<0.1

5. Discussion and conclusion

Industry 4.0 is both an opportunity and threat for manufacturing firms with traditional roots. It is an opportunity if firms manage to innovate and remain relevant in the age of industry 4.0. It is a threat, if firms cannot make this rather radical change from traditional ways of working. This paper contributes by investigating innovation processes of mechatronics firms, immersed in a traditional Italian local productive system. It investigates how the combination of traditional, synthetic knowledge with complementary analytical and symbolic knowledge in-house and from external sources at different spatial scales relate to different types and degrees of firm innovation.

The paper shows that the contextualized 'generative' power of the local synthetic knowledge that has guaranteed the past success of the LPS under scrutiny, as well as of other similar LPSs with traditional roots, has not disappeared. The local peculiarities of synthetic knowledge in a territorial system (expressed by the local firms and the local labor market in which the firms impinge) still plays a role for strengthening firms' capacities to develop product innovation. More importantly, however, the combination of the traditional synthetic knowledge with the other knowledge bases (particularly, analytic knowledge) is essential for producing radical innovations, which allows firms to identify and grasp the opportunities offered by industry 4.0. The statistical analysis, even though not proofing causality, together with the interviews corroborate the hypothesis that the generative power of the synthetic knowledge in traditional LPS can create value if supported by other types of knowledge bases that do not substitute, but complement the functions that synthetic knowledge may have for LPS with traditional roots.

In addition, the survey and interview data support the theoretical idea that the three knowledge bases are in principle unrelated, and thus characterized by relatively high cognitive distance. This cognitive distance makes it more difficult to absorb knowledge that is complementary to the exciting, traditional synthetic knowledge base in the sector. We find that the LPS where geographical, social and institutional proximity help to overcome cognitive distance, is frequently used to source analytical and symbolic knowledge. Furthermore, the empirical evidence indicates that combining knowledge bases in-house (e.g. firms that have recruited staff with complementary knowledge) is an important precondition for sourcing complementary knowledge externally. Moreover, sourcing of basic and scientific research beyond the borders of LPS is largely reserved to firms that also have such knowledge in-house. Consequently, firms that combine knowledge bases in-house have a higher absorptive capacity to access analytical and symbolic knowledge.

Moreover, firms that combine the traditional synthetic knowledge with complementary knowledge bases internally are not only more able to source knowledge at higher spatial scales, but they are also more likely to generate radical innovations and to engage in different types of innovation. Radical innovation are related to the sourcing of analytic and symbolic knowledge outside the LPS. Moreover, the injection of analytical knowledge from international level is associated with generating radical innovations and strengthening the overall innovation capacity. The survey and interview data thus suggest that radical innovations, which are necessary to grasp opportunities of industry 4.0, rest on complementing the traditional synthetic knowledge with complementary knowledge in-house, which then allows combining the internal knowledge with complementary analytical and symbolic knowledge from beyond the LPS. The combination of firm-internal knowledge with the sourcing of complementary knowledge at different spatial scales are intrinsically linked and together fundamental for firms to transition towards industry 4.0.

The study has some limitations. As in many studies drawing from primary data, the measures of innovative performance are based on firms' self-assessment and on small sample sizes. Future research should be devoted to extent the empirical analysis to other similar LPSs to improve the validity of the research findings.

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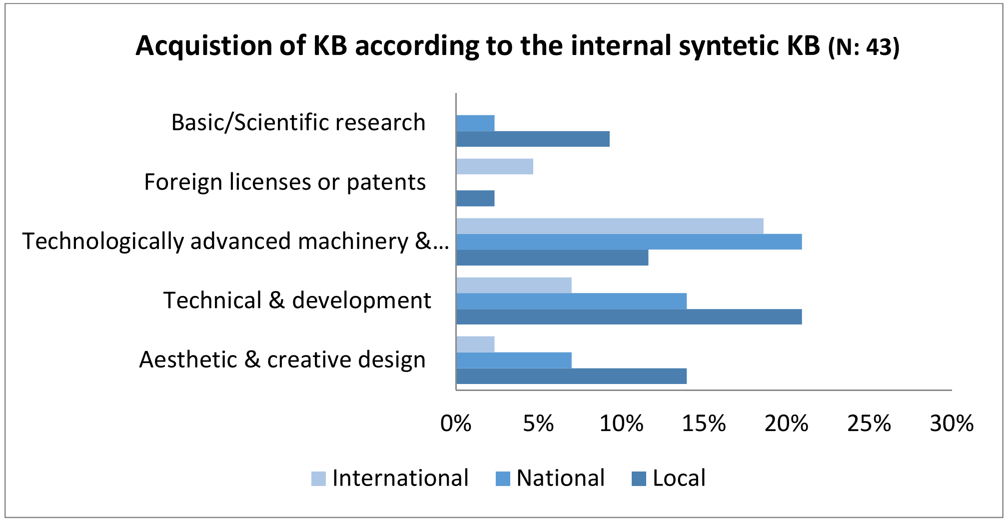
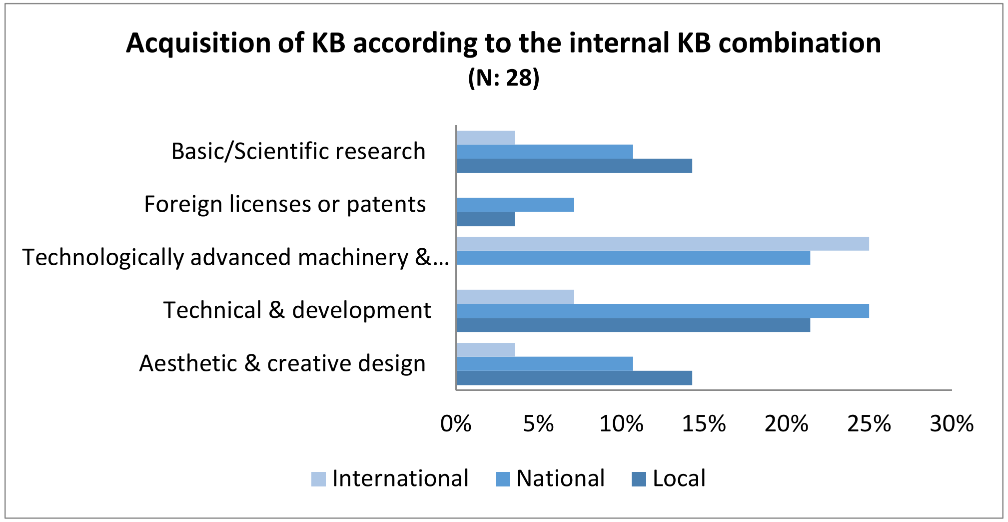
Appendix A


Acquistion of KB according to the internal syntetic KB (N: 43)
Basic/Scientific research
Foreign licenses or patents
Technologically advanced machinery &...
Technical & development
Aesthetic & creative design
0%
5%
10%
15%
20%
25%
30%
International
National
Local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International
National
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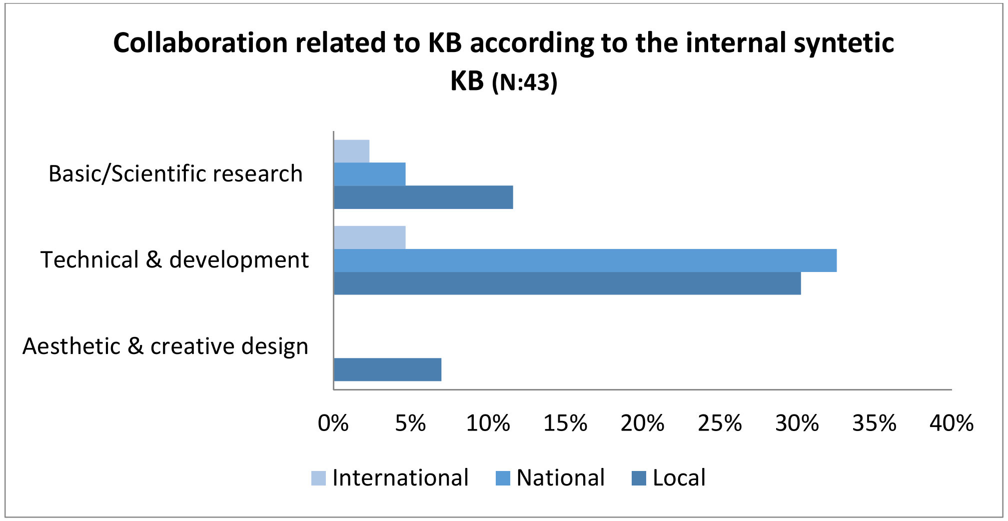
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25%
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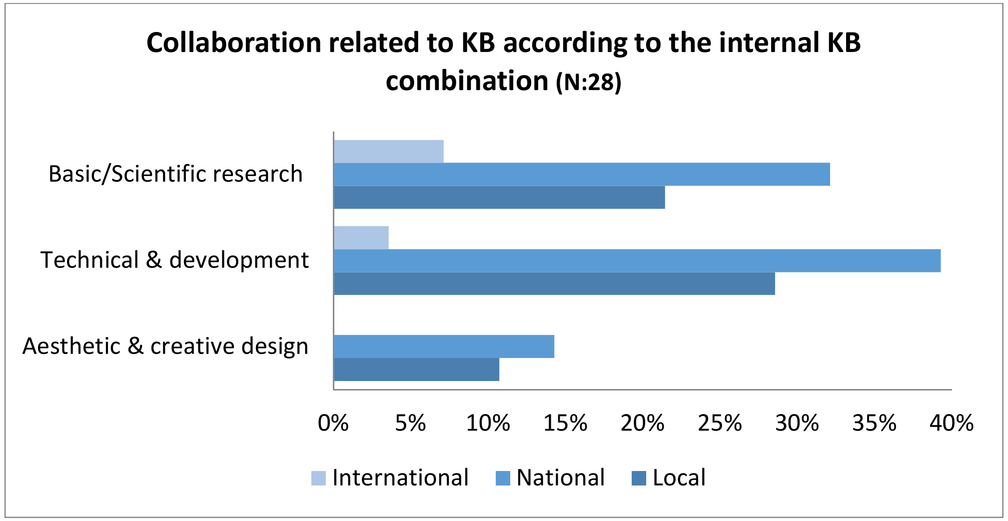
35%
40%
International
National
Local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Basic/Scientific research
Technical & development
Aesthetic & creative design
0%
5%
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35%
40%
International
National
Local

Appendix B. Descriptive Statistics

Variable	Description	Obs	Mean	Std.Dev.	Min	Max
Product Innovation (1)	Dummy variable equals to 1 if the firm has developed a product innovation at least above the sectoral average, 0 otherwise	85	.494	.503	0	1
Top innovation (2)	Dummy variable equals to 1 if the firm has developed a top innovation at the forefront (i.e. being the only one or among the few at the global level to have developed such an innovation in their sector), 0 otherwise	85	.129	.338	0	1
Strength of Innovation capacity (3)	Count variable indicating the overall span and degree of innovativeness. This composite indicator has been built by weighting the different types of innovations (product, service, process, organizational and marketing) introduced and degree of innovativeness (below, on the average, above and vanguard with respect the average sectorial standard)	85	9.718	3.981	0	17
Size (4)	Dummy variable equals to 1 if the firm is at least of medium size in terms of employees (50 or more), 0 otherwise	85	.224	.419	0	1
Group (5)	Dummy variable equals to 1 if the firm is part of a group, 0 otherwise	85	.247	.434	0	1
Synthetic: trained on the job (6)	Dummy variable equals to 1 if the company has employees trained on the job involved in innovation activities, 0 otherwise	85	.176	.383	0	1
In-house knowledge base combination (7)	Dummy variable equals to 1 if the firm declared that at least two different types of knowledge bases (analytic, synthetic, symbolic) has been considered strategic for innovation activity, 0 otherwise	85	.329	.473	0	1
Source synthetic KB (8)	Equal to one if the firm has acquired from/collaborated with other firms and/or organizations in terms of synthetic knowledge, 0 otherwise	85	.635	.484	0	1
Source analytical KB (9)	Equal to one if the firm has acquired from/collaborated with other firms and/or organizations in terms of analytical knowledge, 0 otherwise	85	.541	.501	0	1
Source symbolic KB (10)	Equal to one if the firm has acquired from/collaborated with other firms and/or organizations in terms of symbolic knowledge, 0 otherwise	85	.259	.441	0	1
Synthetic KB (beyond LPS) (11)	Equal to one if the firm has acquired from/collaborated with other firms and/or organizations beyond LPS in terms of synthetic knowledge, 0 otherwise	85	.424	.497	0	1
Analytical KB (beyond LPS) (12)	Equal to one if the firm has acquired from/collaborated with other firms and/or organizations beyond LPS in terms of analytical knowledge, 0 otherwise	85	.482	.503	0	1
Symbolic KB (beyond LPS) (13)	Equal to one if the firm has acquired from/collaborated with other firms and/or organizations beyond LPS in terms of symbolic knowledge, 0 otherwise	85	.118	.324	0	1
Synthetic KB (International) (14)	Equal to one if the firm has acquired from/collaborated with other international firms and/or organizations in terms of synthetic knowledge, 0 otherwise	85	.118	.324	0	1
Analytical KB (International) (15)	Equal to one if the firm has acquired from/collaborated with other international firms and/or organizations beyond LPS in terms of analytical knowledge, 0 otherwise	85	.247	.434	0	1
Symbolic KB (International) (16)	Equal to one if the firm has acquired from/collaborated with other international firms and/or organizations beyond LPS in terms of symbolic knowledge, 0 otherwise	85	.035	.186	0	1

Pairwise correlations

Variables	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)	(16)
(1)	1.000															
(2)	0.320*	1.000														
(3)	0.505*	0.444*	1.000													
(4)	0.148	0.046	0.231*	1.000												
(5)	-0.021	-0.058	0.055	0.216*	1.000											
(6)	0.407*	-0.087	0.142	-0.026	-0.051	1.000										
(7)	0.309*	0.252*	0.366*	0.045	0.179	0.135	1.000									
(8)	0.211	0.219*	0.255*	0.055	0.151	0.094	0.063	1.000								
(9)	0.154	0.285*	0.358*	0.154	0.254*	-0.069	0.193	0.332*	1.000							
(10)	0.061	0.012	0.300*	0.070	0.160	0.290*	0.100	0.392*	0.221*	1.000						
(11)	0.201	0.095	0.145	-0.117	0.171	0.165	0.108	0.649*	0.264*	0.146	1.000					
(12)	0.129	0.259*	0.337*	0.104	0.211	-0.015	0.225*	0.242*	0.889*	0.236*	0.316*	1.000				
(13)	0.004	0.186	0.201	0.067	0.214*	0.118	0.055	0.277*	0.263*	0.618*	0.352*	0.305*	1.000			
(14)	0.004	0.077	0.008	-0.108	-0.040	0.118	-0.101	0.277*	0.190	0.118	0.426*	0.159	0.320*	1.000		
(15)	0.143	0.267*	0.213	-0.045	0.115	0.021	0.063	0.207	0.527*	0.160	0.227*	0.593*	0.129	0.214*	1.000	
(16)	0.066	0.116	0.110	0.050	0.038	0.079	0.002	0.145	0.176	0.324*	0.223*	0.198	0.524*	0.524*	0.186	1.000

* It shows significance at the .05 level