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# The Variety of Related Variety Studies: Opening the Black Box of Technological Relatedness via Analysis of Inter-firm R&D Cooperative Projects

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**Key words:**

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## Abstract

The aim of this article is twofold. First, on the basis of a review of recent literature on related variety, it shows that there are not only differences between ex-ante and ex-post conceptualisations of relatedness, but also several striking methodological differences within this research stream. Therefore, it is argued, the growing number of studies on relatedness using different conceptualisations and methodologies can result in a “hollowing-out” of the original explanatory power of the concept. Second, this paper aims to open the black box of relatedness among industries by exploring one of the main channels through which the effects of relatedness can operate by simultaneous application of both ex-ante and ex-post approaches to measuring relatedness. In particular, joint R&D projects among companies represent a vigorous mechanism of knowledge exchange and mutual learning, but, as of yet, these studies have not been systematically linked to the concept of related variety. Our results prove that R&D collaboration according to technological distance is indeed far from random, but, contrary to our expectation, the results show that R&D collaboration occurs most frequently among unrelated companies. Thus, the search for partners in R&D projects seems to be driven by the novelty of knowledge rather than by probabilities of its comprehension. Conceptually, these findings suggest that in reality there might be various processes that require vastly different level of relatedness. This could lead to important policy implications as overreliance upon support for related industries might be misleading.



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## Introduction

Contemporary evolutionary economic geography is currently enjoying a prominent position within economic geography studies (e.g., Boschma and Martin 2010). Evolutionary economic geography is searching for answers to the one of the most intriguing questions in the field of economic geography (Neffke, Henning, and Boschma 2011), namely, how do countries and regions develop over time? One of the important theoretical advances achieved within this research stream has been employment and the further development of the concept of related variety, thus *inter alia* building upon the work of Rosenberg and Frischtak (1983) on technological systems and upon Noteboom's studies on learning and innovation (Nooteboom 2000). Related variety ranks among the most powerful concepts of evolutionary economic geography in its quest for grasping the key drivers of socioeconomic evolution. The concept of related variety is based on the (now proven) argument that a range of technologically related industries in a region is more beneficial for its development than a diversified but unrelated spectrum of industries, which offers only limited potential for mutual spillover effects due to the large cognitive distance (Neffke, Henning, and Boschma 2011). By contrast, technologically related industries can spur knowledge-sharing and innovation, as their cognitive distance is optimal (Nooteboom 2000; Broekel and Boschma 2012). According to Fornahl, Broekel, and Boschma (2011), optimal cognitive distance can be defined as knowledge that is neither identical (hence it can be usefully exchanged) nor too distant (therefore it can still be effectively absorbed). However, the probability that inter-firm cooperation according to technological distance follows an inverted U-shape curve has already been identified by Mowery, Oxley, and Silverman (1998). Nowadays, there is a large body of literature insisting that optimal cognitive distance enhances the effects of agglomeration economies (Boschma and Iammarino 2009).

This article aims to make two contributions to existing related-variety studies. First, on the basis of a review of recent literature on related variety, it is shown that there are not only profound differences between ex-ante and ex-post conceptualisations of relatedness, but, moreover, that several other striking types of methodological differences within related-variety research can also be identified. Therefore, it is argued, the growing number of studies on relatedness employing different conceptualisations and applying vastly different methodologies to the various data available in particular countries can result in a "hollowing-out" of the original explanatory power of the concept.

Second, this article aims to open the black box of relatedness among industries by exploring one of the main channels through which the effects of relatedness might operate (see plea by Neffke, Henning, and Boschma 2011 or by Kemeny and Storper 2015). Beyond the obvious resonance of related variety in the discussion on spontaneous spillover effects in regions, particular mechanisms that have already been analysed include labour mobility and mergers and acquisitions among companies. In the case of labour mobility, its positive effect upon the performance of Swedish plants has been proven, provided that inter-regional mobility of professionals occurs among related plants (Boschma and

Iammarino 2009). Similarly, the investigation of mergers and acquisitions in the case of Dutch firms showed that the effect of industrial relatedness is stronger than the effect of geographic proximity (Ellwanger and Boschma 2015).

Undoubtedly, vigorous mechanisms for knowledge creation and sharing represent various forms of cooperation in the sphere of R&D. There is already an extensive literature on the geography of collaborative knowledge production (e.g., for overview, see Hoekman, Frenken, and van Oort 2008; Broekel 2015a). According to Hoekman, Frenken, and van Oort (2008), the results of these studies provided evidence about the positive role of geographic proximity as well as the key role of European elite R&D regions in shaping the form of collaborative networks. However, existing studies of R&D collaborative networks are often limited to the analysis of patent data or co-publication of scientific papers (Jaffe 1989; Breschi, Lissoni, and Malerba 2003). None of these data sources is particularly suitable for the analysis of the role of relatedness in moulding R&D networks among companies (e.g., Boschma and Capone 2015a).

Consequently, the patterns of knowledge creation and sharing within collaborative R&D projects among companies were investigated. The analysis was based upon an extensive database covering all joint R&D projects initiated among firms with the support of various Czech grant schemes over the 2003-2014 period. Analysis of these data should allow an answer to the main research question: to what extent does R&D cooperation among companies accord with their technological relatedness?

The article is structured as follows. The next two sections underline the key contributions of the related-variety literature, but at the same time emphasise the conceptual as well as methodological variety of these studies. Building upon these sections, research questions are introduced. The next section introduces data and methodology. The subsequent part provides the key results of the empirical analyses of the role of relatedness on inter-firm R&D collaborative projects. The final section presents the main conclusions and outlines several avenues for future research.

## Theoretical Discussion: Contrasting Notions of Relatedness

The concept of related variety nested within evolutionary economic geography has proved useful for analysing evolutionary trajectories of economic structure of particular regions and of their overall socioeconomic performance. Specifically, related-variety literature insists that technological relatedness among companies in a given region positively affects the scope for knowledge spillovers and learning and thus contributes to regional growth in terms of value-added and employment (Boschma and Iammarino 2009). Therefore, the main argument of the related-variety school is that spatial externalities in the form of learning are strongest among firms in which knowledge is mutually related but not identical (Neffke, Henning, and Boschma 2011). According to the same authors, the "notion of related variety tries to capture a delicate balance between cognitive proximity and distance across sectors in a region that is needed for knowledge to spill over effectively between sectors" (Neffke, Henning, and Boschma 2011, 243). Thus, the notion of relatedness is based upon the argument of Nooteboom (2000) that knowledge is more likely to spill over across two industries if their cognitive distance is neither too large nor too small. Therefore, importantly, related variety is not defined in terms of input-output linkages, but on the basis of knowledge spillovers and learning (Boschma and Iammarino 2009).

At least three main contributions of the related-variety concept can be identified. First, the proponents of the concept of related variety propose a new solution to a traditional dilemma of regional economies, i.e. whether diversification (as a sort of risk-spreading strategy helping to prevent a high unemployment rate in the region in times of crisis) or specialisation (in order to concentrate limited resources on industries with the greatest potential) should be promoted. The researchers applying the concept of related variety suggest that the proper answer to this dilemma is diversification into different but related industrial branches in order to facilitate mutual learning (Frenken, van Oort, and Verburg 2007). Therefore, the concept of related variety allows moving beyond the traditional dichotomy of localisation economies and Jacobs´s externalities by introducing the third category of different but related industries (Boschma and Iammarino 2009; van Oort, de Gues, and Dogaru 2015).

Second, it follows from a general proposition of the related-variety concept that learning is more likely in cases of firms whose activities are technologically related. Therefore, long-term positive effects between related variety and economic development are envisaged (Frenken, van Oort, and Verburg 2007). Consequently, higher gross value-added growth as well as higher employment growth is foreseen in cases of firms where the production is technologically related to other firms nested in a given region (Boschma and Iammarino 2009). According to Boschma, Minondo, and Navarro (2013), this finding can have important implications for regional industrial and innovation policies as, for example, firms that would be able to bridge the gaps in the existing industrial structure of a region can be actively searched for and eventually attracted into the region.

The third contribution is closely interwoven with the previous ones and helps to understand the dynamic of evolutionary trajectories of regions in the form of so-called “regional branching”. According to Boschma, Minondo, and Navarro (2013), regional branching is an important mechanism driving the evolutionary trajectories of the economic structure of regions. This term was introduced by Frenken and Boschma (2007) and can be defined as a process of development of new industries on the basis of a transfer of capabilities and knowledge accumulated in existing industries to new industries with related knowledge bases. Thus, new industries emerge in a given region from existing related industries by a path-dependent branching process. Neffke, Henning, and Boschma (2011) provided evidence from Sweden to show that regions are more likely to expand into industries that are related to existing activities. Moreover, while the industries that were technologically related to existing industries had a higher probability of entering the region, the technologically unrelated industries had a higher probability of exiting the region (Neffke, Henning, and Boschma 2011). Thus, “systematic evidence that the rise and fall of industries is strongly conditioned by industrial relatedness at the regional level“ has been found (Neffke, Henning, and Boschma 2011, 237). Similarly, Boschma, Minondo, and Navarro (2013) have shown that Spanish regions diversified into new industries related to the existing industries in the regions, suggesting that new industries build upon capabilities accumulated in particular regions. Therefore, relatedness to the regional industrial structure plays a much larger role in the emergence of new industries in regions than does relatedness to the national industrial structure (Boschma, Minondo, and Navarro 2013). As a result, “building upon related variety may be an effective way to forge new regional paths towards growth” (Boschma and Iammarino 2009, 293).

## Operationalising Relatedness: Variegated Conceptual and Methodological Approaches

Importantly, two distinctive approaches within the study of related variety can be distinguished. Firstly, the pioneering contributions to related-variety studies focused predominately upon research of *ex ante* relatedness, i.e. upon investigation of the socioeconomic evolution of regions with differing potential for mutual knowledge spillovers among industries on the basis of their technological relatedness (Frenken, van Oort, and Verburg 2007). In fact, these studies succeeded in refining a long-established argument of agglomeration economies, namely, that the clustering of economic activity occurs because firms are benefitting via various types of external economies from proximity (Frenken, van Oort, and Verburg 2007). Nevertheless, more recently, a study on Finland showed that the contribution of industrial relatedness to the economic growth of the regions can be distinctive only in cases of regions dominated by high-tech sectors, as no such effect has been found in cases of low- and medium-tech sectors (Hartog, Boschma, and Sotarauta 2012).

Accordingly, differentiated effects of related variety according to the level of knowledge endowment of particular regions have been documented in a spatial panel analysis by Cortinovis and van Oort (2015). These authors argue that related variety can have a positive effect on growth but especially for regions well equipped in technology and knowledge. Furthermore, Cortinovis and van Oort show that high levels of related variety in regions poorly endowed with knowledge might be detrimental to employment growth. In consequence, Cortinovis and van Oort (2015) and Caragliu, de Dominicis, and de Groot (2016) argue that the context and features of particular regions should be considered, as agglomeration economies operate differently in different areas. These differing results should not be considered as surprising, as studies that describe the economic structure of regions in terms of related and unrelated industries, and which subsequently investigate the relationship between the type of economic structure and the overall performance of the regional economy such as the evolution of (un)employment etc., are obviously analysing just one (even though arguably important) factor driving the evolution of various regions, i.e. the role of relatedness among the industrial branches. In addition, it may reasonably be expected that the role of related variety will be different in developed economies, where competitiveness is based primarily upon knowledge, compared to those regional economies where competitiveness might predominately rest upon low-cost advantage.

The second basic type of relatedness has been called ex-post or revealed relatedness and is often based upon various types of co-occurrence analysis (Neffke, Henning, and Boschma 2011). This second stream within the related-variety school was to a large extent inspired by a seminal study by Hidalgo et al. (2007), who insisted that there are various dimensions of relatedness among products such as the intensity of labour and/or capital, types of inputs and outputs, required institutional framework, endowment by infrastructure, physical factors, etc. Consequently, these authors conceptualised the notion of “product space” based on revealed comparative advantage. According to Hidalgo et al. (2007), particular products are related if they require similar inputs and technology. Indeed, an extensive analysis of international trade data covering 775 different products proved that related products tend to be produced in particular countries in tandem. Moreover, Hidalgo et al. (2007) proved that countries that are specialised in products closely related to many other products, and which are, therefore, located in the core of the product space, are growing faster than countries specialised in less-related products that can be found on the periphery of the product space. In a similar vein, but more recently, Boschma and Capone (2015b) showed via their analysis of world trade data that the path-dependent process of product diversification is driven not only by the past productive structure of a given country, but also by its relationships with other countries. In particular, countries tend to keep a comparative advantage in products that are strongly related to their current productive structure, and, importantly, they also diversify into related products (Boschma and Capone 2015b). Therefore, from a policy perspective, favouring the creation of industries that are very distant from the existing ones in the industry/product space might result in severe failures (Boschma and Capone 2015b). On the contrary, a particular effort might be exerted to attract those industries that are capable of closing the gap in terms of relatedness that might exist in some regions (Neffke, Henning, and Boschma 2011).

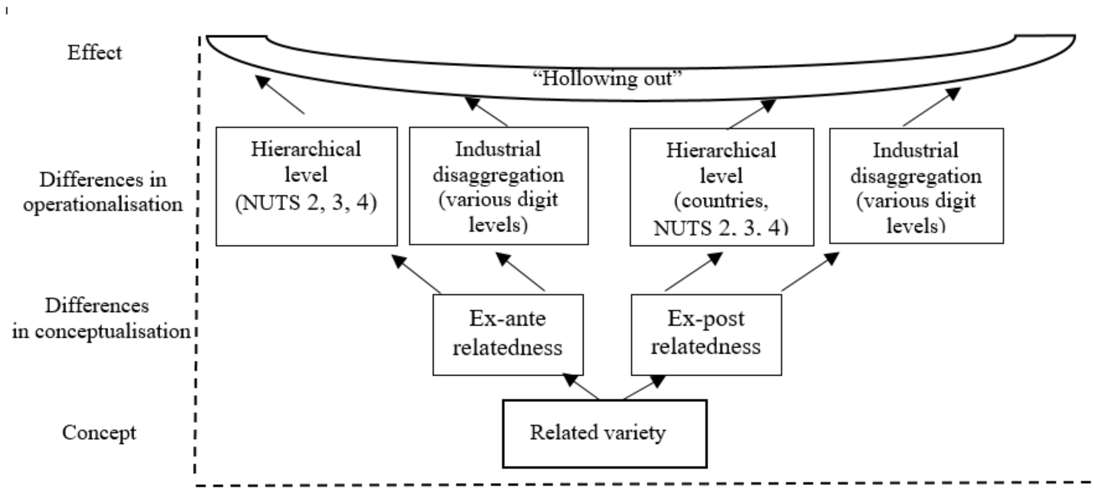
Nevertheless, there are important conceptual differences among these two notions of relatedness. On the one hand, the principal deficiency of ex-ante measures of relatedness based on closeness in standard industrial or product classifications is that the extent to which such relatedness is relevant in practice remains obscure (Neffke, Henning, and Boschma 2011). On the other hand, the definition of related variety based on standard industrial classification schemes is relatively easy to interpret and allows comparisons across various regions and countries. By contrast, revealed or ex-post relatedness encompasses a much broader and conceptually diverse set of dimensions of relatedness among industries or products, far exceeding mere technological relatedness. In particular, revealed relatedness encompasses not only various dimensions of proximities (Boschma 2005), but also covers various sorts of complementarities among products. Therefore, this second notion of relatedness is widely stretched (or even overstretched) and can cover practically any sort of relatedness while the role of particular dimensions of relatedness remains obscure. Moreover, given the fact that the specific contribution of each plethora of factors that may potentially be driving the ex-post relatedness remain unknown, any generalisations across countries and regions might be premature. In addition, according to Neffke and Henning (2013), relatedness derived on the basis of co-occurrence of industries in portfolios of firms is in danger of tautology, as the co-occurrence methods are essentially outcome-based, which means that these methods first assume that portfolios are coherent and then infer the implied relatedness from patterns of co-occurring industries.

Importantly, the relevance of both these notions of relatedness (i.e. narrow, resp. ex-ante, versus broad, resp. ex-post) has been investigated empirically by Neffke, Henning and Boschma (2011). These authors showed that ex-post relatedness captures the economic effects of relatedness better; however, the yielded shares of variability explained by different models do not differ profoundly and in all cases remained rather low. While these results might suggest better relevance of ex-post relatedness, given the much broader spectrum of dimensions of relatedness that are encompassed within this broader notion of relatedness, the share of variability explained is rather modest.

Moreover, in addition to profound differences between ex-ante and ex-post conceptualisations of relatedness, several other types of striking differences within related-variety research can be identified. To start with, perhaps the most obvious discrepancy in studies on related variety, there is a vast span of hierarchical levels upon which the role of related variety is scrutinised – ranging from 686 local labour systems in Italy (Cainelli and Iacobucci 2015), via NUTS 4 (Hartog, Boschma, and Sotarauta 2012), NUTS 3 (Frenken, van Oort, and Verburg 2007; Boschma and Iammarino 2009; Neffke, Henning, and Boschma 2011; Boschma, Minondo, and Navarro 2013), and NUTS 2 (Cortinovis and van Oort 2015; Caragliu, de Dominicis, and de Groot 2016) to countries (Hidalgo et al. 2007; Boschma and Capone 2015a). Another dimension of difference is the level of industrial disaggregation upon which the role of related variety is tested, e.g., from entropy measured at the 3-digit level of industrial specialisation within 2-digit NACE codes or other categorisation schemes, such as export classifications – (Boschma and Iammarino 2009) to 4-digit (Neffke and Henning 2013), 5-digit (Frenken, van Oort, and Verburg 2007; Cainelli and Iacobucci 2015) or 6-digit levels of disaggregation (Fornahl, Broekel, and Boschma 2011; Neffke, Henning, and Boschma 2011). Recently, Caragliu, de Dominicis, and de Groot (2016) measured relatedness at the level of 1-digit sector based upon entropy calculated at the level of 2-digit employment shares. Moreover, while most analyses cover the whole spectrum of manufacturing industries, some researchers have investigated the role of related variety in cases of a single industry (e.g., Fornahl, Broekel, and Boschma 2011 on the role of relatedness in the case of German biotech firms, or Broekel and Boschma (2012) on the Dutch aviation industry). Likewise, technological relatedness of particular products is sometimes measured by their co-occurrence at the plant level (Neffke and Henning 2008) or firm level (Broekel and Boschma 2012), while other authors have investigated co-occurrence in exported products at the country level (Hidalgo et al. 2007). Thus, the issue of granularity in related-variety studies comes to the fore (cfr. Morgan 2015).

Consequently, variation of contexts and methodological approaches in which the concept of related variety is used makes interpretation of results and especially of underlying causal mechanisms uneasy. Conceptual differences between ex-ante and ex-post relatedness as well as profound variation in the methodological approaches used to measure the role of relatedness might even result in a “hollowing-out” of the contribution of the original concept (see Frenken, van Oort, and Verburg 2007) and in stripping the concept of its explanatory power (Figure 1).

Figure 1. Conceptual and methodological diversity within related variety studies.




Source: Own.

Therefore, one possible pathway forward might be to conduct a detailed examination of mechanisms through which the effects of relatedness might operate, as suggested by Neffke, Henning, and Boschma (2011). Various mechanisms by which the knowledge can spread among related industries and which are more likely to operate at the regional level can be considered, such as the creation of spin-off firms, the diversification of activities within particular firms, inter-firm networks or labour mobility (Neffke, Henning, and Boschma 2011).

Other important mechanisms that yield the benefits envisaged by the concept of related variety can also be considered. Given the fact that the notion of combining skills and knowledge has been a central theme within the literature on innovation (Neffke and Henning 2013), R&D collaboration might be a particularly promising arena for further research on relatedness. Specifically, joint R&D projects of companies are widely considered as beneficial for companies in terms of access to external knowledge and in sharing the associated risks and costs (Broekel 2015a). In consequence, R&D cooperative projects are increasingly being encouraged by policy, "which steadily increases the weight of cooperative elements in R&D support programmes" (Broekel 2015a, 1089). However, existing studies of R&D networks are often limited to the analysis of patent data or co-publication of scientific papers. Neither of these data sources is particularly suitable for analysis of the role of relatedness in moulding R&D networks among firms. Patenting is strongly industry-specific, as the general propensity to patent differs vastly among particular industries. Moreover, there are also numerous other problems that hinder the use and interpretation of patent data. For example, the number of patents does not equal the number of actually and effectively used patents. Additionally, in cases of non-core regions, the number of patents can be limited, which makes any generalisation difficult. Likewise, the vast majority of scientific publications are a result of academic collaboration, and, therefore, they are not closely tied to R&D cooperation among firms and hence do not represent a suitable base for investigating the relevance of relatedness for knowledge flows among companies (for detailed discussion, see e.g., Boschma and Capone 2015a).

Surprisingly, according to the best of our knowledge, no study has empirically tested the extent to which inter-firm R&D cooperation projects across the spectrum of manufacturing industries, knowledge-intensive services and other relevant sectors for R&D cooperation follow the propositions stemming from the concept of related variety. One exception is the study by Fornahl, Broekel, and Boschma (2011), in which the authors studied the role of R&D subsidies, geographic proximity and relatedness (as independent variables) on patent performance of German biotech firms. The key results of their analyses included strong evidence that some –but not too much – cognitive distance among actors collaborating in R&D projects increased the patent activity of firms. However, this study investigated the role of relatedness on the patent performance of firms only within a single industry (biotechnology predominately based upon analytical knowledge – Asheim and Gertler 2005). By contrast, according to Broekel and Boschma (2012), the inverted-U relationship between the likelihood to cooperate and cognitive proximity coined by Mowery, Oxley, and Silverman (1998) was not confirmed in the case of the Dutch aviation industry, which represents mainly synthetic knowledge (Asheim and Gertler 2005). However, it has to be acknowledged that, while most of the literature on related variety explicitly emphasises the role (or rather the potential) for knowledge spillovers, joint R&D projects represent highly intentional activity. Nevertheless, the concept of related variety has been already applied in the investigation of mergers and acquisitions (e.g., Ellwanger and Boschma 2015), which can also be considered as highly intentional activities. In addition, even in the case of labour mobility of professionals (see Boschma and Iammarino 2009), it could be argued that this mobility is also to a certain extent intentional, as highly qualified employees might prefer to search for new employment opportunities in companies where they foresee that their existing capabilities and skills might be best re-employed. Therefore, it should be acknowledged that the role of related variety might differ among particular mechanisms and processes with varying levels of intentionality.

Consequently, it is desirable to investigate the role of technological relatedness in joint R&D projects across the whole spectrum of industries. Basically, following the reasoning by Mowery, Oxley, and Silverman. (1998) on the role of technological distance for inter-firm cooperation, Nooteboom (2000) on optimal cognitive distance, as well as a closely related notion of the proximity paradox coined by Boschma and Frenken (2010), an inverted U-shape curve can be expected when depicting the frequency of collaboration in R&D projects in relation to relatedness between participating firms. Considering that a primary characteristic of R&D projects is to apply existing knowledge in a novel way or even to advance the knowledge frontier, the search for partners with a lower degree of relatedness can be expected, in contrast to cooperation during routine production activities. This leads us to the research questions and hypothesis.

## Research Questions and Hypothesis

In line with the related-variety concept, we expect that the most beneficial (and hence frequent) type of inter-firm R&D projects should be cooperation among firms, where knowledge or technological distance corresponds to the optimal level. However, we foresee this optimum to be skewed to lower values of relatedness, as the absorptive capacity of R&D project participants tends to be higher, as well as the demand for novelty of knowledge acquired via collaborative R&D activities. In the same way, cooperation among unrelated firms can be stimulated by the fact that such firms are less likely to be competitors compared to firms with a closer knowledge base. As a result, the R&D cooperation patterns might also span at least partially over unrelated industries. On the contrary, mutual cooperation among firms with strongly unrelated knowledge can be hindered by a lower probability of mutual acquaintance as well as of trust, which is a crucial factor given the uncertainties and risks accompanying R&D efforts. Nevertheless, the strength of these factors in reality remains an empirical question.

Therefore, our research aims to answer the following main research question. To what extent does the relatedness among companies expressed by similarities in the portfolio of activities they perform translate into a pattern of their R&D inter-firm cooperation? As explained above, our expectation is that the frequency of inter-firm R&D cooperation would follow an inverted U-curve in relation to relatedness, i.e. we envisage that the inter-firm collaboration would be highest between partners representing a technological distance optimal for R&D activities and that the intensity of collaboration would fall in accordance with both increases and decreases of knowledge distance between firms.

## Data and Methodology

Measuring relatedness remains a challenging issue. At least two broad approaches towards measuring relatedness can be identified. First, conventionally, ex-ante relatedness can be measured on the basis of economic activity or product classification. In particular, Frenken, van Oort, and Verburg (2007) argue that 5-digit industries according to the Standard Industrial Classification are technologically related if they share the same 2-digit class. However, this method is rather static and does not follow different dynamics in technological evolution among particular industrial branches (Boschma and Iammarino 2009). Nevertheless, this method is commonly used in current research (Cainelli and Iacobucci 2015; Cortinovis and van Oort 2015).

Second, several methods were developed to measure revealed or ex-post relatedness, which can manifest itself on the basis of a broad spectrum of factors affecting similarities among products, including similarities in distribution channels, similarities in market segment or a broad spectrum of tangible and intangible resources such as machinery, strong brands, etc. (Hidalgo et al. 2007; Neffke, Henning, and Boschma 2011; Neffke and Henning 2013). In particular, this method is based on the notion of product space (Hidalgo et al. 2007); the product space is constructed on the basis of relatedness among products as revealed by the frequency of similarities in export structure of countries or regions. Revealed relatedness can be also measured at the micro-scale on the basis of co-occurrence of products belonging to different industries in the same manufacturing plants (Neffke and Henning 2008; Neffke, Henning, and Boschma 2011). Consequently, in this stream of research two products are considered to be related if they are often produced jointly at a plant level (Neffke, Henning, and Boschma 2011).

Our research is based upon an analysis of the Czech database on R&D activities co-financed by the state budget (R&D Information System 2015).[1] The database contains interconnected records on beneficiaries, programmes and projects. Our analysis covered more than 24,000 projects that had been initiated between 2003 and 2014 to capture the reality of collaboration over the last 12 years. Out of these projects, about 36% (8729) were investigated by two or more participants, of which 1743 cases represented collaborative projects of at least two companies. Altogether, 1667 companies participated in our sample of joint projects. Within the collaborative network, 4132 particular linkages were found among businesses based on the co-presence of partners in joint projects, of which 723 linkages were repeated twice or more times. Thus, the total number of linkages equalled to 5,500 (see Table 1 and 2). Therefore, the average weight of the relation

[1] The database is available at: http://www.isvav.cz/

(representing the frequency count) remained relatively low (1.331). Nevertheless, repeated linkages represent an important subset within our database, as it can be argued that the repeated R&D projects indicate that the previous cooperation was considered beneficial by the respective companies. In order to investigate the variation in frequency of linkages according to relatedness, our dataset was extended by detailed information from the Business Register (CSO 2015) about all types of economic activities performed by companies as captured by 272 3-digit NACE groups. In line with Breschi, Lissoni, and Malerba (2003), we made no assumption about the meaning of the main classification codes as opposed to the supplementary ones. Therefore, all codes were treated as being of equal relevance, as we believe that the main as well as the supplementary activities are performed with the support of the skills portfolio accumulated in a given firm (Neffke and Henning 2013) including some general ancillary activities, such as accounting, transportation, sales, repair and maintenance, etc.

Nevertheless, despite the critical remarks regarding the measurement of (un)related variety on the basis of industrial classifications such as NACE, we stay with this classification as it represents an attempt to form a systematic classification of all economic activities. In particular, according to NACE methodology, "an economic activity is characterised by an input of resources, a production process and an output of products (goods or services). The activities are grouped together into classes when they share a common process for producing goods or services, using similar technologies" (Eurostat 2008, 15). The main criteria applied in delineating groups and divisions of NACE concern the character of the goods and services produced and the uses to which the goods and services are put. Thus, NACE Rev. 2 consists of 21 sections, 88 divisions, 272 groups, and 615 classes (Eurostat 2008). In our case, a unit of analysis is identified as a unique legal or physical entity (company or firm). A unit may perform one or more economic activities described in one or more categories of NACE.

In both datasets (i.e. the excerption from the Business Register – see below – as well as the database of collaborating businesses), only 60% of NACE records are available at the 4-digit level. Therefore, the shift to a more detailed level would be associated with significant data loss. Moreover, the structure of the NACE classification is asymmetric, as the number of categories does not increase proportionally (tenfold) while shifting to a more detailed level. In particular, whereas 92% of 88 divisions are further divided into groups with specific additional meaning, only 49% of 272 groups are divided into specific classes. Furthermore, the structure is highly uneven between individual divisions. For instance, “manufacture of food products” divides into nine groups, whereas “manufacture of rubber and plastics products” unfolds into only two groups. Another 14 divisions do not divide at all (as, for example, in the case of “computer programming, consultancy and related activities”). Therefore, after a comprehensive review of the classification, of the data in the Business Register, and of our dataset, we concluded that the 3-digit level was the most appropriate for our analysis.

In order to construct the revealed relatedness index a reference population of commercial companies were excerpted from the Business Register. In January 2015, 2.7 million entities were listed in the Czech Business Register, of which about 1.4 million demonstrated regular economic activities through statistical monitoring. Subsequently, we limited the dataset to commercial companies only, because they account for a decisive share of value created in the business sector, and, moreover, commercial companies represented 92% of the participants in our dataset of collaborative R&D projects.

Consequently, the database was limited to 300,000 commercial companies, for which 1.4 mil. 3-digit NACE codes were provided. These figures can be compared with our database of 1667 collaborating businesses, to which almost 16,000 NACE groups were assigned (i.e., on average 9.6 NACE groups per company, range from 1 to 61). Therefore, unsurprisingly, the firms participating in R&D collaborative projects on average perform a broader spectrum of economic activities than the remaining firms.

In order to evaluate the linkages in collaborative R&D projects among businesses, which are always defined by the characteristics of the two partners forming the linkage, all combinations of NACE groups assigned to the two partners were analysed. Consequently, for 4132 linkages among businesses based on the co-presence of partners in joint R&D projects, more than 494,000 combinations of NACE codes were identified. Thus, on average, 120 combinations were analysed per linkage (range: from 1 to 1870).

Subsequently, two methods were used to calculate relatedness among cooperating firms by characterising each linkage in terms of cognitive distance. The application of two methods allows a comparison of results and, consequently, production of more robust results. Both methods take into account all NACE categories assigned to the company, thus relying not only upon the principal but also upon the secondary or ancillary codes. We believe that this approach avoids the excessive simplification associated with the use of the principal category alone.

## Empirical Analysis of Relatedness among Firms pursuing Joint R&D Cooperation Projects

In this section, two methods of measuring technological relatedness among companies are employed and compared.

### Ex-ante Relatedness based upon the Hierarchy of Codes of the NACE Classification

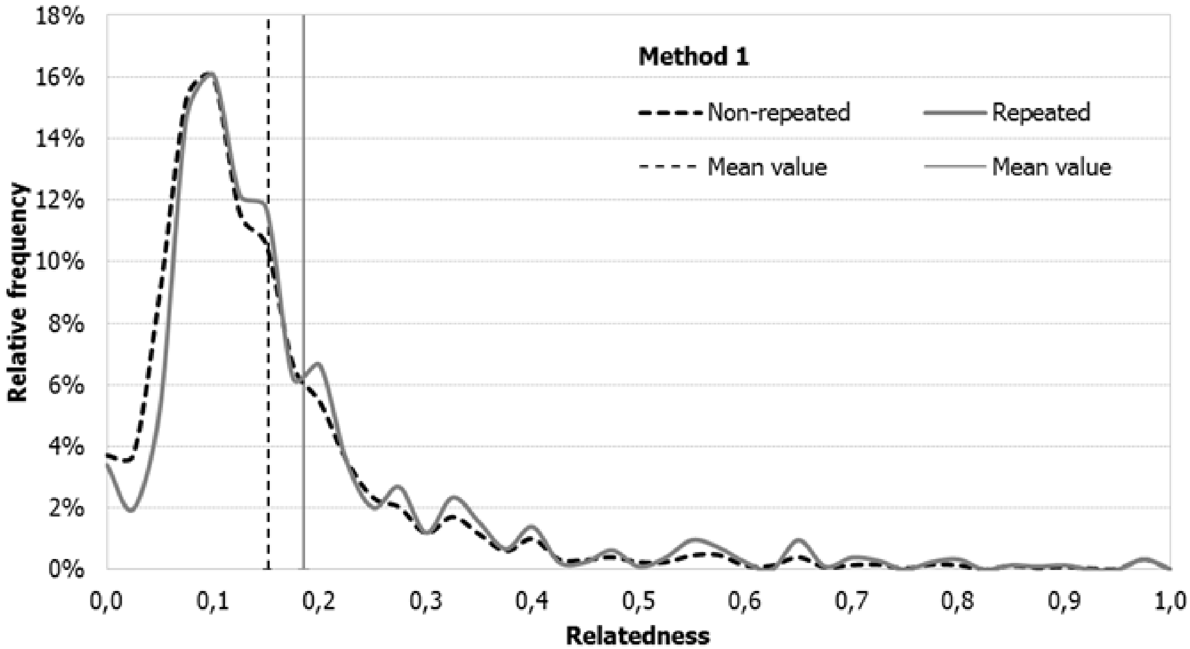
The first stream of our analysis in principle follows the traditional and well-known method of using the hierarchy of the NACE classification (Frenken, van Oort, and Verburg 2007). Generally, it is argued that industries are related if they share the same 2-digit NACE code (Frenken, van Oort, and Verburg 2007). However, to overcome some of the evident limitations of the traditional ex-ante approach, we modified the method for measuring relatedness among companies. Namely, one specific feature of the NACE classification is the fact that companies can declare not only the main code covering their key economic activity, but also supplementary codes capturing other activities they perform. Even though the number of declared NACE codes differs sharply among companies, sets of codes declared by particular companies allow relatively fine-grained analysis of their mutual relatedness.

In the first step, all combinations of NACE codes assigned to mutually cooperating companies were analysed and classified in the following way. If the companies shared the same NACE code at the 3-digit level, three points were assigned. Analogously, two points and one point respectively were assigned in cases where the companies shared the same code at the 2-digit or 1-digit level. Importantly, given the sharply differing occurrence of particular NACE codes among Czech companies, as well as the differences in coverage of portfolios of individual companies, the points assigned had to be standardised before the index could be calculated. Consequently, the level of technological relatedness ranges between 0 (for cooperation between companies with unrelated portfolios of activities) and 1 (for cooperation between companies with identical portfolios of NACE codes).

The results yielded by this established method based on the analysis of NACE codes, and expanded by the analysis of all codes assigned to particular companies, show that R&D collaboration according to technological distance is indeed far from random, and the results suggest that there is a strong preference of firms to search for partners with a certain level of technological distance. In particular, the most frequent R&D collaboration occurs between unrelated companies. While this finding confirms that technological distance plays an important role in selecting partners for R&D collaboration, this result does not support a hypothesis that expects intensive collaboration among partners for which knowledge distance corresponds at least broadly to the concept of related variety. Consequently, we have to acknowledge that even though we expected that the distribution might be skewed to the left, indicating a stronger tendency for R&D collaboration also to take place among firms with lower levels of relatedness, this result was unexpected. The main explanation might rest in the very nature of joint R&D projects, as collaborative projects are not necessarily performed jointly, but may involve subcontracting of certain R&D activities, as firms are often looking for partners with specific complementary knowledge. Moreover, it should be emphasised that firms performing R&D are likely to have a strong capacity to absorb external knowledge. Accordingly, these firms, in their quest for knowledge, might be able to span considerable technological distance well beyond the distance foreseen by the related-variety concept. In short, the search for partners in R&D projects seems to be driven rather by novelty of knowledge than by probabilities of its comprehension.

Nevertheless, the resulting pattern of R&D cooperation still follows the specific form of an inverted U-shape curve as proposed by Mowery, Oxley, and Silverman (1998). Importantly, however, in the case of repeated R&D projects, a certain shift towards a higher relatedness was identified. An explanation can be sought in several features of the environment for effective inter-firm collaboration. From an evolutionary perspective and in line with (Broekel 2015b), various proximity configurations in networks are systematically interrelated. Repeated collaboration is associated with trust-building, which can be manifested by lower anxiety to share strategic know-how with competitors that demonstrate a similar portfolio of activities (i.e., high relatedness). Moreover, Balland, Boschma, and Frenken (2015, 5) pointed out that “in the short run, proximity creates knowledge networks, in the long run, knowledge networks create proximity”. Using the words of (Broekel 2015b, 926), “actors that frequently interact become more similar in the cognitive dimension, which, in turn, increases their chances to interact again”. Co-evolution of both the cognitive and the social proximity (i.e., relatedness and trust, respectively) may play a role in repeated R&D collaboration. Without qualitative insight into the particularities of repeated relations, we do not see any basis for judging which of these factors should be stronger. Moreover, the examination of individual data reveals that frequently collaborating companies include partners that are linked by property relationships. Thus, ownership linkages represent yet another factor shaping the pattern of R&D collaboration.

Figure 2. Frequency curves comparing the frequency of repeated and non-repeated collaboration with relatedness measured on the basis of the NACE classification (Method 1).




Source: Own calculation based on CSO (2015) and R&D Information System (2015).

Table 1. Descriptive characteristics for Method 1 (comparison of repeated and non-repeated linkages)

| Descriptives | Total | Weight=number of projects undertaken among particular companies | |
|---|---|---|---|
| | | 1 (Non-repeated) | 2+ (Repeated) |
| Cases [number] | 5500 | 3409 | 2091 |
| Cases [percent] | 100% | 62% | 38% |
| Mean | 0.1645 | 0.1520 | 0.1849 |
| Median | 0.1284 | 0.1224 | 0.1394 |
| Std. Deviation | 0.1348 | 0.1221 | 0.1510 |
| Minimum | 0.00 | 0.00 | 0.00 |
| Maximum | 1.00 | 1.00 | 1.00 |
| Skewness | 2.723 | 3.006 | 2.360 |
| Kurtosis | 10.223 | 13.875 | 6.758 |

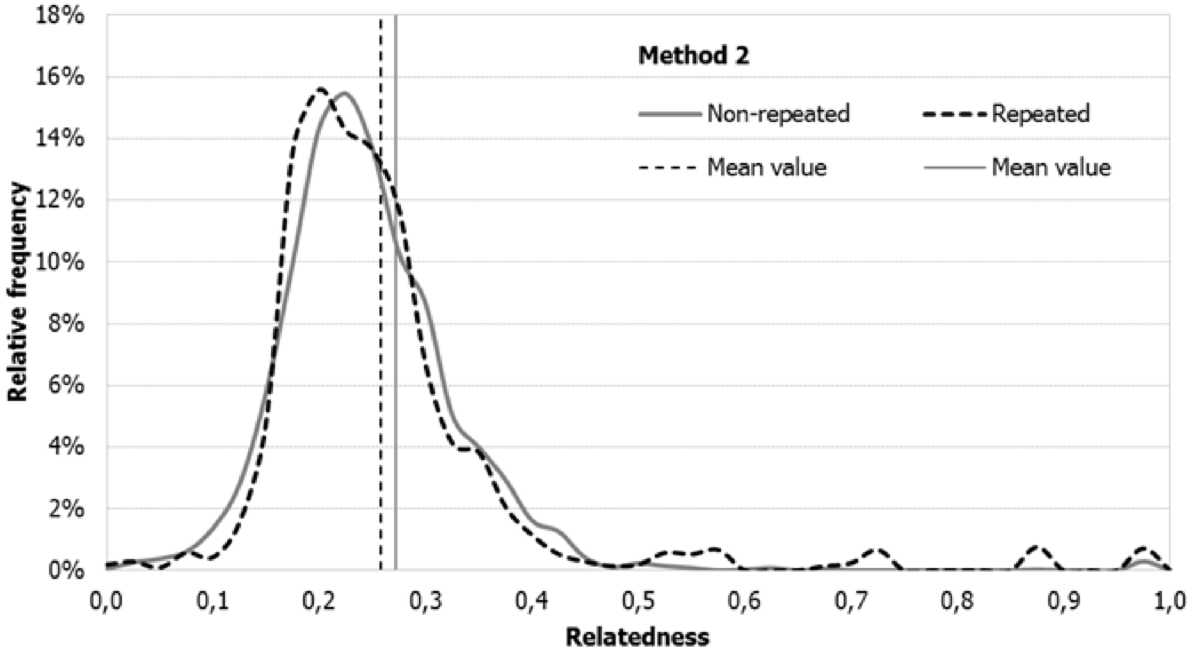
Source: Own calculation based on CSO (2015) and R&D Information System (2015).

**Revealed (ex-post) Relatedness based on Co-occurrence Analysis**

In contrast to the first empirical exercise, where ex-ante relatedness was derived from the hierarchical structure of the NACE classification system, we used co-occurrence analysis to identify the role of revealed relatedness, as elaborated by Neffke and Henning (2008) and subsequently employed, for example, by Neffke, Henning, and Boschma (2011). Co-occurrence analysis has recently become a frequently used methodological approach for assessing inter-industry relatedness (Hidalgo et al. 2007; Fornahl, Broekel, and Boschma 2011; Neffke, Henning, and Boschma 2011). "Co-occurrence analysis measures the relatedness between two industries by assessing whether two industries are often found together in one and the same economic entity" compared to an expected baseline (Neffke, Henning, and Boschma 2011, 242).

Relatedness of economic activities here is derived from the co-occurrence of 3-digit NACE groups assigned to commercial companies in the Business Register. We assessed the co-occurrence of economic activities in the whole population of active companies (as a reference population to construct the revealed relatedness index), consisting of 300,000 businesses, for which 1.4 million 3-digit NACE groups were assigned (i.e., on average 4.7 NACE groups per company; range: 1 to 61).

Figure 3. Frequency curves comparing the frequency of repeated and non-repeated collaboration with relatedness measured by the use of co-occurrence method (Method 2).




Source: Own calculation based on CSO (2015) and R&D Information System (2015).

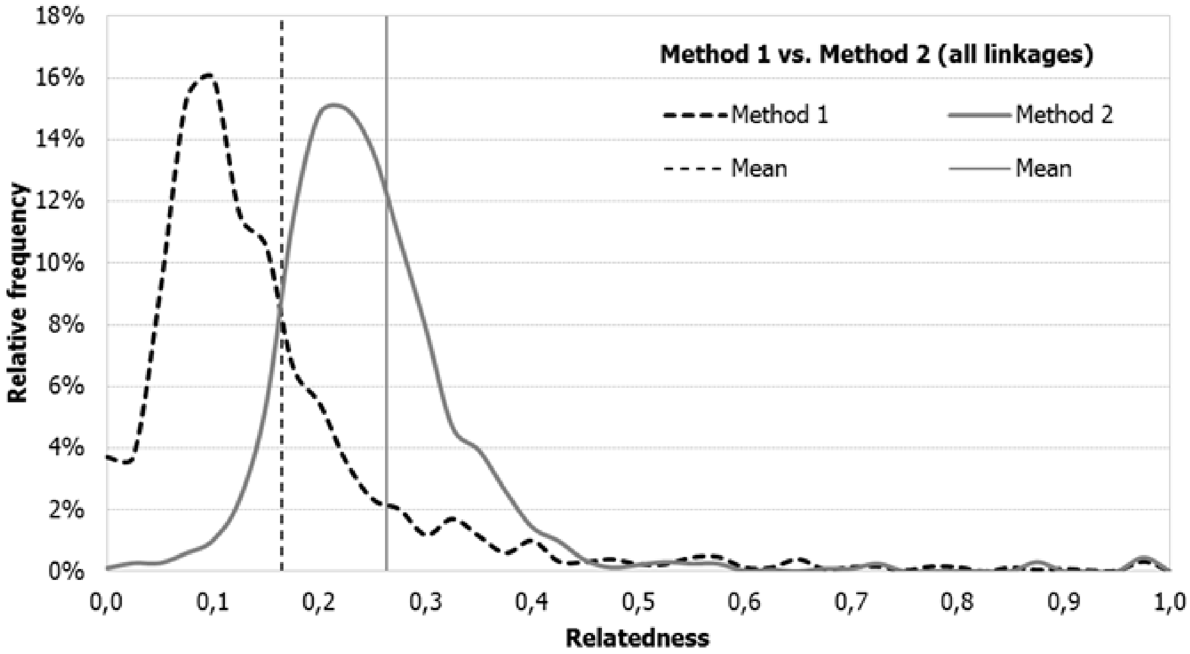
Table 2. Descriptive characteristics for the co-occurrence method (comparison of repeated and non-repeated linkages).

| Descriptives | Total | Weight | |
|---|---|---|---|
| | | 1 (Non-repeated) | 2+ (Repeated) |
| Cases [number] | 5500 | 3409 | 2091 |
| Cases [percent] | 100% | 62% | 38% |
| Mean | 0.2632 | 0.2583 | 0.2712 |
| Median | 0.2472 | 0.2478 | 0.2464 |
| Std. Deviation | 0.1023 | 0.0866 | 0.1232 |
| Minimum | 0.00 | 0.00 | 0.00 |
| Maximum | 1.00 | 1.00 | 1.00 |
| Skewness | 3.073 | 2.342 | 3.200 |
| Kurtosis | 17.244 | 16.445 | 13.914 |

Source: Own calculation based on CSO (2015) and R&D Information System (2015).

The results obtained by this co-occurrence method are quite similar to the outcomes obtained by the previous method. Again, the pattern of R&D collaboration among Czech firms closely follows the inverted U-shape curve envisaged by Mowery, Oxley, and Silverman (1998), but the curve implies that the cooperation in the sphere of R&D is much more likely in cases of technologically unrelated companies than in cases where the companies use related or even identical technology. As with the previous method, a shift towards a higher relatedness was identified in cases of repeated R&D projects. However, in this instance, the shift is relatively modest. Nevertheless, R&D projects performed among companies with a relatively higher degree of relatedness are more likely to be repeated in future.

Figure 4. Comparison of results yielded by ex-ante (Method 1) and co-occurrence method (Method 2).




Source: Own calculation based on CSO (2015) and R&D Information System (2015).

Comparison of collaboration patterns obtained by both methods shows that, in cases of relatedness measured by the co-occurrence method, the optimal knowledge distance among companies is clearly smaller than in cases of the ex-ante method based on the NACE classification. This result can be interpreted as an indication that the co-occurrence method affords greater insight into the optimal knowledge distance among companies, as it is not based upon pre-given NACE classifications, but upon similarities in their portfolios of assigned NACE codes. Therefore, the co-occurrence method is also able to capture various complementarities that are not encompassed by the standard NACE classification.

## Conclusions

The related-variety school offers unique insights into the evolution of the economic structure of regions and countries, as well as into the functioning of particular mechanisms of knowledge spillovers such as the labour mobility of professionals. However, it has been shown that a growing number of studies performed within this school exhibit a surprising variety of conceptualisations, approaches and methods used in the investigation of the role of related variety. By contrast, the number of studies that explicitly scrutinise particular mechanisms by which relatedness might operate and evolve remains limited. This is unfortunate, as such research might offer new and surprising insights into the drivers of socioeconomic evolution as well as new inspiration for policy-makers.

Overall, the contribution of our empirical analysis is twofold. From a methodological perspective, we reflected on the contemporary approaches and methodological differences within related-variety studies and employed two multi-dimensional methods for measuring relatedness. The first approach was built on the standard method, based on the NACE classification, and was enhanced by an analysis of all NACE codes assigned to a particular company. The second method was based on a co-occurrence analysis of particular NACE codes among different companies, thus bypassing the pre-given classification scheme. We believe that our method of co-occurrence analysis based on a comparison of all principal and secondary NACE codes is more realistic than the traditional approach to measuring relatedness, and that it makes the concept of relatedness more powerful in terms of its explanatory strength. In particular, this method removes some of rigidities of the traditional method based on NACE classification and also captures a wide spectrum of complementarities.

Second, the contribution of the paper is based on a detailed analysis of a unique database of collaborative R&D projects among companies. The results yielded by both methods prove that R&D collaboration according to technological distance is indeed far from random, revealing a strong preference of firms to search for partners with a high level of technological distance. Nevertheless, the optimal knowledge distance among companies identified by the co-occurrence method is noticeably smaller than in case of the ex-ante method based on the NACE classification. Thus, the co-occurrence method proved to be able to capture also various complementarities that are not encompassed by the standard NACE classification.  Despite this difference, the results do not support our hypothesis of expecting intensive collaboration among partners for which knowledge distance corresponds to the related-variety concept.

Thus, our results provided evidence that joint R&D projects among firms span over a much larger distance than the one envisaged by the related-variety concept. However, this result should not be taken as proof of the irrelevance of the related-variety concept, but rather as an indication that the effects of relatedness might differ according to varying levels of sophistication as well as the level of spontaneity of particular mechanisms. Undoubtedly, joint R&D projects represent highly sophisticated and intentional activities, and their potential contribution is carefully considered by managers before such ventures are undertaken. Consequently, patterns of R&D collaborative projects contrast with patterns of knowledge spillovers, which are by definition spontaneous in their nature (cfr. e.g., Neffke, Henning, and Boschma 2011). Moreover, the role of the relatively high absorptive capacity of knowledgeable partners performing R&D activities should not be underestimated, as it can help to extend the distance over which these companies are able to cooperate effectively, thus representing a form of "upper echelon" of the particular economies. Conceptually, it can be argued that, while the related-variety concept seems effective in capturing the modes of operation of relatively spontaneous processes, highly intentional and sophisticated activities can span over much larger cognitive distances.

These findings suggest that in reality there might be various processes that require different optimal knowledge distances. This might lead to important policy implications. In particular, while the role of related variety as an important factor driving the evolutionary trajectories of regions via facilitating various forms of spillovers should be acknowledged, overreliance upon support of related industries might be misleading. Companies need to be engaged in various types of processes, including highly sophisticated and intentional activities such as joint R&D projects, which might require a larger knowledge distance than the concept of related variety might suggest.

Moreover, while there seems to be a general agreement that a delicate balance between cognitive proximity and distance across industries in a region is needed for effective knowledge spillovers (Neffke, Henning, and Boschma 2011), a fundamental question emerges, namely, what type and what intensity of learning is allowed by particular and vastly different national or regional innovation systems existing across Europe and beyond (see Boschma and Iammarino 2009; Rodriguez-Pose 2013)? In particular, while related-variety studies extensively invoke the notion of varying capacity of stakeholders to absorb external knowledge, the other side of the coin – the ability and willingness of actors in different industries, regions or innovation systems to emit and share knowledge – remains largely unexplored. Consequently, characteristics of regional systems such as the nature of untraded interdependencies, the intensity of formal and informal knowledge flows, the level of trust, laws, customs, traditions, etc. come to the fore (Boschma and Iammarino 2009; Boschma and Capone 2015b).

However, several factors might hinder future efforts to derive broader generalisations concerning the role of related and unrelated variety for the evolution of regional economies. To start with, in every region there is a plethora of particular and ever-changing constellations of industrial specialisations; moreover, even within the same industry, activities can be performed at vastly different levels of sophistication. Profound variation in sophistication, even if using finely grained 10-digit product-level data, has recently been documented by Kemeny (2011); likewise, for a detailed analysis of the vastly differentiated nature of linkages and spillovers according to particular tiers of suppliers integrated into global value chains/global production networks within a single (automotive) industry, see Pavlínek and Žížalová (2014). In addition, as Kemeny and Storper (2015) recently proved, the role of relatedness depends also on whether relative or absolute specialisation is analysed and the results are closely linked to the position of the region within the regional/urban hierarchy, which again reflects the differing nature of the activities performed. Moreover, relatedness undoubtedly plays a differing role in instances of growing, mature or declining industries.

In addition, given the fact that the majority of related-variety studies have been performed on cases of highly developed countries, it cannot be ruled out that the role of relatedness might differ significantly according to the level of socioeconomic development of a given region. It could reasonably be expected that the competitiveness of companies nested in highly developed regions and countries is based upon a different set of factors than the competitiveness of firms placed in less-developed regions. Consequently, if the competitiveness of companies located in less-developed regions is primarily driven by various types of cost-based advantages, the role of knowledge spillovers in their competitiveness might be significantly lower. Therefore, the extent to which the related-variety concept can also be an important driver of evolution and competitiveness for companies in less-developed regions represents an important avenue for future research. Consequently, important conceptual, empirical and policy challenges lie ahead.

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