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Related to What? Reviewing the Literature on Technological Relatedness: Where we are now and where can we go?

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Abstract

Related to What? Reviewing the Literature on Technological Relatedness: Where we are now and where can we go? Adam Whittle School of Geography, University College Dublin September 2014 - September 2018 adam.whittle@ucdconnect.ie State-of-the-art It is now commonplace to assume that the production of economically valuable knowledge is central to modern theories of economic growth and regional development. Particularly among evolutionary economic geographers, one of the recent contributions has been attempting to untangle the "black box of knowledge" in relation to regional diversification. Here the concept of relatedness - how related economic activities are to one another - has been particularly influential, as it moves beyond absolute values in terms of economic concentration to explain 'distance' between technologies as a key factor enabling regional diversification. Research Gap Theory argues that regions diversify into new industries that are technologically related to their current specialisation rather than those that are technologically unrelated (Neffke et al., 2011). As such, an existing set of local capabilities (specialisation) can be seen to determine the possibilities of future diversification. The principle aim of this paper is to provide a more comprehensive framework of regional diversification by considering 1) a more geographical and micro-economic approach, and 2) by highlighting a number of methodological limitations currently employed. Theoretical Arguments Against this backdrop the purpose of this paper is to critically evaluate some of the recent theoretical and empirical work on the concept of relatedness and regional diversification, by realigning longstanding theories of agglomeration economies with more modern concepts of evolutionary economic geography (Boschma and Martin, 2007) and network theory (Hidalgo, 2015). To date, the literature has identified three measures of generating relatedness networks, those base off; hierarchy (Frenken et al., 2007), co-occurrence (Kogler et al., 2013) and resources similarity (Essletzbichler, 2015). Geographic extensions of these arguments have also been developed to analysis the branching capabilities of regions (Hidalgo et al., 2007), products (Neffke et al., 2011) and technologies (Kogler et al., 2013). Results While the relatedness framework has the capacity to be a great many things, it is not yet a unified theory, and the tendency to treat it like one is hampering future progress. One possible explanation for this is that our attempts to conceptualise and qualify relatedness and regional diversification have been overwhelming quantitative in nature. As a result, a number of authors have begun to question the validity of the concept in terms of what exactly is been captured. An alternative technique would be to develop more qualitative measures of diversification and to being analysing relatedness beyond

manufacturing e.g. finance/services. This approach would additionally begin to shed light on a number of related issues, chiefly concerning: unrelated diversification, recombination innovation and the geography of knowledge creation. Finally, the relatedness framework has the capacity to advance the recently advocated smart specialization thesis by analyzing the actual type of technological knowledge produced within specific places, and how this shapes the innovative capacity of a locality, and its future technological prospects.

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RELATED TO WHAT?
REVIEWING THE LITERATURE ON TECHNOLOGICAL RELATEDNESS: WHERE WE ARE NOW AND WHERE CAN WE GO?

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INTRODUCTION

It is now commonplace to assume that the production of economically valuable knowledge is central to modern theories of economic growth and regional development. At the same, it is also well known that not all knowledge is equal (Rigby and Balland, 2016) and that the spatial and temporal distribution of knowledge is highly uneven (David, 1994). Particularly among evolutionary economic geographers, one of the recent contributions has been attempting to untangle the "black box of knowledge" in relation to regional diversification and structural change. Here the concept of *relatedness* - how related two economic agents are to one another - has been particularly influential, as it moves beyond absolute values in terms of economic concentration and industrial composition to explain 'distance' between technologies as a key factor of future regional development (Essletzbichler, 2015). Intuitively this makes sense, as firms are more likely to diversify into industries that are technologically proximate to their current specialization rather than those that are technologically unrelated (Frenken *et al*., 2007). What is more, the guiding principle behind the evolutionary theory of the firm (Nelson and Winter, 1982) has highlighted that firms develop skills, routines and specializations over time that in some ways determine the possibilities of future diversification.

From an evolutionary point of view there are two intrinsically related arguments here. First, the ability to accurately capture distance (relatedness) between technologies opens up a platform for understanding future regional diversification as a branching process grounded in local capabilities (Penrose, 1959; Boschma and Frenken, 2011). Of key importance here are the processes of; labor mobility, firm diversification, spinoff firms and social networks all of which possess a local character, thus highlighting the need to consider a geographic dimension in the study of regional diversification. Secondly, concerning the scale of knowledge spillovers it is more likely that a range of technologically related firms will be more beneficial than a set of technologically unrelated firms, as technologically related firms satisfy both the search for novelty (cognitive distance) with effective communication (cognitive proximity) (Nooteboom, 2000).

Against this backdrop, the purpose of this paper is to critically review some of the recent theoretical and empirical work on the concept of relatedness and regional diversification. To date, the literature has identified four measures of relatedness all of which are based off an input-output intensity relationship, where more frequent relationships occupy denser segments of; the product space (Hidalgo *et al*., 2007), the industry space (Neffke *et al*., 2011) the knowledge space (Kogler *et al*., 2013) and the skill space (Neffke and Henning, 2013). The objective here is not too subject or elevate one measure over another, as each has their relative and regional specific strengths and weaknesses. Rather, the focus is to showcase progress to date, identify future research direction and thereafter highlight some current limitations which may hamper future progress.

AGGLOMERATION EXTERNALITIES AND CONNOTATIONS OF SPACE

The introduction of geography as a palpable medium to organize economic activity is one of the starkest contrasts between neo-classical economics and evolutionary economic geography (Witt, 2003). One particular claim is that this geographical dimension functions as a malleable platform through which firms interact and technological change and knowledge transfer takes place (Boschma and Martin, 2010). As such, the nexus between geography and technological change has decisive regional component chiefly concerning whether or not regions should specialize in one economic activity or many. Broadly speaking the overlap between geography and economics, as well as the advantages and disadvantages that they incur are called agglomeration externalities (Marshall, 1890; Glaeser *et al*., 1992; Henderson *et al*., 1995). Although many definitions of agglomeration externalities have been put forward in the literature, a simple explanation focuses on the processes by which one firm learns from the activities of another, therefore enhancing their own productivity without fully compensating the other firm for the value of this knowledge. Or to put it more poetically, the proclaimed benefits of agglomeration externalities are simply 'in the air' (Marshal, 1890, p. 198) available to all firms by just 'being there' (Gertler, 2003).

As pervasive as these claims are, reducing regional development to a by-product of simply 'being there' ignores a number of important geographical elements namely; socialization and face-to-face interaction (Storper and Venables, 2004), absorptive capacity (Cohen and Levinthal 1990) and place-based indicators (Martin and Sunley, 2006) all of which significantly determine the rate and direction of future regional diversification. Not wanting to re-hatch the historic, specialization versus diversification debate (Beaudry and Schiffauerova 2009; De Groot *et al*., 2009) as an either or question (Van Oort, 2015). Instead, the objective is to look at recent developments it the field of evolutionary economic geography and its focus on the role of relatedness in driving regional diversification (see also, Van Oort, 2015).

Thematically the debate surrounding the spatial clustering of firms in general and agglomeration externalities more specifically have gone either one of three ways. Those that advocate Localization externalities, Jacobs externalities and Urbanization externalities.

Localization externalities, otherwise known as Marshallian externalities refer to the fortunes available to firms that operate in the same industry. Historically, these fortunes were primarily economic, but recent contributions have also highlighted the secondary role of formal and informal institutions as well as political actors in shaping the development of firms and regions (Cooke *et al*., 1997; Boschma and Capone, 2015).

Following his seminal piece on agglomeration externalities, Marshall (1890) is often accredited as the forefather of the spatial organization of the firm. He argues that the co-location of a number of highly specialized firms are more conducive for economic growth because it facilities the internalization of knowledge within specialized techno-industrial structures. Here, localization externalities can be divided into three distinctive advantages; the presence of a highly skilled labor force, an environment of related firms and more targeted knowledge spillovers. Moreover, this specialization enables the transmission and exchange of knowledge, of ideas and information, whether tacit or codified, of products and processes through imitation, business interactions, inter-firm circulation of skilled workers, all without monetary transactions (Saxenian, 1994). Expanding on the ideas of knowledge, it is important to differentiate between codified and tacit knowledge, as both have profoundly different effects on the diversification capabilities of regions (Polanyi, 1967). Codified knowledge is easily obtainable and reproducible through books and blueprints and following recent advances in communication technologies it is also relativity mobile. Conversely, tacit knowledge is both highly complex and spatially sticky (Maskell and Malmberg, 1999). Moreover, as technological change and knowledge production have gradually become more socialized and interactive, a premium is increasingly being placed on shared experiences via face-to-face interactions. Both of which are easier to orchestrate within shorter geographic distances (Boschma, 2005).

Contrarily, there are the advantages and disadvantages associated with urbanization externalities. Urbanization externalities primarily reflect the spatial attributes of city size. The central premise is that by virtue of being a larger city that firms operating within this city have access to a larger market through which they can buy and sell their products. Discussing the dynamism between space and place, Neffke *et al.,* (2014) provide further evidence to this point demonstrating that workers are often attracted to those areas the best match their qualifications, while specialized suppliers choose to locate in regions that host potential clients. Moreover, much of the recent work on urbanization externalities (De Groot *et al.,* 2015) has sought to combine some of the earlier work on industry location theory (Kuznets, 1930) with more recent theories on labor economics (Ehrenberg and Smith, 2016) in order to highlight the advantages that arise with city size. These include; knowledge externalities arising from universities and research facilities, a progressive working environment, a functioning urban network ecology, as well as a well-developed political and institutional system.

Finally, there are those who advocate Jacobs's externalities as the primary driver of regional diversification. For the sake of clarity, if Marshallian externalities were associated with highly specialized regions, then Jacobian externalities are associated with highly diverse regions. Regarding Jacobs externalities, the central premise is that knowledge is external to both the firm and the local industry but is internal to the geographic unit (Jacobs, 1969). Therefore, in order for regions to remain competitive, it is important that their industrial composition is sufficiently diversified. What is important here is not just increasing the scale of production, but also the scope of production; as Jacobs (1969, p. 49) highlights, 'Our remote ancestors did not expand their economies much by simply doing more of what they had already been doing … They expanded their economies by adding new kinds of work. So do we'. Among other things, Jacobs argues that cities are the locus of economic development whose primary economic function are to act as incubators for potential innovations (Acs, 2003). In addition to its economic functions, Jacobs also claims that cities enact important social processes not just by bringing many people together but also by bringing together a wide variety of ideas from which potentially new knowledge can be created. In this regard, Jacobs externalities draw extensive parallels with Schumpeter's (1912) *neue Kombinationen* thesis whereby new innovations literally recombine pre-existing technologies. Furthermore, since this cross-fertilization of ideas is greatest in diversified cities, it is cities that hold the most potential for regional diversification. In their review of the literature, De Groot *et al*., (2009) reviewed 31 articles that adopt a Jacobs framework and find positive evidence for competition and diversity in explaining regional development.

In reality what is often most conducive to regional economic growth is a mixture of both specialization, diversification and urbanization, as neither concept should be treated in isolation. It is possible that as regions evolve from one period to another that they require different types of agglomeration externalities. Van Oort (2015) and Balland *et al*., (2015) have both drawn attention to the static versus dynamic nature of agglomeration economies, given that the specific nature of these externalities will vary both in terms lifecycle *e.g*. young versus old firms and in terms of size *e.g*. small versus large firms (Beaudry and Schiffauerova, 2009).

In spite of this, the aforementioned studies have recently been criticized on a number of theoretical and methodological grounds, given their tendency to ignore the evolutionary paradigm inherent to firms and regions. They follow the assumption that the industrial structure and the absorptive capacity of regions remain constant over time which in turn makes them comparable with one another (notable exceptions include; Neffke *et al*., 2011; Kogler *et al*., 2013; Boschma *et al.,* 2014; Kogler *et al*., 2016); while in reality regions are inherently heterogeneous both shaping and been shaped by the environment in which they exist. Here, studies that adopt an evolutionary discourse (Nelson and Winter, 1982) and especially those that seize upon the concepts or related variety (Frenken *et al.,* 2007) and more recently technological relatedness

(Boschma and Frenken, 2011) are particularly useful as they move beyond absolute values in industrial concentration to consider similarity between technologies as key to understanding regional diversification.

RELATED VARIETY, RELATEDNESS AND REGIONAL DIVERSIFICATION

For Frenken *et al*., (2007) variety alone is not necessarily enough to result in knowledge exchange because there are a lot of technologies that cannot be meaningfully combined. They coined the term *related variety* suggesting that knowledge can only be meaningfully exchanged between actors that share a common knowledge base. They argue that, while Jacobs externalities are undoubtedly important for innovation and regional growth, there is a need to deconstruct variety into related and unrelated variety, as both processes affect regional diversification differently. Here, it has been argued that a high degree of related variety between actors is more conducive for knowledge spillovers because of complements in their knowledge base, while unrelated variety is unlikely to produce any significant knowledge spillovers due to cognitive differences. For Frenken and colleagues (2007) related variety was defined as the average entropy measure across employment in five-digit industries within each two-digit class and unrelated variety is the entropy in employment across 2-digit classes (Content and Frenken, 2016). Since then, the original thesis has been extended spatially (Saviotti and Frenken, 2008; Quatraro, 2010; Bosma e*t al*., 2011; Falcioğlu, 2011; Hartog *et al*., 2012; Caragliu *et al*., 2016) and methodologically (Boschma and Iammarino, 2009; Bishop and Gripaios, 2010; Boschma *et al*., 2012; Mameli *et al*., 2012; Cortinovis and van Oort, 2015) although the initial hypothesis remains constant. Boschma and Iammarino (2009) found that a high degree of export-related variety was essential for explaining regional economic growth in Italy. While Quatraro (2010) examined the relationship between related variety and regional productivity growth in Italy finding that related variety appears to be positively associated with regional productivity growth, while unrelated variety was found to be insignificant. Particularly interesting in this regard has been the work of Bishop and Gripaios (2010) who suggest that impacts of related and unrelated might be sector specific highlighting the need to further delineate between manufacturing and services industries.

Moreover, the contribution of Frenken *et al*., (2007) can be seen to reiterate the findings of Nooteboom (2000, p. 153), who argues that 'a trade-off needs to be made between cognitive distance, for the sake of novelty, and cognitive proximity, for the sake of efficient absorption'. Effective knowledge transfer and learning needs a degree of costive distance (to avoid redundant knowledge) while at the same time maintaining cognitive proximity (for the sake of novelty). Related variety achieves this delicate combination by balancing similarity with dissimilarity.

While the recent geographically reprisal in economics has seen an increased focus on relatedness and regional diversification in economic geography, the topic itself is not all that new. Some authors have argued that this interest has existed as long as a Marshal's (1890) Industrial Districts thesis, although a more recent application can be traced to the work on technological systems (Carlsson and Stankiewicz, 1991) and organizational relatedness (Engelsman and Van Raan 1991; Teece *et al*., 1994).

With the development of more sophisticated databases, economic geographers have renewed their focus on regional diversification and have begun to analysis diversity between (within) products (Hildigo *et al*., 2007), industries (Neffke *et al*., 2011), technologies (Kogler *et al*., 2013), and skills (Neffke and Henning, 2013). Relatedness or 'distance' between industries is, therefore, a crucial aspect in determining not just how industries and regions learn, but also how they evolve from one period to the next. In this vein Boschma's (2005, p. 1) focal contribution that 'geographical proximity per se is neither a necessary nor a sufficient condition for learning to take place' has served to highlight the role of other forms of proximity, most notably cognitive as a precondition for knowledge exchange. Only very recently have these ideas of space and distance been adequately investigated in the literature (Frenken *et al*., 2007). While space can refer to the physical distance or geographical proximity between two entities; distance refers to the cognitive distance between two technologies from which potentially new economic knowledge is created. In his writing on Regional Innovation Systems (*RIS*), Philip Cooke approaches the idea of distance from a

technological standpoint. According to Cooke (2001), distance should be conceived as a measure of relatedness between industries and technologies. He explains that even in regions with the most advanced infrastructure system may not be related if they are not technologically similar. Accordingly, what is most important for knowledge exchange among actors is a relatedness measure, without which firms are no better than 'cathedrals in the desert, often in agglomeration but not clustering and not creating synergies through spin-off and subcontracting activities' (Cooke 2001, p. 6).

According to Waldo Tobler (1970, p. 3) the First Law of Geography is that, 'everything is related to everything else, but near things are more related than distant things', which, in the context of economic geographies recent 'relational turn' has yielded some useful insights into the industrial branching and diversification processes of regions. Simply put, it is believed that regions expand their knowledge base through the processes of creative destruction, thereby enabling them to branch out into related economic activities (Schumpeter, 1939; Nelson and Winter, 1982; Boschma and Frenken 2006; Neffke 2009).

In this vein, the literature has identified three broad approaches for measuring relatedness, those based on hierarchy of industry classifications, co-occurrence matrixes and resource similarity (Neffke and Henning, 2013; Essletzbichler, 2015).

Hierarchal Relatedness

The first measure of relatedness is based on the hierarchy of industry classifications. Here industries are defined as 'related' if they belong to the same broad digit industry class. Following the advent of information communication technologies (*ICTs*) and thereafter the digitisation of databases most modern classification systems employ some measure of hierarchy - SIC, NACE, USPTO, EPO - which remain fairly constant overtime. The logic underpinning this approach is relatively straightforward; two industries are considered related if they belong to the same broad digit industry class. For instance, SIC-4- digit industries belonging to the same SIC-2-digit industry are considered as related (Essletzbichler, 2015). Not least since Frenken *et al*., (2007) has this approach has enjoyed a position of stature among economic geographers as the 'go to' methodology in terms of measuring industry-based relatedness (see also; Boschma and Iammarino, 2009; Boschma *et al*., 2012). However, while relatively new in terms of economic geography, this approach has had a long history in the corporate diversification literature (John and Harrison, 1999) and what is particularly interesting is that both approaches share the same criticisms. While the benefits of using hierarchal based relatedness are that it is relatively straightforward to implement, Fan and Lang (2000) have voiced a number of criticisms. Theoretically speaking there is a rather weak justification to assume that just because two industries share a common two / three-digit classification that this automatically implies that there related, nor does it imply that they share resources. Further criticisms are that this type of relatedness is particularly poor when measuring vertically related business. For example, Fan and Lang (2000, p. 2) demonstrate that 'oil-refining (SIC 29) and chemical (SIC 28) businesses are classified as unrelated according to the two-digit SIC code classifications, when in fact, they are vertically related'.

Co-occurrence Relatedness

The second measure of relatedness is based on the notion of co-occurrence. Here relatedness is defined in terms of how often two agents are found to 'co-occur' in the same portfolio. According to the authors best knowledge, this type of relatedness measure was first developed by Engelsman and Van Raan (1991) to examine relatedness between patent classes. Using the co-occurrence of patent classes Engelsman and Van Raan (1991) derived relatedness measures from the fact that patents can be filled across multiple technology classes, and that the classes in which these patents are filed must, therefore, be related to one another.

Following the 'evolutionary' turn in economic geography (Grabher, 2009) and with the development of more sophisticated databases, the co-occurrence methodology has been adapted to analysis networks of

space. Using country-level export data, Hidalgo *et al.,* (2007) developed a network-based representation of a countries *product space* to show how often two counties co-export the same product. Kogler *et al.,* (2013) adopt the same general principles in their portrayal of the US *knowledge space*. Using information of the co-occurrence of patents, these authors discern the distance between individual patent classes as a means of how related each patent class is to one another. Finally, Neffke *et al.*, (2011) develop an *industry space* using information on the co-production of products in plants.

Each of these strategies has their respective advantages and disadvantages reflecting various contextual, historical and geographical limitations. Advantages are that each of the approaches are relatively easy to implement and all of them fit nicely within the contours of the recent evolutionary turn which cast regional diversification as an inherently endogenous process, grounded in a branching logic. Additionally, this data - which ranges from macro to micro - covers a lot of sectors and industries, giving it a geographical reach. In spite of this, Neffke and Henning (2013) have highlighted a major shortcoming of this approach is that it is largely outcome based. That is to say, these papers assume related-diversification will occur without considering issues of economies of scope. Thus, it is difficult to disentangle the specific type of relatedness been measured.

Resource-based Relatedness

The third measure of relatedness is based on the similarity of resources used between industries. This approach differs drastically from the other two types of relatedness insofar as it is a primarily bottom-up approach. Moreover, it focuses on the origin of these resources and from there deduces a measure of relatedness between industries (Neffke and Henning, 2013).

In their well-cited paper Breschi *et al.*, (2003) use patent analysis to measure relatedness across technological resources. Their point of departure is that, because most firms engage with more than one technology over their lifecycle, that relatedness between the resources of the firm may explain diversification patterns. Moreover, the extent to which these technologies are employed affects the firms 'knowledge proximity' through which future learning and diversification will occur. In a not too dissimilar vein, Fan and Lang (2000) construct a measure of relatedness from commodity flow data in US using a series of input-output tables. The importance of their study is that they differentiate between vertically related businesses, something most hierarchal measures do not. As such, their relatedness measure is better able to capture inter-industry relatedness as well as inter-segment, vertical and complementarity relatedness.

Notwithstanding this, this approach is arguably the least utilized measure of relatedness nowadays. Indeed, a number of authors have criticized its industry-specific nature given that the importance of resources varies by industry. Along these lines, Essletzbichler (2015, p. 4) has highlighted that 'patent-based indicators may shed light on relatedness among patent-intensive industries, while input–output-based measures may be more useful for an investigation of manufacturing rather than service industries.'

RELATEDNESS, REGIONAL DIVERSIFICATION AND THE FOUR TYPES OF SPACE

In the foregoing section, this paper outlined how relatedness - between products, technologies and industries - affects the scale and scope of future regional diversification. Although inherently different in their methodological approach, these three relatedness measures all share a common thread in that, firms/industries are more likely to diversify into areas that they are proximate to. The purpose of this section is to continue developing on these ideals while introducing a more geographical dimension. In all, the diversification literature has brought with it a series of important geographical implications for countries, industries, regions and firms.

Product Space

Recently, Evolutionary Economic Geography has greatly benefited from the work of Hidalgo *et al.,* (2007) who analyzed these diversification capabilities at the country level. Using international trade data, their approach sought to analysis whether or not a country develops a comparative advantage in a new product on the condition that that new product was related to the countries current export portfolio. In doing so the authors develop a *product space,* a network based representation that captures the levels of cognitive proximity based on the frequency of co-occurrence of in a countries exports. The authors argue that two products are considered related if two countries have a comparative advantage in both products. Developing on this idea, Hausmann and Klinger (2007) found that those countries that populate denser sections of the product space have a greater opportunity to diversify into related areas of the export market. Intuitively this approach makes sense as more developed countries have increased opportunities to expand their export portfolios, while less developed countries have a more limited capacity.

Since then, this study has been replicated in different geographical contexts using various methodologies. Extending these arguments to a sub-national level, Boschma *et al*., (2013) use export data to access the impact related variety has on economic growth for 50 Spanish regions for the period 1988-2008. While the study broadly confirms the initial findings of Hidalgo *et al.,* (2007) in that regions diversify into industries that are related to an existing set of industries. An interesting caveat is that they also found that the regional structure is more important than the national structure. These latter findings provide new evidence to the claim that certain resources are less mobile than others, suggesting that capabilities should be built at a regional level to enable them the development of new capabilities.

Despite this, the broad nature of the product space has caused authors to question its validity and whether or not what it is showing is actually relatedness between products. Along these lines, Boschma (2016) has pointed out that the authors do not reveal relatedness between products, but instead construe it from the frequency of the co-location of the same products. This indirect measure of product relatedness is based on frequency and does not necessarily capture synergies between the products.

While the Hidalgo *et al.,* (2007) study might have been the capture the branching phenomenon, it has not been the last. Since then a number of scholars have adopted these general principles to analysis diversification patterns at the regional and industry level.

Knowledge Space

A similar branching logic as also been applied to the study of technologies. The *knowledge space* is an intuitive way to model the processes of technological specialization / diversification. The knowledge space is generated using information of the co-occurrence of technology classes listed on patent documents. Here it is assumed that technologies that are closer together *i.e*. technologies that share a common core or similar competence, should be closer together in the knowledge space than those that do not. Prior research on the US knowledge space has linked relatedness between technologies to faster rates of patenting per worker (Kogler *et al.,* 2013), while Rigby (2015) found that technologies that were related to the regions pre-existing knowledge space had a higher probability to enter that region that those technologies that did not. Similar results were also found by Boschma *et al*., (2015) for the rise and fall of technological knowledge in US metropolitan areas, the growth of fuel cell technologies throughout Europe (Tanner, 2014), nanotechnologies in European regions (Colombelli *et al.,* 2014) and for the spatial diffusion of the rDNA technology across US metropolitan regions (Feldman *et al*., 2015).

In their most recent application, Kogler *et al*., (2016) trace the evolution of the EU15 knowledge space from 1981 to 2005. Using NUTS2 information, the authors map changing patterns in regional specialization across the each of the regions. They found that only 50% of the technology class-region

pairings found in 2001-05 existed in 1981-1985, suggesting that most of these regions have increased their specialization over that period of time. Finally, they deconstruct these regional changes in specialization using an entry and exit model finding that entry is responsible for about 34% change in specialization, while exit is responsible for about 29% change in spécialisation.

As with any methodology, the knowledge space has its own unique set of advantages and disadvantages. For Neffke (2009), its greatest advantage is that patent based relatedness captures the notion of technological relatedness very well. At the same time, this can also be seen as one of its greatest limitations insofar as, patenting only covers a certain few industries where the propensity to patent is high and therefore would not shed light on traditional or more creative industries.

Industry Space

Within the regional diversification literature, it was the work of Neffke *et al*., (2011) that first analyzed how regions enter into new markets. Using plant-level data on 2,766 events the authors measured the degree relatedness between manufacturing industries in Sweden over the period 1969 to 2002. Using the authors' own revealed relatedness index (Neffke and Henning 2008), the industry space is generated using the co-occurrence of products that belong to different industries in the portfolios of manufacturing plants (Neffke *et al*., 2011). This study is the first of its kind to provide systematic evidence to the structural branching processes of an entire country, finding that firms that were technological related to the existing industries in a region had a higher probability of entering that region than firms that were technologically unrelated.

Skill Space

Although still in its infancy, a number of working papers have proposed an additional measure of relatedness which attempts to capture skill-relatedness (Neffke and Henning, 2013; Nikulainen and Pajarinen, 2013; Timmermans and Fitjar, 2015; Csáfordi *et al*., 2016; Neffke *et al*., 2016; Haussmann and Neffke, 2016). The *skill space* builds on a series of theoretical and empirical advances from the emerging branching literature (Hidalgo *et al*., 2007; Boschma and Freknen, 2012) and combines them with the literature of regional diversification and labor mobility. As such, the skill space can be understood as a continuation of the industry space, given that labor mobility remains the driving force behind the process of diversification. In spite of that, we argue here that there is caveat enough to begin a discussion regarding the individual nature of the skill space and how it affects regional diversification.

The starting point for this approach is the observation made by Neffke and Henning (2013, p. 1), that 'skills acquired in one industry can often also be used in other industries' and when individuals change job they do so into industries where their current skill set are related. Thus, the s*kill space* is operationalized by capturing what types of skills can be used in different industries by comparing labor flows between industries.

More recently, a number follow up studies have begun to examine the evolution of regional skill spaces. Attempting to improve on their original methodology as well as provide answers to some unanswered questions, Neffke *et al*., (2016), examine how displaced workers navigate the skill space while searching for a new job. The authors propose a number of coping strategies, finding that displaced workers often change industry and region. They found that one way to mitigate against these effects was if the region was characterized by a large proportion of old industries, given that the positive effects of Marshallian externalities would dampen job losses through highly specialized labor force. A second coping strategy concerns the presence of industries related to the old industries. Again the authors find that the presence of related industries decreases post-displacement in a region by up to 21%. Similar studies have also been carried out on Finnish ICT sector for 1989-2010 (Nikulainen and Pajarinen, 2013), in Norwegian regions

(Timmermans and Fitjar, 2015) and to access the impact foreign-owned firm have on the productivity gap in Hungary (Csáfordi *et al.,* 2016).

In sum, the skill-relatedness framework can be seen as an exciting addition to the relatedness approach not least because it overcomes some of its recent criticisms and shortcomings (Tanner, 2014). Geographically this approach has the benefit of capturing relatedness through labor mobility at a micro level, something that the previous measures of relatedness have either failed to do or done so inadequately. At the same time, it should be mentioned that a limitation of this approach is the availability of data. Both of the studies by Neffke and colleagues used extremely detailed information of matched employee - employer labor mobility via their social security numbers, which makes these studies difficult to replicate in the future.

The writings on relatedness and regional diversification are currently fueling some of the most exciting debates within economic geography and regional studies. The evolving nature of the relatedness methodology and the novel networks of space it creates have given researchers a number of exciting new directions in which to examine the evolution of; countries, regions, technologies and firms. In doing so however, this has also given rise to a number of questions and potential limitations. It is to these issues that this paper now turns.

WHERE CAN WE GO?

Thus far this paper has sketched out the contours that underpin the relatedness framework. In doing so it provided a critical overview of, its theories and methodologies, its successes and limitations as well as its geographical scope. In this section, we set ourselves the task of casting a wider research agenda with the aim of highlighting some future research direction as well as potential policy implications chiefly concerning; unrelated diversification, recombination innovation and smart specialization. Pulling these three ideas together, the section concludes by highlighting some staunch limitations within the relatedness framework, as well as what can be done remedy these issues in the future.

While there have been ample discussions detailing at length the capabilities necessary for related regional diversification (Neffke *et al*., 2011; Tanner, 2014), as well as the multitude of relatedness measures (Neffke and Hennning, 2013). Far less attention has been directed towards the processes of unrelated diversification (Neffke *et al*., 2014; Boschma *et al*., 2016).

On the surface, it is reasonable to question why firms would want to engage in such a process given their risk-aversive nature (Audretsch and Feldman, 2004). One answer, according to Penrose (1959) and Jacobs (1960) is that firms - and by extension regions - need to continually extend their product portfolios if they want to remain competitive. Armed with this logic, economic geographers have begun proposing theories of unrelated diversification through which firms/regions can recombine distant pieces of knowledge in order to avoid technological lock-ins (Saviotti and Frenken 2008) develop new growth paths (Martin and Sunley, 2010) and generate entire new technologies (Feldman *et al.,* 2015) and industries (Tanner, 2014).

The issue of unrelated diversification is that it is fluent with uncertainty and would require a complete reworking in terms of agency and the distribution of resources. Whereas related diversification infers relatedness based on how cohesive economic agents are to one-another (product relatedness etc); unrelated diversification would require a wider range of resources in terms of, skills, technologies, materials, legality, money, institutions and workers (Boschma *et al.,* 2016). In their original study, Frenken *et al*., (2007) found that unrelated variety was negatively related to unemployment growth suggesting that a set of unrelated sectors in a region dampen unemployment shocks, as the effects will not be felt throughout each sector. However, while a number of follow-up studies have confirmed the initial hypothesis on related variety, far fewer studies have adequately answered the question of unrelated variety (Content and Freknen, 2016). In their Pan-European study Caragliu *et al*. (2016) found a positive and significant effect of unrelated

variety on employment growth, however, this study has been criticized because the authors defined unrelated variety as the entropy measure at the one-digit industry level. Further research by Bishop and Gripaios (2010), suggest that impacts of related and unrelated might be sector specific with considerable heterogeneity across sectors.

Despite the fact that research supporting the unrelated variety or unrelated diversification thesis is scarce, it is becoming possible to identify some key trends (Boschma and Frenken, 2011). In their study on technological breakthroughs in the US, Castoldi *et al.,* (2015) argue that breakthrough innovations are fundamentally different that innovation in general and therefore require a separate framework of analysis. Technological breakthroughs benefit more from unrelated variety as these types of innovation depend more on technological variety and the recombination of different types of knowledge. Here, regions characterized by a high degree of Jacobs' externalities are seen to be more conducive to unrelated diversification as innovation is essentially a recombinant process. Extending this analysis to include the role institutions, Boschma and Capone (2015) found that liberal market economies are more likely to diversify into unrelated industries while coordinated market economies are more likely to diversify into new products. Liberal economies can, therefore, be seen to enjoy a greater degree of freedom when attempting to diversify into new (unrelated) industries.

At the same time, there is a stream of ongoing research - primarily in organizational science - demonstrating that a large component of structural change is enacted from outside the region i.e. by non-local actors (Isaksen, 2015) Along these lines, a series of authors have theorized that an upper echelon exists, limiting the extent to which a single firm or even a single industry can generate all the knowledge required internally (Boschma and Frenken, 2009). Here, the literature on Foreign Direct Investment (*FDI*) has some potential insights particularly in relation to technology transfer through new subsidiaries. Influential in this line of enquiry has been the early work of Almeida and Phene (2000) who have found that foreign subsidiaries have the unique ability to access skills and resources from multiple distinctive networks. In a more of an evolutionary context Neffke and colleagues (2016) found that structural change primarily originates via unrelated diversification, through new establishments and especially those with non-local roots. Although the unrelated diversification framework remains fragmented at best (Boschma, 2016), there has been a series of notable advances not least in relation to economic geographies renewed interest in recombinant innovation (Fleming, 2001).

Recombinant innovation refers to the way that old ideas can be reconfigured in new ways to make new ideas (Weitzman, 1998). Thus far in the literature, it is commonplace to assume that related diversification is the rule, and unrelated diversification is the exception (Isaksen and Trippl, 2014). In saying that, the writings of unrelated diversification should not be overlooked as it has the capacity to address a number of issues beyond the reach of related diversification, not least when one considers knowledge recombination and radical technological change. The issue is that while related diversification is said to induce incremental innovation via learning from firms in their own industry. Unrelated diversification, by virtue of combining distant pieces of knowledge, is said to forge radical changing in the techno-economic paradigm of regions through creating entirely new industries.

In a geographic context, unrelated diversification can be seen to open up a number of unique insights into the geography of path creation. Indeed, while numerous studies invoke notions of path dependence (David, 1994), far fewer studies attempt to engage with the related phenomenon of path creation and how new paths came to light (Martin and Sunley, 2007; 2010). Garud and Karnøe (2001) have argued that, while entrepreneurs are embedded in economic paths they are not completely constrained by them. As such, purposeful actions by economic agents to bridge a divide or bring together previously distance technologies can result in the creation of a new industrial path for a region. Within the economic geography and business

management literature, there are a number of re-combinatory / breakthrough industries, the most salaient example of this is being the development of the US automobile industry. Rather than creating an entirely new industry from scratch, the automobile industry was an amalgamation of two separate but well-established industries; the stage coach and the mechanical engine (Klepper, 2007). Along the same lines, Tanner (2014), examined the evolution of the fuel cell industry across Europe. The findings provide additional support to the recombination innovation thesis namely that, the higher variety of fuel cell related technologies present in a region, the more likely that region was to branch out into fuel cell technologies due to increased recombination potential.

In spite of its perceived predictive ability (Boschma and Frenken, 2011), there are some who remain critical towards the relatedness framework, due to issues of measurement and identification (Tanner, 2014), and geographical limitations (Neffke and Henning, 2013). As such, while the relatedness framework has the potential to be a great many things, it is not yet a unified theory and the tendency to treat it like one is hampering future progress. Of particular importance, the literature has identified two caveats that require more scholarly engagement to determine *if* and *how* relatedness varies over time and by region. A fundamental question here is, does relatedness remain constant throughout space? Throughout the literature, the issues of symmetry and complementarity are continuously shied away from. In terms symmetry, relatedness automatically assumes that technology A is as related to technology B as much as technology B is to technology A, while in reality this may not be the case (Boschma, 2016). Similarly, there are geographic connotations to these arguments, insofar as technology A and B might be related in region C, but the same technologies might be unrelated in region D. To date there has been no systematic evidence to this effect.

Additionally, the role of institutions has seldom been discussed in relation to regional diversification. Institutions play a pivotal role in the creation, diffusion and regulation of knowledge flows and their importance has long been discussed throughout economics in general (Storper and Walker, 1989; Martin, 2000; Boschma and Frenken, 2009). Early engagements by Stephen Klepper into the role of spinoff firms and entrepreneurs would be a fertile starting ground for these discussions, albeit his writings did not consider the socio-economic importance of other actors or the importance of the local environment (Boschma, 2016). In their seminal piece on Silicon Valley, Moore and Davis (2001) discuss the interplay between firm diversification and institutional (organizational) management. Moreover, what they found to be most important for Silicon Valley's success were leadership and management. They hail the development of the 'Technologist Manager' as the main reason why Silicon Valley has managed to rejuvenate their knowledge base throughout the decades, while other regions have stagnated and declined (see also Saxanian, 1994). Most importantly Moore and Davis (2001, p. 7) found that:

> *The methodologies of laboratory organization of science don't tell you how to manage independent minds, how to divide people into jobs and tasks, or how to organize a workplace or market strategy… that this process of firm-building lies at the heart of understanding regions like Silicon Valley. Those individuals that possess both technical insight and business capability – the technologist managers – are the firm builders who do the hard work of making viable enterprises out of science.*

While the successes of Silicon Valley stretch far beyond a supportive institutional environment, its teachings yield important insights for regional diversification. Nowadays, the industrial composition of regions - firms, workers and institutions- and the allocation of resources - human and monetary capital - all rank high on the political agenda. Therefore, it is not by accident that the literature regional diversification is increasingly been tied up with the European Union's cohesion policy (Brandsma *et al.,* 2015) and its strategies on smart specialization (McCann and Ortega-Argilees, 2016).

Before concluding, we think it is important to highlight what we consider to be the greatest limitations to the relatedness framework in terms of its theoretical scope and methodological underpinnings. Theoretically speaking, it is difficult to say that relatedness is a global phenomenon when it has yet to be analyzed globally. So far, the study by Hidalgo *et al*., (2007) - which is considered the benchmark study for the relatedness methodology - is the only paper that has analyzed these diversification patterns on a global level. The issue here is that, due to its crude measurement of relatedness this approach has been subject to mounting levels of criticism (Tanner, 2014; Boschma, 2016). By in large, economic geographers have analyzed the diversification patterns of regions for which we have the available data, which happen to be Westernized developed economies. As a result of this, the geography specific nature of relatedness remains largely unclear. There is a gap in our understanding of how the political/institutional framework or the territory specific factors of the Global South or less developed economies would impact the treatment of relatedness.

At the same time, there is also a number of sector-specific limitations given that we have only examined those industries for which there is an availability of data *i.e*., manufacturing and knowledge intensive sectors. Our understanding of relatedness for sectors beyond manufacturing remains unclear. One particular claim is that, despite the increased global importance of services and financial based sectors, the diversification patterns of these industries has yet to be studied in a systematic way.

Methodologically speaking, it is somewhat ironic that the greatest strength of the relatedness framework has also proven to be its greatest weakness. The increased digitalization of data and the ability to accurately capture distance between technologies has opened up a plethora of future research direction. In spite of this, what is arguably most needed in the regional diversification literature is not more quantitative analysis, but qualitative analysis? Qualitative or mixed method methodologies have long been recognized as a stable methodology in economic geography, but for whatever reason has not been incorporated into the study of regional diversification and technological relatedness. This shortcoming is particularly worrisome given that a more qualitative approach would address a number of the criticisms. At the same time, this methodological problem could, in fact, be more systemic insofar as, there is a tendency among economic geographers not to pool resources and target specific questions, *i.e*. combine quantitative and qualitative methodologies to answer questions beyond that of a single methodology.

CONCLUSION

As is often the case in research, what you find when you open up one black box is another black box inside of it, and the relatedness framework has proven to be no different. Indeed, while the relatedness framework has the capacity to be a great many things, it is not yet a unified theory and therefore requires a great deal more engagement and scrutiny. As such, the purpose of this paper was to make a number of much-needed advances in this direction, by providing the first systematic overview of the literature of relatedness and regional diversification. Although still in its infancy, we argue that the emerging concept of relatedness lies at the heart of regional diversification and economic growth and therefore can be seen to show promise not least in terms of, economic geography, regional studies, and network theory. Against this backdrop, our arguments have been organized around four pillars.

To start with, this paper realigned longstanding theories of agglomeration economies with more modern concepts of evolutionary economic geography and regional science. In doing so, we have moved beyond analyzing regions in terms of absolute values in industrial concentration, to considering *distance* between economic agents as a key factor behind regional development. Particularly important in this regard has been work of Frenken and colleagues (2007) and the adoption of the related variety thesis. Accordingly, what is most important to economic growth and regional diversification, is not variety *per se*, but a measure of related variety as not all technologies - types of knowledge - can be meaningfully combined.

Along these lines, while space can refer to the physical distance or geographical proximity between two entities; distance refers to the cognitive distance between two technologies from which potentially new economic knowledge is created. If knowledge exchange is constrained by technological, geographical, institutional and social barriers, then we except a set of related technologies be more conducive to economic growth than a set of unrelated technologies. With the development of more sophisticated and novel databases, economists and geographers have begun to capture these measures of cognitive proximity (distance) through information on; hierarchy classification orders (Frenken *et al.,* 2007), co-occurrence (Hidalgo *et al*., 2007; Neffke *et al*., 2011; Kogler *et al*., 2013) and resource similarity (Breschi *et al.,* 2003; Essletzibchler, 2015).

Stemming from these distance metrics, a number of relatedness networks have been developed to capture the structural branching capabilities of products, industries and technologies. While these branching capabilities where first capture by Hidalgo *et al.,* (2007) in their study on the *product space,* it has since then been adapted both methodologically and contextually to analysis the branching capabilities of regions (Neffke et al., (2011), technologies (Kogler et al., 2013) and skills (Neffke and Henning, 2013). Following an evolutionary logic, these studies broadly confirm the initial branching hypothesis, *i.e*. that economic agents branch out into the respective areas that they are cognitively closer to. As such studies such as these can be seen to hold important theoretical and empirical insights into the evolutionary patterns of regions, a question that warrants much more investigation in the future.

Finally, on the point of future research, this paper would argue that the concept of relatedness and regional diversification has the capacity to continue fuelling debates of regional studies in three particular areas which have not yet been sufficiently tackled. Firstly, while it is fair to say that related diversification is the rule, and unrelated diversification is the exception. There is a growing need to consider unrelated diversification, as unrelated diversification can be seen to lie at the heart of radical new grow paths and the emergence of new technologies. Out of these concerns, the second strain of literature has begun to focus on the idea of recombination innovation. In terms of the branching capabilities of firms and regions, a key question here has been in terms of symmetry and asymmetry and in particular at understanding what types of technologies can be meaningfully combined. While initial discussions in this direction have yielded some interesting and fruitful finding (see: Tanner 2014) more research is still needed in this direction. Finally, while the literature of economic geographer has recently tried to align itself with policy doctrines most notably in the form of the smart specialisation thesis. Our attempts at providing any systematic evidence have been at best lacklustre. Here commentators have pointed towards a lack of theoretical clarity and empirical clarity which makes it difficult to implement on regional bases.

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