Transformation paths and the multi-scalarity of knowledge bases under Industry 4.0 challenges

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Papers in Innovation Studies
Paper no. 2018/14

This is a pre-print version of paper, which has been submitted to a journal.

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http://www.circle.lu.se/publications

WP 2018/14

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Keywords: Combinatorial knowledge bases; internationalization; I4.0; Makers Project; path transformation

JEL: R11; R12; O30; O19

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Acknowledgement: Support from the Marianne and Marcus Wallenberg Foundation (MMW 2012.0194) and the Horizon 2020 project Makers (Marie Sklodowska-Curie Actions – Grant agreement number 691192) is gratefully acknowledged.

1. Introduction

This chapter discusses the role of combinatorial knowledge and its multi-scalarity on transformation paths in local productive systems (**LPS**) that are under the gales of contemporary technological change. Specifically, we look at the role of access and combination of different knowledge bases at different territorial scales (local/regional, national, international/global) supporting different paths of industrial upgrading in LPS in face of the challenges of Industry 4.0 (**I4.0**). We adopt the **I4.0+** (plus) perspective defined in the Introduction of this book, which aims to address sustainable development.

Local and regional transformation paths are based today on complex knowledge dynamics (Grillitsh et al., 2018), particularly in relation to different types of knowledge

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that can interrelate and support some degree of innovativeness in local systems (Asheim et al., 2017; Grillitsch et al., 2017). This refers not only to knowledge with a different degree of transferability between spaces (tacit vs. codified knowledge), but to differentiated knowledge bases: synthetic (science based), analytic (engineering based) and symbolic (cultural based) (Asheim and Gertler, 2005; Asheim and Coenen, 2005).

Traditionally the literature on knowledge bases has argued that synthetic knowledge and symbolic knowledge - which have both a high tacit content – tend to be accessed in close proximity, with the recourse to limited international interactions (Martin and Moodysson, 2011, 2013). In contrast, analytic knowledge - which has a higher codified content – tend to be access on wider geographical settings. However, recent evidence suggests that also synthetic and symbolic knowledge can be sourced at international level, which extends the potential for knowledge bases combination by opening up the possibility to access all knowledge bases at different geographical scales (Martin et al, 2018).

In this paper, we build on such suggestion, and propose a novel conceptual frame on the matching of different potentialities of path transformation to combinatorial knowledge creation. Here, matching involves different knowledge bases sourced at all geographical scales (from regional to international and even global). Furthermore, effective sourcing depends on the use of specific mechanisms and on the presence of place-specific conditions (Section 2).

This extended frame will be applied to the reflection on access and combination of knowledge for alternative models of value creation in LPS transforming towards new or renewed paths of development, to take advantage of the opportunities open by *I4.0*. Digital technologies that characterize the core of *I4.0* may open the way to new value creation in LPS, with impacts not only on economic growth, but also on societal development (OCSE, 2016; Word Bank, 2017). On one side, *I4.0* impinges on an increasing role of analytical/scientific knowledge supported by digital coding. On the other side, the outcomes of innovation processes in *I4.0* incorporate an ever-deeper combination of product, service and societal contents. This implies the necessity of accessing synthetic/engineering and symbolic/cultural knowledge within complex multi-scalar settings (Section 3).

In a last step of the paper, we will extract some exemplifications from case studies of the MAKERS project discussed in the Introduction and other chapters of the book (Section 4).

2. Access and combination of different knowledge bases across space for path transformation in local productive systems

2.1 Knowledge bases and local path transformation

We have recalled in the introduction a stream of contributions arguing that local/regional path transformation is favored when different types of knowledge can be accessed, combined and effectively integrated [4]. Combining different types of knowledge is indeed today a distinct feature of innovation processes across a variety of industries (Strambach and Klement, 2012; Grillitsch and Trippl, 2014). This is even more so in the context of disruptive technological challenges such as the ones brought by Industry 4.0 or when there is a need to pursue sustainable societal as well environmental goals (Strambach, 2017).[5]

Attending to the degree of codification and the processes of knowledge creation, Asheim and Coenen (2005) and Asheim and Gertler (2005) distinguish between three types of knowledge bases:

- *Analytic knowledge (science based)* is often created with the application of experiment-based methods. The value is extracted from the application of scientific principles and theoretical modes of learning. Many of its contents can be transferred in codified form (lectures, reports, publications, patents). Often firms rely for its absorption on formal R&D laboratories, and for its creation on collaboration with research organizations.
- *Synthetic knowledge (engineering based)* relies on inductive processes of problem-solving. In production contexts, it is associated to the engineering of new results emerging from doing, using, and interacting (DUI) forms of learning (Jensen et al., 2007). The value can be extracted by means of socialization and synthesis of the existing knowledge (Herstad et al., 2014).
- *Symbolic knowledge (cultural based)* concerns cultural contents, aesthetic as well as immaterial values. Its creation relies on a variety of heritage and life suggestions elaborated by means of trained artistic and cultural intuition. The value can be extracted from creativity and contextualized sense-making. It is highly place specific, as the interpretation of images, design, and symbols varies significantly from one location to another; but it can embed in artefacts and media communication by means of design and various types of applied and performing arts.

Due to its mostly codified nature, analytical knowledge could be accessed across large geographical distances and, consequently, industries dominated by analytical knowledge bases would portray a high propensity to establish international networks. Synthetic knowledge combines elements of tacit and codified nature and, as a consequence, the knowledge could be acquired both through local and to a lesser extent international networks. Symbolic knowledge creation processes would rely significantly on local knowledge networks (Bathelt et al., 2004; Martin, 2011).

Considering processes of local or regional transformation, when the access to different knowledge bases as well as their combination are limited, there is a high risk of path exhaustion if not decline. On the contrary, when different types of knowledge

[4] See in particular the special issue on Knowledge bases in Economic geography: vol. 93 (5), 2017.

[5] In this later case, the generation of value derives often from unrelated knowledge bases taken from other sectorial contexts and recombined in traditional sectorial specialization (Ibid.).

can be accessed and effectively combined, this may lead to some forms of path upgrading. In particular, new path creation would require a high degree of combinatorial knowledge, which implies often an extensive use of differentiated knowledge bases as well as complex multi-scalar interactions[6].

While some of the initial literature on knowledge bases tends to suggest that synthetic and symbolic knowledge will be sourced in local and regional networks while analytical knowledge will be often sourced at international level (Martin and Moodysson 2011, 2013), more recent works (Martin et al., 2018) underpin the notion that different knowledge bases supporting processes of transformations of LPS can be acquired at different scales depending on needs and capabilities of the local firms. However, they fail short to explain how this is done, which mechanisms are more likely to be used to access different knowledge and at which different geographical scales. This will be discussed next.

2.2 The multi-scalar mechanisms for knowledge access and combination in local productive systems and knowledge-led transformation paths

A key issue that emerges from the literature that links knowledge bases to transformation paths is that effective combinatorial knowledge processes require some interrelation between local and global spaces. Such interrelation, as well as supporting mechanisms at the micro level, need better understanding. Firms and supporting organizations may use a variety of mechanisms that facilitate the access of different knowledge bases (Trippl et al., 2009). They include market mechanisms, networks (e.g. alliances), spill-overs (e.g. mobility) and hierarchies (e.g. FDI).

Knowledge is typically exchanged in *Markets* when it is embodied in goods or services whose value is potentially easy to measure. That embodied knowledge likely corresponds to analytic or to codified synthetic bases knowledge. Typical examples would be the use of patents in a new drug development, or the acquisition of machinery for a specific engineering process. *Networks*, on the other hand, are based on trust and reciprocity (Powell, 1990). The reciprocal character implies similar or complementary absorptive capacity of the actors as well as frequent face-to-face interactions and/or the sharing of habits and collective rules. Networks are a good mechanism for the transmission of know-how and know-who and, in that respect, they are likely to be used for the collaborative transfer and the absorption of tacit contents prevailing in synthetic and symbolic knowledge. Networks for knowledge creation and innovation can take different forms: R&D contracts, alliances, research consortia, epistemic communities or communities of practice. *Hierarchies*, which can be inter-firm and intra-firm, are mainly based on power enforcement, and the sharing of private rules, common routines or a history of previous interactions. Those characters reduce institutional distance also across spaces (Martin and Salomon, 2003). By opening subsidiaries in different locations, multinational corporations (MNCs) can access knowledge of different

[6] Various contributions develop concepts and cases around such relations. See Asheim et al., 2011, 2017; Chaminade et al., 2017, 2018; Grillitsch et al., 2017, 2018; Isaksen and Trippl 2016; Manniche et al. 2017; Trippl et al., 2017.

scientific and technological fields that has been accumulated in different countries or regions around the world (Kafouros et al., 2012). Finally, knowledge can also be accessed via *unintended spill-overs* associated with mobility of human capital, monitoring of competitors, or informal one-term face-to-face contacts. Spill-overs tend to occur in close geographical proximity, although larger geographical distances are not excluded, for example through international mobility (Rosenkopf and Almeida, 2003; Song et al., 2003) or temporary geographical proximity (Torre, 2008).

The propensity of firms to use different mechanisms to access distant knowledge will ultimately depend on the transferability and availability of the knowledge as well as the capabilities of firms. Transferability is the possibility to transmit and receive knowledge without noise, bias, leakages, and depends on the degree of codification. By availability we refer to the degree of concentration of that knowledge in specific regions around the world. The sources of highly novel analytic knowledge, highly specialized synthetic knowledge, or key symbolic knowledge are sparse and often highly concentrated in specific locations (knowledge hubs). This also means that firms located in knowledge hubs have an advantage in terms of the access to the required knowledge for transformation without the need to engage in extra-regional linkages. But having access to knowledge is not enough. The ability of the organization to tap into pools of knowledge is strongly related to its absorptive capacity. So, transferability, availability and absorptive capacity determine the choice of mechanism to access knowledge at different scales.

At what different geographical scales do the mechanisms mentioned above help firms and related organizations to access different knowledge bases and to enter combinatorial knowledge creation processes enabling local transformation?

In order to delimit the discussion of the question to a specific regional unit of investigation, we focus on *local productive systems* (LPS) (Becattini and Rullani, 1996). They are (relatively) small regions (urban or rural areas, industrial districts, etc.) featuring one or a few productive specializations, more or less complementary. The specializations are related to the activity of a population (cluster) of firms and supporting business and public organizations operating in the place. Productive decisions and activities have key roots in local business and socio-cultural and institutional networks.

Table 1 provides a schematic summary of the main mechanisms supporting the access of LPS to different types of knowledge bases that can be levered at different geographical scales. The *appropriateness of the mechanisms* and their role for path transformation in LPS depend on the wealth of knowledge sources in LPS and the type of proximity that can be used when accessing different knowledge bases[7].

--- TABLE 1 ABOUT HERE ---

[7] Another condition not discussed in this chapter is the *appropriability* that concerns how agents interpret and use the acquired knowledge for extracting value.

In *transformation processes*, market mechanisms are used by companies to access internationally available analytic knowledge, for example, through patents (Herstad et al. 2014). However, firms whose innovative processes are driven by the creation and/or the development of new analytic knowledge, either cluster in highly innovative hubs around the world, or tend to link to key players in international knowledge hubs. Networks in this case is a preferable mechanism for distant interactions. Firms located in LPS with strong research infrastructure are also more likely to have high technological capabilities enabling an active participation in research networks at a global scale.

Networks and spill-overs facilitating or implying face-to-face interaction are likely to be used intensively for accessing synthetic knowledge at different scales. Networks in general are likely to work better at local or national level where institutional distance is limited (Martin and Moodysson, 2013; Mattes, 2012). When the accessibility of synthetic knowledge is not high or networks and spill-overs at local level do not provide new input for generating value, firms may decide to use hierarchies, opening for example a subsidiary abroad (offshoring of R&D) to acquire synthetic knowledge in a distant location (Liu et al., 2013). The access to new synthetic knowledge may be favoured also in the host LPS since MNCs may import knowledge accumulated in other places that can find a different re-use in the LPS.

Symbolic knowledge is highly context specific and tacit, moving with individuals or embedded in specific communities (e.g. communities of practice, epistemic communities). Access to symbolic knowledge is therefore expected to be based on networks and spill-overs. Social proximity, temporary proximity or international mobility can compensate for the lack of geographical proximity (Gertler, 2008; Martin and Moodysoon, 2011). This is particularly crucial when there is a need for companies in LPS either to link to places where new creative processes take place or to inject in established cultural contexts new sense of interpretation and new intangible values.

The framework just suggested helps draw connections within the fragmented empirical evidence on the geography of different knowledge bases. In particular, by looking at the knowledge characteristics, the type of proximity and the mechanisms of linkages, it is possible to have a better understanding of how different knowledge at different scales can *generate value* for sustainable path transformation in a LPS.

3. The geographical scales of competing models in current Industry 4.0 technological transformation

According to the Introduction of this book (De Propris, *forthcoming 2019*), it is possible and desirable to include considerations of social and environmental sustainability within and around the pure technical core of the current digital and science driven industrial transformation that goes under the name of *Industry 4.0*. Such inclusion takes to an expanded perspective, so-called *Industry 4.0 plus (I4.0+),* and implying the generation of alternatives to mainstream models of value creation and distribution, which otherwise would seem to respond deterministically to "natural" efficiency driven arguments. Such efficiency-driven arguments would include the centrality of smart and webbed factories and platforms, the ruling of large and multi-national firms, combining mass-customization of products and a very high intensity of capital in core processes, together with market domination, skill polarization, and the digitally driven deterioration of the citizen's control over choices on local public and common goods.

In contrast, *I4.0+* is based on the idea that the new technologies should and could be addressed to help bringing sustainable growth, a wide mobilization of human capabilities, and prosperity within territories, their populations of firms, workers, families, and between territories. Specifically, the *I4.0+* perspective aims at better understanding alternatives in industrial local and regional development that face the current challenges of social, economic and environmental sustainability in models of value creation and distribution.

3.1 Alternative I4.0+ models of value creation and distribution

The alternatives to conventional "efficiency" based models concern various aspects. We refer to Bellandi, De Propris, Santini (2018) for a broader discussion, but we may evoke briefly the core contents of the composite solutions supporting *I4.0+* models as alternatives to the technocratic and centralistic mainstream.

- *Interdependencies around smart networked micro-manufacturing* (SNMM): small factories are able to incorporate new digital based technologies in production processes led by craft skills and care. Small firms managing such factories access international networks of designers, customers and suppliers. Localized pools of SNMM drive a transformation of LPS specialized in manufacturing into product-service systems incorporating territorial servitization (Bellandi and Santini, 2018).
- *Digital participation and distributed service provision*: an open and enlarging set of digital based services would allow a territorial servitization of LPS, strong and non-dependent on large oligopolistic providers. Service concern trade, finance, advertising, labour selection and training, enterprise resource planning and relationship management, collaborative knowledge and innovation networks, etc. (De Maggio et al. 2009). They may develop on local platforms where small firms and citizens are granted digital sovereignty, information freedom, and open access (Morozov and Bria, 2018). The local counter-balancing power should be inserted within and supported by national and supra-national anti-trust action.
- *Makers and smart skills*: operative well-trained skills are still crucial in key phases of value chains, if production digital-based technologies are developed not in substitution but in support to professional/creative processes. This would allow to meet customer-specific demand in complex ways and expand smart micro-manufacturing. Examples are the matching of materials of variable quality with multi-purpose tools (I4.0 as well), related quality control, prototypes of new digital based production processes, etc. (Bettiol and Micelli, 2014).
- *Quadruple-helix governance of projects of sustainable socio-economic development*: integrated productive development and innovation projects involve, together, engaged developmental universities, local/regional networks of SMEs non-

captured by oligarchies, anchored MNCs under non predatory strategies, and civic society, also involving non-local social networks and supporting social innovation towards common goods for a sustainable life (Aoyama and Parthasarathy, 2016).

The contents of alternative manufacturing models under *I4.0+* suggest innovation processes that could promote path transformation in LPS characterized by a networked plurality of firms and organizations and by manufacturing specializations grown with the previous wave of technological change (Perez, 2009). It is apparent that a wide and coordinated introduction of such contents would imply the access, absorption, and creative combination of different types of knowledge. This would be the basis for paths of accentuated upgrading in those systems.

3.2. Knowledge bases and multi-scalar mechanisms in I4.0+

We apply now the framework elaborated on section 2 to the distributed model discussed just above under the *I4.0+* perspective, in order to devise general suggestions on the relations between mechanisms and the multi-scalar setting of knowledge access and combination that drive transformations of LPS. The core of such model, we have seen, lies on small networked smart manufacturing solutions[8]. Within and around such core, it demands the development of digital participation and distributed service provision; the diffusion of neo-maker competences, combining artisan attitudes and digital skills; and the quadruple-helix governance of projects of sustainable socio-economic development.

Our concern now is to understand what are the geographical scales of processes of knowledge access and combination for innovation needed either by the mainstream technocratic and centralistic model or by an alternative (*I4.0+*) distributed model. In particular, we investigate to what extent processes of innovation accumulate along the alternative model in LPS characterized by a networked population of independent specialized business organizations, and possibly support paths of sustained upgrading and regional transformation (path renewal or even path creation).

Starting from the productive core, the basic feature that the alternative distributed model shares with the centralistic efficiency-driven one is the importance of codified knowledge in terms of digital coding and software development underlining the I4.0 technologies or their applications. R&D on new types of coding and new application to multiple fields of scientific and technological problems pertain obviously to efforts of creation of analytical knowledge. Such efforts are concentrated, though non-exclusively, in hot high-tech hubs around the word. The results of the efforts may be in principle transmitted in codified form at a distance. However, successful transfer and acquisition of such results demand absorptive capacity. This implies digital competences internal to user-firms, either for generating ideas of new combinations with the other knowledge bases of the firm, or just for the adoption of new technologies developed elsewhere.

[8] This concerns also analogous productive solutions outside manufacturing, e.g. with precision agriculture, sustainable tourism, creative industries, personalized welfare, etc. (Crespi et al., 2014).

Given the extension and the speed of development of new digital frontiers, the support of specialized intermediary agents in LPS is also needed. They are knowledge intensive business or service providers (KIBS/KIS) that combine parts of analytical knowledge with the synthetic knowledge related to features and idiosyncrasies of specific technological, production or corporate fields. In certain cases, KIBS/KIS providers combine also significant components of symbolic knowledge, as with design driven innovation (Cooke and Eriksson, 2011). Such combinatorial services may be more or less standardized or customized to the needs of particular users.

Large firms driving mainstream Industry 4.0 easily access, with their large demand, the services of national and international KIBS/KIS providers by means of relational contracting and formal networking. While temporary geographical proximity by means of resident teams is to be expected during the developmental phases or in presence of unexpected shocks in the use, ordinary maintenance and upgrading can be supported at a distance.

It is a quite different scenario with non-centralized LPS trying to navigate Industry 4.0 with innovations addressing (more or less robustly) the alternative model. Here there are two challenges. Firstly, the single business organizations (even local entities of MNCs) included in those LPS ordinarily cannot represent a large demand of service within the portfolio of national or international providers of KIBS/KIS. Secondly, it seems plausible that LPS addressing alternative models to Industry 4.0 should find their competitive advantage in market fields featured by a continuous stream of differentiation, incremental innovations and decentralized creativity, combining personalization of products and artisan care. Here, synthetic knowledge and symbolic knowledge have key functions in terms of value creation, together with an increasing degree of codification and automation in various phases of the value chain. A real servitization of the variable and differentiated digital components needed by the firms belonging to the core productive specializations of the LPS would need geographical proximity and versatility, and the help of various types of mechanisms, also including spill-overs and informal networks. It is a territorial servitization (Lafuente et al., 2017), whereby local KIBS/KIS work in stable contact with the LPS users (Bellandi and Santini, 2018).

National/international providers of KIBS/KIS may be involved as well. If there is the possibility to develop digital platforms servicing in a relatively aggregated way some smart and connectivity components for the local users, the large providers may invest in local entities (R&D outsourcing). On the other side, if the LPS is not able to express an effective territorial servitization, digital services may be acquired by LPS users in standardized forms by means of market relations. It would be a situation where the alternative distributed model to Industry 4.0 has reduced chances of success.

Around the productive core, the alternative way needs also to expand from business organizations and networks to the society. Neo-makers, local digital sovereignty, quadruple helix methods of governance express a function played by the contexts of out-of-the factory life that is deeper and larger than just consumption and labor supply. It concerns knowledge access, value creation and value distribution. Giacomo Becattini saw this relation between in-factory and out-factory life at work in the development of industrial districts. He pointed to the neo-artisan tendencies opening windows of opportunities in many non-centralized LPS of the western world in the second half of the XX century. "*The ever-changing multiplicity of needs demands an exit of capitalist production from the 'factory', and its return to a plenty of 'laboratories' within the society, searching for artisanship, customized service, ties with historical-cultural and environmental sources of peculiar experiences*" (Becattini and Bellandi, 2006, p. 86). And in the words of Sebastiano Brusco: "*Both the 'in-factory' and 'out-factory' spheres contribute directly to shape not only the quality of civil life but also productivity levels and market competitiveness*" (Brusco, 1996, pp. 155-156).

This perspective on the societal side extolled the importance of geographical and social proximity. The local contents of synthetic and symbolic knowledge, that are at the core of DUI modes of learning and innovation (Jensen et al., 2007), were seen as sourced also from the experiences of ordinary life. It was acknowledged, nonetheless, that trans-local networks, local agents of versatile integration, and local centers of services were also needed in order to link the LPS with the development of scientific and technological frontiers (Becattini and Rullani, 1996).

The effective involvement of the societal side is key also in the definition of the distributed non-centralistic approaches to the contemporary digital transformation under the *I4.0+* perspective. The opportunity to combine, at various degrees of breadth and depth, the different knowledge bases is open to more than a few bridging, integrating, gate-keeping business actors. In principle, it may involve a multitude of business, socio-cultural and institutional agents. What makes a difference among LPSs, in their capacity to innovate and take upgrading paths of transformation, is both the effective diffusion of combinatorial competencies and the collective capability to share a vision on path transformation.

The vision may be led by the idea of a key role played by the development of new analytic or synthetic knowledge. However, the vision in itself has necessarily a high local and non-local symbolic content, since it requires a creative exploration of the potentiality generated by Industry 4.0, in which new values and new senses for interpreting society are collectively constructed (Rullani and Rullani, 2018).

Furthermore, it should be supported by collective (public and private) investments on specific open and multi-disciplinary platforms for the development of combinatorial capabilities and digital based innovations. The development of such platforms has necessarily key contents in terms of analytic/scientific knowledge.

Weak capabilities on such sides would probably take to lower paths of transformation, including the insertion within centralistic routes of Industry 4.0, or more generally a subservient role in feeding economic resources within globally distributed contexts of production and consumption (Storper, 2009, pp. 155-156).

4. Exemplifications from the Makers project

In this section, we present some applications of the framework developed in the previous sections to the interpretation of the geographic scales of knowledge linkages relevant to path transformation in LPS under *I4.0+* perspectives. Facts and reflections are collected from eight cases discussed within the Reports of the MAKERS project (see Introduction of this volume), and in part included in other chapters of this volume[9].

We would partition the eight cases into three sub-sets. The first one includes the transformation of the "paper province" in the Swedish Värmland Region and the Viareggio yachting industry in the Tuscany region (Italy). The second sub-set consists of three textile-based LPS, which are Prato in Tuscany, Borås in Western Sweden, and St. Gallen, Appenzell and Glarus in Eastern Switzerland. The third sub-set corresponds to the mechatronic LPS in Veneto (Italy), the automation LPS in Värtmanland (Sweden), and the life sciences LPS in Tuscany. Only the Tuscany life sciences LPS has a strong basis in a metropolitan area (Florence). The Eastern Switzerland LPS is based on a set of relatively small cities, and it includes traditionally a related variety of sectors around the decreasing textile specialization. All the other cases correspond to industrial districts supported by different types of regional innovation systems.

In what follows, we focus in particular and discuss about the cases of the first sub-set, that is the traditional medium tech industries (the pulp and paper industry in Värmland; the yachting industry in Viareggio), and their geographical scales, knowledge bases, and path transformation under *I4.0+* perspectives. The cases of the other two sub-sets will be used just for extracting some complementary suggestions at the end of the section. The first two industries have developed in the past decades as the main manufacturing specialization of the respective LPS, with competitive advantages grounded into the relation between a strong basis of synthetic knowledge and specific locational factors. Both cases are interesting because such locational factors have been turned in the last decades in a strong source of symbolic knowledge, still combining with local synthetic knowledge, but also attracting the activity of providers of analytic knowledge. The two cases suggest examples in the way of alternative I4.0+ models to the challenges raised by Industry 4.0, and allow to look at the geographical scales and knowledge bases of some paths of upgraded transformation.

4.1. Combinatorial knowledge bases and multi-scalar mechanisms in the transformation of pulp and paper in Värmland (Sweden)

In this case, the locational factor is represented by the proximity to a large land of forests, an abundance of woods that may be easily treated for pulp extraction, and a tradition of preservation of the natural patrimony. The pulp and paper industry has developed for almost a century, with a strong presence of manufacturing plants and R&D laboratories of some large national and international companies, together with a population of specialized SMEs, also included those related to forest works.

[9] A cautionary note is needed: the researches on the cases, which we refer have not been developed directly for application and test of the interpretative framework illustrated in this chapter. Therefore, some implications concerning the single cases are rather speculative. Nonetheless, we are confident about the robustness of the overall comparative panel.

The chapter by Ramirez (forthcoming 2019) illustrates the emergence of a path of transformation, from the traditional pulp and paper specialization to a more differentiated and analytic knowledge intensive path, which is called the "forest-based bio-economy" within a plan promoted by a local cluster organization in the last decade. The enduring basis is a multiplicity of nuclei of manufacturing synthetic knowledge, in dialogue with the synthetic knowledge of forest related activities. Crucial manufacturing synthetic knowledge is hosted within the larger plants and accessed thanks to networks and spill-overs at the local level or through technologies partly acquired on external markets. The access to analytical knowledge has been also important both for the absorption and partly for the development of some more capital intensive technologies in the pulp processes, and for an environmental sustainable approach to large scale exploitation of wood resources.

The cluster initiative in the last years has tried to promote the shift to an economy specialized in the production of renewable biological resources, also with the support of digital technologies. In that cluster initiative, a critical role seems to be played by the strategic orientation of national and regional innovation systems, the investments by multinational companies (MNCs) embedded in the local economy, and the role played by technological intermediaries. New analytic knowledge is developed thanks to the presence of R&D laboratories of large MNCs firms. However also networks with local and national universities result supportive in this respect.

The cluster management agency, the national innovation agency, and the international technological intermediaries have been able to elaborate an integrated vision and strategy that has pulled a wave of investments also from the distant headquarters of the MNCs. This includes the reference to the highly symbolic contents of the "bioeconomy" (combination of the local forest tradition, the green strategy of the national innovation system, and EU programmes). Moreover, it extends to the answer to relevant manufacturing problems (e.g. the disposal of industrial waste), with the interaction between traditional synthetic know-how (accessed with local spill-overs, informal networks, hierarchy) and analytic knowledge (accessed with local formal network, R&D laboratories of large firms related to sophisticated digital control of all the phases of the production processes). Around the productive core, the cluster initiative include projects aimed at diffusing digital competences and increasing the capacity of small local ICT services to access the new demand of the forest based bio-economy (Ramirez, *forthcoming 2019*).

All in all, this case shows a virtuous combination of all three knowledge bases, accessed with appropriately different mechanisms at different spatial scale. The LPS seems ready for accomplishing a path transformation that could be seen, if realized, as a case of successful path creation (See table 2).

----- TABLE 2 ABOUT HERE -----

4.2. Combinatorial Knowledge bases and multi-scalar mechanisms in the transformation of the luxury yachting industry of Viareggio.

In this second case, the locational factor is represented by the promiscuity with an important seaside local touristic industry, in the same LPS of Viareggio (including the towns of Viareggio, Forte dei Marmi, etc.), which is associated to the image of high quality recreational products and services.

The chapter by Bellandi, De Propris, Santini, Vecciolini (forthcoming 2019) tells us that, in industrial terms, the long-run synthetic knowledge base of the yachting system is the artisan know-how in small ship-building. The industry has evolved in the last decades thanks to the international inflow of analytic knowledge, that has allowed the introduction of new advanced materials, constructive solutions, and gadgets in the building of top-end boats for recreational uses. Nowadays, the LPS is specialized in the production of luxury yachts, with a highly sophisticated and price-inelastic demand from wealthy people.

Each luxury yacht is almost a unique piece with unique design, artisanship and sophisticated technology, including solutions absorbing many types of smart and connectivity digital components. Analytical knowledge is accessed in various ways, but a key role is played by the R&D offices of the local shipyards (which correspond to the sectoral headquarters of large national and international companies), by formal networks with research organizations supported by a regional intermediary organization, and by market relations and informal networks with providers of technology at local, national and international scale. However, R&D is mainly aimed at the creation of new symbolic knowledge for improving design, rather than at the development of new analytic knowledge. Furthermore, the realization of each yacht is highly demanding in terms of practical learning and creativity requested to a large population of specialized SMEs and artisans. This local core of synthetic knowledge is based on reciprocal spill-overs, formal networks with the shipyards, and informal networks with the providers of technology. Small scale and personalized ICT services for the yacht industry are granted by an ICT cluster based in the nearby city of Pisa. Various types of initiatives (local fairs, professional schools, etc.) tend to involve the citizens in the destiny of the local industry, even if the growth of neo-maker competences seems quite weak, nor quadruple helix projects on this or other related topics are surfacing at the moment. Indeed, the main out-factory relations concern the hints and requests raised by the wealthy buyers around the world, as well as by the skippers employed by the buyers.

The case of this LPS appears quite peculiar. However, the luxury yachts may be seen as an exemplification of the extreme personalization that is one of the end lines of product development under *I4.0+* models. The uniqueness of products and the continuous introduction of new solutions and technologies make difficult to classify the path followed here as just extensive. Perhaps it points to a class of paths of “continuous” renewal, where the creativity that drives personalization may become, in subsequent steps, a source of inspiration for part of the local community to re-use the acquired technologies and develop other related business or civic services. This case, for what it would tell on the features of such class, is led by the development of symbolic and synthetic knowledge and the absorption of analytic knowledge (See Table 3). In particular, symbolic knowledge has strong local roots, but it demands multi-scale flows and mechanisms of creation and image-building, combined with the absorption of new analytic and synthetic knowledge. Perhaps the local structure would not support local path creation, but the multi-scalar actors involved in the realization of the highly sophisticated unique products which are present at local level could favour new value chains and path creation in other places (Bellandi, De Propris, Vecciolini, *forthcoming 2019*; Bailey, *forthcoming 2019*).

----- TABLE 3 ABOUT HERE -----

4.3. Other cases from the Makers project

We come now to the other sub-sets of MAKERS cases, to extract some supportive facts and final qualifications. Starting from the textile cases of the second sub-set[10], we see that they illustrate the *various transformation paths of strong synthetic knowledge based* LPS under the pressure of contemporary challenges. In all the three cases, symbolic knowledge has acquired a key role, playing nonetheless partially different functions. In the Prato textile district, the image of creativity and quality of made in Italy is applied to the synthetic knowledge-based capability to produce rapidly an open and variable range of fabrics, in very small batch (i.e. with a high degree of personalization and some help given by digital technologies). In the Borås textile district, a strong governance and innovation system at regional and national level has promoted a vision that facilitated the absorption of new global analytic knowledge for the development and production of high-tech textile products. In the Eastern Switzerland district of embroidery and textile machines, a local system supporting innovation and some civic initiatives, coupled with the presence of local diversified research and manufacturing capabilities, present also at national and international scales, helped to combine the synthetic knowledge basis with the creation of new symbolic and analytic knowledge. In the first case, symbolic knowledge combines directly into strategies of high personalization of products, and the variety of mechanisms for accessing and absorbing new analytic knowledge is still quite low. In the second case, symbolic knowledge seems to play a role of support to strategic convergence around a collective strategy of analytic knowledge intensification, helped by multi-scale mechanisms and integration. In the third case, symbolic knowledge apparently plays both roles (personalization and vision). From such cases, it emerges a confirmation of some aspects detected in the first sub-set. The first is that high personalization of products demands the guidance of symbolic knowledge coupled with synthetic knowledge. The second is that a higher potentiality for radical innovation and path creation seems to demand the guidance of analytic knowledge (accessed in a multi-scalar setting) coupled to a subservient but necessary role of symbolic knowledge. In

[10] Bellandi et al, (*forthcoming 2019*) on Prato; MAKERS Report by E.Santini et al. including the case of Eastern Switzerland; Chaminade et al. (2018) on Borås.

all cases, the local access to synthetic knowledge cannot be dispensed in models that seem to evoke alternative *I4.0+ models*. However, in the stronger cases, also the reproduction and creation of synthetic knowledge is an open field of local converge of multi-scale strategies.

Coming at last to the third sub-set, which includes cases *at high intensity of use of analytic knowledge*[11], we just raise a reflection. Even here, where the guidance of analytic knowledge would be more needed for any path of upgraded transformation, the strength of upgrading seems related not only to a high degree of local capabilities of creation of such base. In particular, paths consistent with the alternative *I4.0+* models, like in Värtmanland, require - beyond the presence of strong local pools of synthetic knowledge - an important access to symbolic knowledge for various creative and absorptive functions and at different geographical scales.

5. Conclusions and further research

The previous discussion linking knowledge bases, multi-scalarity and transformation of LPSs brings some interesting insights into policies (particularly at regional level) sustaining LPS. *Firstly*, regional policies do not necessarily have to ensure that all three knowledge bases (synthetic, analytic and symbolic) are co-located in the same LPS. Contrary to what has often been argued in the literature, firms and other innovative organizations could access different knowledge even in distant locations. Regional policies aiming at strengthening LPS need therefore to go hand in hand with more general policies supporting the use of mechanisms to access knowledge at other geographical scales. Which mechanisms are more adequate depends strongly on the type of knowledge base, the capabilities of the firms located in the region, and conditions to access knowledge. It depends also on which type of model of path transformation is pursued. In particular, and in relation to the challenges of Industry 4.0, it depends on the prevalent vision (e.g. if centralistic & technocratic or non-centralistic & distributed) informing public policies and private strategies. *Secondly*, our framework could help to extend policies to the consideration of why two firms in the same industry and with similar levels of innovativeness − one located in a knowledge hub and the other one located in a peripheral region − may portray very different configurations.

This paper has some limitations. Firstly, applying a multi-scale framework on knowledge bases, which brings in knowledge characteristics and meso- and micro-conditions, it would require data that are beyond what is currently available. In the short term, dedicated firm-based surveys or case studies in different LPS around the world could provide a starting point to conduct empirical analysis based on the proposed framework. Secondly, based on the premises that combinatorial knowledge creating processes involves sourcing of knowledge at different geographical scales, our focus has been on theorizing when and how these multi-scale knowledge-sourcing processes

[11] Corò and Volpe (*forthcoming 2019*) on the Veneto mechatronic LPS and the automation LPS in Värtmanland. For the life sciences LPS in Tuscany we refer to the MAKERS Report by P. Ramirez .

will take place. Admittedly while sourcing of knowledge is paramount for innovation, it is only one part of the combinatorial knowledge base processes. Knowledge acquired externally needs to be further processed internally, inside both the singles firms and related organizations and among them within LPS. In other words, while this paper provides some insights on how different knowledge bases are *sourced* using different mechanisms at different scales, it does not discuss how the firm *combines* them into knew knowledge. Other chapters of this book take more directly this point, also considering in depth some of the cases referred above within the researches of the MAKERS project.

Acknowledgements: We gratefully acknowledge the support by the EU Horizon 2020 project MAKERS, which is a Research and Innovation Staff Exchange under the Marie Sklodowska-Curie Actions, grant agreement number 691192 Conferences. All errors remain exclusively of the authors.

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Table 1. Some key mechanisms for firms in LPS to access different Knowledge bases in a multi-scalar setting

Mechanisms / **Knowledge bases**	**Markets (Within LPS)**	**Markets (Other geographical scales)**	**Spillovers (Within LPS)**	**Spillovers (Other geographical scales)**	**Networks (Within LPS)**	**Networks (Other geographical scales)**	**Hierarchies (Within LPS)**	**Hierarchies (Other geographical scales)**
Analytical	Trade (e.g. patents)	Trade (e.g. patents)			R&D collaboration (e.g. research consortium)	Domestic/International R&D collaboration, but necessary some cognitive/organizational proximity) **(can be key for knowledge creation**)		
Synthetic	Trade (market technologies/goods for codified aspects of engineering process)	Trade (market technologies/goods for codified aspects of engineering process)	Local mobility of human resources and face to face interactions	International mobility, temporary geographical proximity	Networks (often informal)	Domestic networks (also informal, but institutional proximity is necessary)	R&D offshoring from MNCs in loco (**can be key for knowledge renewal)**	International R&D offshoring (e.g. in specialized hubs) (**can be key for knowledge renewal)**
Symbolic			Local mobility of human resources	National/international recruitments of skilled labour	Networking within local community (e.g. community of practice)	International communities(e.g. epistemic communities, some social proximity is necessary) **(can be key for new sense making)**		

Source: Own elaboration

Table 2. MAKERS cases: Combination of knowledge bases in a multi-scalar setting in the paper province

	Path creation towards I4.0 "PLUS": use of combined analytical, synthetic and symbolic knowledge at different geographical levels transforming a paper and pulp specialized LPS to Forest based bio-economy LPS							
	Markets (Within LPS)	**Markets (Other geographical scales)**	**Spillovers (Within LPS)**	**Spillovers (Other geographical scales)**	**Networks (Within LPS)**	**Networks (Other geographical scales)**	**Hierarchies (Within LPS)**	**Hierarchies (Other geographical scales)**
Analytical		Digital technologies in the pulp processes and aimed at sustainable environment			R&D collaboration with large firms; Networks with local universities	Networks with national universities		
Synthetic		Market technologies related to synthetic processes	Spillover from domestic/international MNCs within Pulp industry located in LPS		Interactions at local level between traditional and forest related activities (mediated by cluster organization)	Bridge role in international networks played by local MNCs and technological intermediaries	R&D offshoring from MNC located in LPS	
Symbolic					Bio-economy concept: shared value at local level (emerging from a cluster initiative)	Bio-economy concept: shared value with national and international stakeholders		

Source: own elaboration on MAKERS cases

Table 3. MAKERS cases: Combination of knowledge bases in a multi-scalar setting: The luxury yachting industry

	Continuous path renewal driven by extreme personalization: development of new symbolic and synthetic knowledge with absorption of analytic knowledge							
	Markets (Within LPS)	**Markets (Other geographical scales)**	**Spillovers (Within LPS)**	**Spillovers (Other geographical scales)**	**Networks (Within LPS)**	**Networks (Other geographical scales)**	**Hierarchies (Within LPS)**	**Hierarchies (Other geographical scales)**
Analytical		Digital technologies advances material, new constructive solutions			Networks with research organizations; networks with provider of technologies (weak R&D)	National and International networks with providers of technologies (weak R&D)		
Synthetic			Local companies reciprocal spillover		Formal networks within the shipyards; Informal networks with providers of technologies			
Symbolic					R&D collaborations for new symbolic/design knowledge	R&D collaborations for new symbolic/design knowledge		