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On inter-industry relatedness and regional economic development

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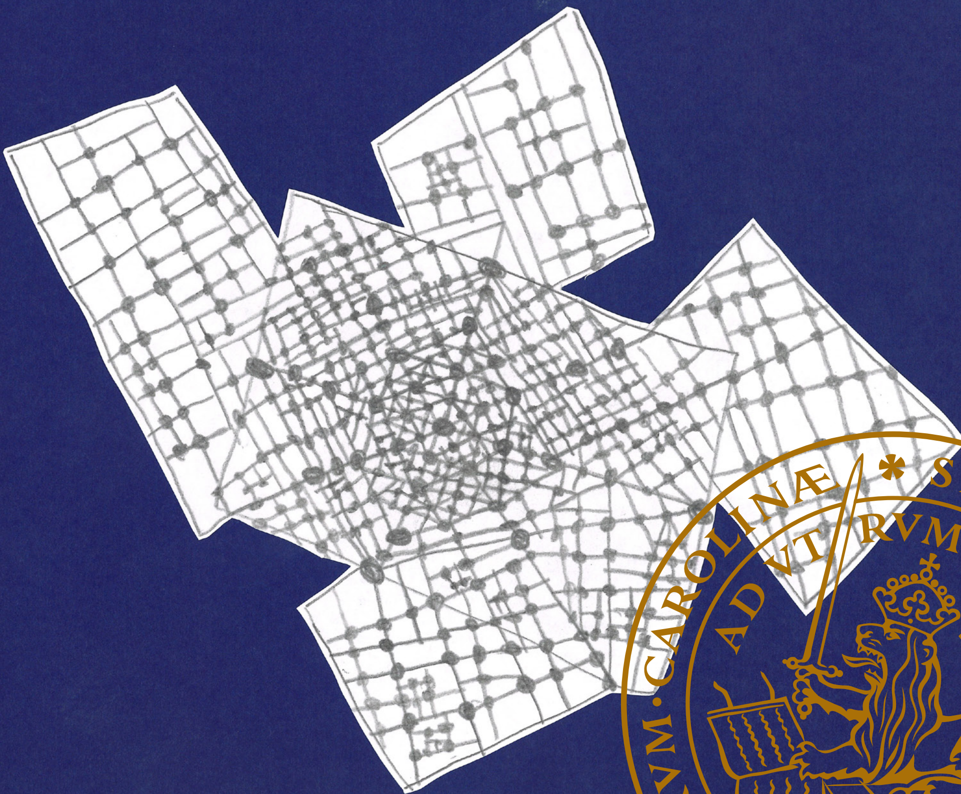

On inter-industry relatedness and regional economic development

Kadri Kuusk

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DOCTORAL DISSERTATION

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Abstract

The dissertation aims to advance our understanding about the role of local industry structure in regional economic development. More specifically, it investigates how relatedness between local industries (i.e. similarities in what kind of knowledge industries use) contributes to and constrains regional economic development. Empirically, the dissertation investigates Swedish regional development in 1991-2010.

Inter-industry relatedness is a key concept in evolutionary economic geography and has a prominent role in narratives explaining the evolution of regional economies. The diversity of local industries and relatedness between them serve as sources of feedback and path dependencies that mould regional development trajectories. It is widely accepted that firms benefit from the local presence of other firms in related industries and such local related variety increases regional employment growth. Often these growth benefits are assumed to be 'in the air' or in local 'buzz' taking the form of pure knowledge spillovers via unintended interactions between individuals. The dissertation argues that the role of market-mediated knowledge flow channels like labour mobility is underestimated.

Economic diversification is a major source of dynamics in regions. Researchers and policymakers increasingly recognise that existing industrial structure and local capabilities condition which new activities will be feasible to develop in regions. This is supported by empirical studies showing that regions tend to diversify into activities that are related to their current industry mix. For example, regions manufacturing cars are more likely to start producing motorcycles than tennis rackets. The dissertation demonstrates that regions' potential for such related diversification has an inverted U-shaped relationship with regional size. The highest potential is in large and medium-sized regions, while core regions have few related diversification opportunities since they already host most industries. Actual diversification events are largely in line with the potential – fewer new related industries enter small and core regions than medium-sized and large regions. The dissertation also proposes a framework that connects various regional development paths (ranging from path shifting to path creation) to the features of local industrial structure that supports these paths (e.g. related variety, related diversification potential) and to the mechanisms associated the paths (e.g. incremental innovation, entrepreneurial cost discovery).

Finally, the dissertation challenges the current static view of relatedness and demonstrates that relatedness is a dynamic phenomenon. Furthermore, growth impact of emerging, stable and disappearing relatedness linkages varies by regional type. Relatedness ties have a 'best before date' and over time deplete their potential to generate inter-industry knowledge spillovers and stimulate innovation. At a more general level, the dissertation calls for studying the role and evolution of inter-industry relatedness as part of broader structural change processes.

Key words
Economic geography, relatedness, regional economic development, structural change, agglomeration economies, knowledge spillovers, labour mobility, path development, Sweden, innovation, economic growth, related variety, related diversification, regional growth, evolutionary economics, labour market

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The beginnings of important journeys often lay in the past and the future meaning of these events can only be grasped in retrospect. As for this one, it could be traced back to one snowy winter day in 2002 in Ann Arbor, Michigan, when my thoughtful roommate Thede Loder bought me Waldrop's book *Complexity* as he was leaving for Christmas break. Sure enough, I was hooked. But it took 10 years, another round of master studies in Lund and hearing again the terms emergence, scale and complexity for me to find my way into economic geography.

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Kadri

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1 Introduction

The general point of departure of this thesis is the curiosity in why some regions grow faster and enjoy higher levels of development than others, and why these differences persist over time. The relatively age-old topic is still actively debated among geographers, economists and policymakers alike. A recent wave of increasing polarisation between regions in many developed countries has ignited political discontent (Rodríguez-Pose, 2018; Storper, 2018) and brought these issues on top of the research and policy agenda once again. This makes fresh takes on theoretical understanding and practical policy advice on regional economic development highly welcomed.

Traditional models of long-term economic development typically consider how aggregate inputs like capital and labour are converted into aggregate economic output. With the rise of endogenous growth theory in the early 1990s[1], the emphasis has been on one input – knowledge – and the role its accumulation via learning and innovation plays in generating growth (Lucas, 1988; Romer, 1986). Accordingly, disparities in economic performance are considered to be caused by the differences in local knowledge, innovation capabilities and activities, and the increasing returns they generate.

From a spatial perspective, these increasing returns due to better abilities to generate, acquire and make use of knowledge in some regions are related to agglomeration economies – the benefits firms get from locating close to each other. Hence, the main interest in disciplines focusing on spatial patterns has been the interplay between agglomeration, innovation and economic development. Indeed, these ideas have a long pedigree in those disciplines (McCann & Van Oort, 2019). Various traditions in economic geography, regional studies and urban economics have produced an impressive body of work, and since the pioneering works of Marshall (1920) and Jacobs (1969)

[1] In regional science there was an increased focus on endogenous factors that emphasised the role of local context, especially technological externalities, already in the 1970s (Capello, 2009).

agglomeration economies carry the lion's share among the factors explaining economic fortunes of regions.

Since the 2000s, the academic discussion in economic geography has seen a revitalised interest in the topic of agglomeration benefits. However, instead of focusing on pure size of agglomerations and aggregate economic inputs, the evolutionary turn in the field (Boschma & Martin, 2010) has brought a growing interest in the structure of regional economies and heterogeneous nature of economic inputs. Arguably, the composition of regional portfolio in terms of specific economic activities (e.g. industries) gives a more accurate picture of its current economy and future development potential than single figures about regional size and aggregate input levels.[2] This has stimulated a new, rich body of mostly empirical research focusing on the concepts of *related variety* (Frenken, Van Oort & Verburg, 2007) and *related diversification* (Boschma & Frenken, 2011; Frenken & Boschma, 2007) in explaining regional economic development.

This strand of research falls under broad umbrella of evolutionary economic geography (EEG) and revolves around the key concept of *relatedness* that is used to represent similarities and complementarities between industries. This dissertation aims to contribute to this still relatively new body of work in EEG, but in doing so touches also upon the classical issues of agglomeration economies and the role of regional context in economic development.

The dissertation first takes on the relatedness concept itself. Inter-industry relatedness has over the past decade been applied enthusiastically in explaining the evolution of regional economies (see literature review by Content & Frenken, 2016). It can be visualised as a network of industry classes linked based on how related they are to each other.[3] For example, manufacturing of cars is more likely linked in this network to motorcycle production, than to making tennis rackets because the first two industries use similar knowledge. While there have been great advances in techniques to measure inter-industry relatedness, the conceptual maturity is still to be attained. Beyond suggestions of new indicators (e.g. skill relatedness, occupational relatedness etc.), the underlying definition of which industries are related is rarely questioned. Amongst the authors who recently have started to engage with these issues, has multi-dimensionality aspect of relatedness received the most attention (Boschma, 2017). At the same time, discussion on relatedness' connection to

[2] This is not to argue that 'doing many things is more important than doing the right thing(s)'.

[3] Such network is usually called *industry space*.

similarity and complementarity[4], and on dynamic aspect of relatedness is almost lacking.

Concerning the latter, it has been speculated already a while ago that relatedness is dynamic (Boschma, 2017; Boschma & Frenken, 2011; Castaldi, Frenken & Los, 2015; Desrochers & Leppälä, 2011), but so far empirical work has used relatedness as a static measure. The two notable exceptions are Kogler, Essletzbichler and Rigby (2017)[5] on patents and Hidalgo (2009) on export products which both find that density of relatedness network increases over time, but relatedness dynamics is not the main focus of these studies.

The static view becomes problematic when one studies long-term economic development. In long-term context, knowledge and resource-use profiles of industries change and together with that changes also relatedness between industries. Thus, the dissertation argues that in these cases it is important to regard relatedness as dynamic and view it as co-evolving with general economic processes (Kuusk & Martynovich, 2021). The dissertation investigates empirically the dynamics of relatedness network and its consequences to regional economies. The results suggest that applying a dynamic view of relatedness can contribute to a more nuanced understanding of its role in regional economic development.

Next, the dissertation engages with both main strands of EEG that apply relatedness concept in describing regional economic development – literatures on related variety and on regional diversification.

A key premise in EEG is that (knowledge) variety at local level is central to the beneficial feedback mechanisms and path dependencies defining regional economic development patterns (Frenken & Boschma, 2007). Frenken et al. (2007) argue in their seminal article that not any local diversity, but regional presence of industries with related knowledge profiles – *related variety* – is best for triggering these positive feedback mechanisms since it facilitates knowledge spillovers[6] between industries and local learning. Currently, the growth benefits of regional related variety is a dominating view in academic literature and in policy circles.

[4] Respective discussion exists in strategic management literature (e.g. Lüthge, 2020; Weiss, 2016).

[5] I would like to thank David Rigby for pointing out this reference.

[6] Beneficial exchange of ideas between individuals.

Empirical findings are, however, still inconclusive (Content & Frenken, 2016). Benefits from related variety differ by industries (Bishop & Gripaios, 2010; Hartog, Boschma & Sotarauta, 2012) and regional types (Firgo & Mayerhofer, 2018; Kuusk & Martynovich, 2021; van Oort, de Geus & Dogaru, 2015). Therefore, one can only support the call for a more context-sensitive re-theorisation of related variety (Gong & Hassink, 2020). The dissertation contends that such re-theorisation(s) should pay close attention to specific mechanisms (learning, matching, sharing) and channels (e.g. local buzz, labour flow, cooperation between firms) that convert related variety into improved regional performance in various regional contexts. More specifically, it demonstrates that market-mediated channels (like labour flows) play a larger role than is usually assumed (Kuusk, 2021).

Empirical evidence on the role of relatedness in regional diversification process is more solid. Most studies find that related diversification – entry of related industries into regional portfolio – is more likely than unrelated diversification (Alonso & Martín, 2019; Antonietti & Boschma, 2020; Boschma, Balland & Kogler, 2014; Boschma & Capone, 2015; Coniglio et al., 2018; Cortinovis et al., 2017; Neffke, Henning & Boschma, 2011; Xiao, Boschma & Andersson, 2018). For example, car producing regions are more likely to start making motorcycles than tennis rackets. With the focus on probability of entry and exit of industries, regional level studies have not assessed the overall potential for related diversification that various regions have. At country level, Hidalgo et al. (2007) argue that diversification options have an inverted U-shaped relationship with income level. Less developed and rich regions both have few related diversification options – the former since they host few industries and that means few potential new industries can be related to their industry mix, and the latter since most industries are already present. Middle-income countries have the best diversification options because they host many industries that are related to several potential new diversification options. The dissertation shows that at a regional level similar inverted U-shaped pattern exists between related diversification potential and population size.

Moreover, the dissertation argues that there is a close connection between local levels of related variety and related diversification potential – if one changes, so will typically the other. Hence, a closer look is taken at this understudied aspect of the relationship between the two. This relationship is discussed in the context of different types of regional development paths that related variety and related diversification potential facilitate (path extension/renewal vs path branching).

Finally, we can expect regions of different type, namely those belonging to different regional hierarchy levels (from core regions to small, peripheral regions), to have distinct capabilities, opportunities and constraints for economic development. Thus, the dissertation focuses on how the role of inter-industry relatedness and composition of local industrial structure varies by regional type.

Empirically, the dissertation investigates the case of Sweden in 1991-2010. During these years, Swedish economy underwent a considerable transformation process – manufacturing employment declined as the economy shifted towards more knowledge-intensive production. This was accompanied by a strong divergence between successful regions and the rest of the country in the first decade, reversing to a more equal growth trajectories only in the 2000s (Henning, Lundquist & Olander, 2016). Despite this catch-up in later years, several small regions still ended up with shrinking employment levels over this period. This broad economic transformation process, characterised by innovation spurts and economic adjustment during boom-and-bust episodes, and the accompanied rebalancing between core and small, peripheral regions, make Sweden an interesting case for studying spatial evolutionary forces.

1.1 Aim and research questions

The aim of this work is to advance our understanding about the role of local industry structure in regional economic development. Introductory discussion argued that in evolutionary economic geography a critical element of such investigations is the diversity of local industries and relatedness between them – these serve as sources of feedback and path dependencies that mould regional development trajectories. The main question driving the research reflects this standpoint: how relatedness between local industries contributes to and constrains regional economic development?

The investigative questions that guide the research are:

- How dynamic is inter-industry relatedness?
- What is the relationship between related variety and economic growth?
- How do regions convert their related variety potential into economic growth?
- How does related diversification potential vary by regional size?

The focus of the research is on how these relationships and patterns vary by regional type – core, large, medium-sized and small regions (see section 3.2 about choice of spatial units and regional levels) – because these regions are expected to have different capabilities, opportunities and constraints for economic development.

By tackling these research questions, the dissertation seeks to contribute to scholarly debate on interplay between agglomeration, innovation and economic development in the following ways:

- It demonstrates that relatedness is a dynamic phenomenon, and the growth impact of emerging, stable and disappearing relatedness linkages varies by regional type. Furthermore, the dissertation argues that relatedness ties have a 'best before date' and over time deplete their potential to generate inter-industry knowledge spillovers and stimulate innovation. At a more general level, it suggests that relatedness network co-evolves with broader economic structures and processes, and calls for studying the role and evolution of inter-industry relatedness as part of broader structural change processes.
- It argues that related variety works through two mechanisms associated with agglomeration economies (namely *learning* and *matching*) (Duranton & Puga, 2004). While earlier studies focused on learning via knowledge spillovers (Frenken et al., 2007), for many less innovation-intensive regions opportunities for resources reallocation via better matching at labour market might be equally if not more important. In addition, the results indicate that the role of market-mediated knowledge flow channels like labour mobility might be underestimated compared to the role of pure knowledge spillovers in generating growth benefits from local related variety. This is especially the case in peripheral regions that are too small for diversity-based development dynamics to emerge (Eriksson & Hansen, 2013). Thus, it resonates with the research that questions the importance of local buzz and emphasises the role of labour mobility (Breschi & Lissoni, 2009; Fitjar & Rodríguez-Pose, 2017; Power & Lundmark, 2004).
- It adds to the empirical evidence that not all regions benefit equally from related variety (Firgo & Mayerhofer, 2018; Hartog et al., 2012; van Oort et al., 2015) and suggests two new explanations. First, nature of relatedness ties (emerging, stable, disappearing) should match regional context to provide growth benefits (e.g. core regions gain

from emerging ties, but small ones from disappearing ones). Second, core and large regions that host knowledge-intensive industries and have advanced innovation systems are able to gain from variety of mechanisms and channels (e.g. labour mobility, cooperation between firms, pure knowledge spillovers), whereas small, peripheral regions benefit mainly from labour flows. More generally, the dissertation suggests that studies on related variety and economic growth should pay more attention to specific mechanisms at work and to regional context.

- It shows that regions' related diversification potential has an inverted U-shaped relationship with regional size – large and medium-sized regions have the highest potential, while core regions have used up most related diversification options. It proposes a framework that connects various regional development paths (ranging from path shifting to path creation) to the features of local industrial structure that supports these paths (e.g. related variety and related diversification potential) and to the mechanisms associated the paths (e.g. incremental innovation, entrepreneurial cost discovery (Rodrik & Hausmann, 2003)).

1.2 Dissertation outline

This dissertation is comprised of three articles and an introductory framing text *kappa*. The objective of kappa is to contextualise and synthesise the articles and to clarify overarching theoretical and methodological approaches of the dissertation. The kappa is written in style of an explanatory stand-alone piece.

The articles included in the dissertation are:

Article 1: Kuusk, K., & Martynovich, M. (2021). Dynamic nature of relatedness, or what kind of related variety for long-term regional growth. *Tijdschrift voor economische en sociale geografie*, 112(1), pp. 81-96.

Article 2: Kuusk, K. (2021). Regional differences in how related variety 'works': the case of labour mobility. *European Planning Studies* (in press).

Article 3: Kuusk, K. Related diversification potential and pattern of Swedish regions in 1993-2008 (an unpublished manuscript).

2 Theoretical points of departure

[The economy is] 'always creating itself, alive and full of messy vitality.'
Arthur (2021)

2.1 Evolutionary perspective on regional economic development

Since the 2000s, economic geography has witnessed an evolutionary turn. This new branch called evolutionary economic geography (EEG) is mainly concerned with how regional economies over time transform themselves from within (Boschma & Martin, 2010). At a more aggregate spatial level, it engages with both sides of these transformation processes – how forces leading to economic change in regions shape the spatial landscape of economies, and how the landscape itself in turn feeds back to influence those forces (Boschma & Martin, 2010). The dissertation engages mainly with the latter aspect.

According to EEG, similarly to endogenous regional growth theories (Acs & Sanders, 2014), the central economic forces in sculpting the development of regions are knowledge creation, innovation and its diffusion. Unlike traditional economic development models, knowledge is not thought of in terms of a simple production factor, but rather something that is in constant change, in creation (Boschma & Martin, 2010). This leads to the view of a dynamic economy that is 'always creating itself, alive and full of messy vitality' (Arthur, 2021).

The paradigm of EEG has not condensed into one coherent over-arching theory. Rather it is a diverse collage of ideas. This can partly be explained by the diversity of its roots – it borrows from and builds on three theoretical approaches: evolutionary biology/generalised darwinism, complex adaptive systems and path dependence ideas (Essletzbichler & Rigby, 2010; Kogler, 2015). Each of these approaches dominates explanations in one of the key themes in EEG: what shapes the spatial dimension of novelty creation, how spatial structures of economy emerge from micro-behaviour of economic agents, and how processes of path creation and dependence interact to create spatial landscape of economy (Boschma & Martin, 2007).

The prevalent approach has been generalised darwinism which is the basis for studying what shapes spatial dimension of novelty creation. From economic point of view, it is the novelty converted into *innovations* – ideas applied in practice and having economic or social significance (Schumpeter, 1961) – that is of interest. Typically, research distinguishes between the introduction of new product or service (*product innovation*), and new methods of production (*process innovation*) (Fagerberg, 2006). For the former, another important distinction is made between incremental innovations, which are continuous improvements of previous innovations, and radical innovations which introduce a totally new type of technology (Fagerberg, 2006).[7] All these innovations are mostly 'new combinations' of existing knowledge (Schumpeter, 1961). This combinatory nature of innovations emphasises the role of variety, selection and continuity – the key concepts of evolutionary thinking (Nelson & Winter, 1982).

Variety[8] – heterogeneity of agents, strategies, products, technologies etc. in population – is continuously created by a trial-and-error, or search, process (March, 1991; Simon, 1991). Search tends to be local – to occur in low uncertainty and low effort areas that tend to be cognitively similar – implying that improvements are small and incremental (Boschma & Martin, 2010). EEG has introduced the concept of *relatedness* – similarity (and complementarity) between knowledge profile of activities – that captures the cognitive dimension of localness in search and in other economic processes. Hence, variety of related knowledge in region is a more likely source of innovations than just any knowledge diversity (Frenken et al., 2007). Only when local search is unsuccessful or combinatory potential is depleted, are firms more likely to switch to more explorative search mode (March, 1991). Furthermore, firms are often assumed to engage in search or imitation behaviour only if they do not enjoy sufficient profits or during crisis (Boschma & Martin, 2010). However, it is more likely that most imagining about the growth opportunities is done before any crisis arrives, via routinised search activities (Dopfer, Foster & Potts, 2004).

[7] Most innovation research focuses on these two innovation classifications. The reason is that these innovation types are assumed have different social and economic impact.

[8] Terms *diversity* and *variety* are used interchangeably in this dissertation.

The created variety (new ideas, products) is then exposed to *selection* processes that reduce existing diversity. The selection is determined by the interaction between entrepreneurial competences and contextual factors (Lambooy, 2002). It rewards the firms that are best adapted to the current conditions leading to survival of the sufficiently fit (Essletzbichler, 2015; van den Bergh, 2004).

Turning to the idea of *continuity* and 'memory', the evolutionary theory emphasises the cumulative nature of knowledge which to a great extent accumulates via learning-by-doing at firm level. This knowledge is embodied in individuals (e.g. skills) and firms (organisational routines) (Nelson & Winter, 1982). The latter are the building blocks of the most cited work of evolutionary theory by Nelson & Winter (1982). Routines are the equivalent of genes in modern theory of evolution in biology and consist of 'more or less standardised work processes embedded in organisations and firms' (Lambooy, 2002:1021). In each period, current and new generations of actors inherit the routines from older generation of previous period by replication via reproducing or copying which leads to the diffusion of the routines in the economy. This means the routines serve as the sources of cumulative processes, creating the continuity. This strand of EEG views economic landscape as a spatial distribution of routines over time (Boschma & Frenken, 2006). According to the proponents of generalised darwinism, spatial agglomerations arise from historically developed concentration of knowledge embedded in organisational routines (Boschma & Frenken, 2006).

The second approach – complex adaptive systems – emphasises instead of selection mechanism the idea of *emergence* of self-organised order via agents interacting with each other and with the environment. While complex systems ideas have not been as visible in EEG as generalised darwinism, there is potential for great contributions from studying multi-scalar operation of economy where spatially emergent and spatially embedded meso-level systems (e.g. agglomerations, institutions etc.) feed back into both macro- and micro-level (Martin & Sunley, 2010).

The nature of such feedback mechanisms related to emergence can be of three kinds (Deacon, 2008; Martin & Sunley, 2012). In first-order emergence micro-level actions lead to emergence of macro-level patterns, but these do not provide feedback to micro-level. In second-order emergence self-organising structures are amplified at macro-level which through feedback further amplifies micro-level patterns, essentially creating a lock-in. Emergence of a cluster of firms that are influenced by cluster-level properties, and which keeps attracting more firms is an appropriate example. In third-order emergence micro-level agents selectively sample macro-level's downward influences, and thereby create heterogeneity and divergence in the system. The dependence on memory and selection creates a complex pattern of continuity, ongoing adaptation and mutation. The changes in macro-level patterns do not simply add up or converge to a pre-determined state, but rather represent 'constant formation and reformation' (Martin & Sunley, 2012:349). Such economic landscapes are both historically organised, but also unpredictable.

These ideas are highly relevant to the discussions in this dissertation. For example, it is suggested to interpret the central EEG concept of relatedness as an emergent phenomenon (Ingstrup & Menzel, 2019). In this view, relatedness between industries emerges and is upheld through interactions between firms as a bottom-up process. It forms a semi-stable meso-level system that feeds back into the actions of the same firms (e.g. by redirecting their search activities towards related industries and routinising them), but also influences macro-level economic processes (for example, by supporting the birth of a strong wind-turbine industry in Denmark as described by Ingstrup and Menzel (2019)). Hence, it is a third-order emergence.

The third approach – path dependency literature – has been more successful in establishing its foothold in EEG. Its core argument is that development trajectories of firms, regions and industries are constrained by the historical processes that created them and take place in specific local environment (Boschma & Frenken, 2006; David, 1985; Martin & Sunley, 2010). The past and the place are seen as conditioning factors of development with spatial outcomes remaining probabilistic rather than determined. And since there is no final pre-determined outcome, the future unfolds and is created through the actions (both purposive and accidental) of agents at various scales. There has indeed recently been an increasing interest in the role of agency in shaping regional development paths (Grillitsch & Sotarauta, 2020), even though EEG remains still focused on regional economic structures. Compared to the other two approaches, path dependency literature has also paid more attention to institutions and their role in conditioning path development.

A major contribution of path dependency approach to EEG literature is development of micro-foundations for how firm, and thereby also regional, diversification into new activities is related to its existing activities and knowledge base (Boschma & Frenken, 2011). Empirical evidence supports this view of regional diversification as a stylised and path dependent, and not a random phenomenon as assumed in traditional growth theories (Whittle & Kogler, 2020) – most empirical research finds that related diversification is much more likely than unrelated (Content & Frenken, 2016).

To sum up, EEG has made important contributions to our understanding of how regional economies over time transform themselves relying mainly on recombination and gradual reallocation of their local resources, and hence advancing in a path dependent manner. However, there is still lots of potential to advance and deepen these theories, especially through combining insights from the three main approaches – general darwinism, path dependency and complex adaptive system – which so far have focused each on their own specific research questions. The dissertation makes use of ideas from all three approaches – e.g. variety, emergence of structures like agglomerations and feedback between micro-meso-macro-levels, and continuity and change in regional path development.

2.2 Agglomeration economies

There is a long tradition of literature in economic geography addressing the topic of agglomeration externalities – the benefits[9] that firms obtain by locating near each other – and their impact on regional economic growth. One key question is what kind of firms, or more generally what kind of industries, benefit more from each other's presence. Some authors (Marshall, Glaeser) advocate for specialisation as a source for productivity gains and knowledge diffusion, while others (Jacobs, Henderson, Weitzman) hold that diversified industry structure is beneficial for emergence of innovations and hence also for economic development.

Benefits from specialisation, typically defined as nearby firms in the same industry[10], are called localisation externalities. Marshall (1920) was the first to draw attention to this phenomenon when he argued that labour market pooling, input sharing and information/knowledge spillovers can benefit firms located close to each other in industrial districts. These ideas were later formalised by Arrow (1962) and Romer (1986). As a result, these positive externalities

[9] Agglomeration can also have negative externalities (e.g. congestion costs), but these are not the focus of the dissertation.

[10] In empirical studies specialisation is typically defined as co-location of firms from the same industry which is often defined by 3-or-4-digit industry code. However, some critical voices argue that specialisation should rather be understood as a broader concept than just a set of firms from one narrow industry classification class and should include industries that are related to each other for example through input-output linkages or by some other relationship involving their economic activities (Grillitsch, Asheim & Trippl, 2018; Kemeny & Storper, 2015).

associated with specialisation have become commonly known as Marshall-Arrow-Romer- or MAR-externalities. These externalities are expected to facilitate local development through improving productivity by lowering costs and through supporting innovation via knowledge spillovers.

Proponents of the benefits of diversified industrial structure emphasise the value of economies of scope (i.e. efficiencies from diversity) and potential for knowledge combination. They build on work of Jane Jacobs by whose name the positive externalities arising from co-location of different sectors are also known today – Jacobs externalities (Jacobs, 1969). The common hypothesis is that regions benefit from variety in their industry mix because it offers higher potential for inter-industry knowledge spillovers. These, in turn, support innovation and lead to higher (employment) growth.

These potential local externalities can be converted into improved economic performance through various channels like labour mobility, cooperation between firms, social and professional networks, chance encounters etc. Such channels remain underexplored in most empirical studies which lean towards assuming that the externalities are *in the air* (Marshall, 1920) or in local *buzz* (Storper & Venables, 2004), and take the form of pure knowledge spillovers.[11] However, knowledge flows can also be transaction-based flows (e.g. inter-firm collaborations) or market-mediated spillovers (e.g. labour mobility) (Johansson, 2005). The role of market-mediated spillovers (like labour flows) is often underestimated (Breschi & Lissoni, 2001; McCann & Simonen, 2005).

Duranton and Puga (2004) take a different angle on agglomeration economies and advance our understanding by focusing on mechanisms behind these benefits. They identify three main mechanisms: sharing (e.g. sharing indivisible facilities, sharing gains from variety of local input suppliers or narrow own specialisation, sharing risks), matching (e.g. improving the expected quality, probability and timeliness of matches, for example between employers and job seekers on labour markets) and learning (i.e. gains via generation, diffusion and accumulation of knowledge).

They do not focus on specialisation or diversity per se, but rather link agglomeration economies to the size of region.[12] However, they also point out that heterogeneity of actors is key to most if not all of these mechanisms. This

[11] These can happen through professional and social networks, chance encounters, information buzz etc.

[12] These are known as *urbanisation economies* (Hoover, 1937).

links their work to the regional industrial specialisation-relatedness-diversity debate.

Active debate on the topic of specialisation vs diversity started in the early 1990s with the seminal works Glaeser et al. (1992) and Henderson, Kuncoro and Turner (1995), but despite ample empirical studies has not reached conclusive results (Beaudry & Schiffauerova, 2009; de Groot, Poot & Smit, 2016). A recent comprehensive review concluded that there are almost as many studies that find support to specialisation hypothesis as those that do not (de Groot et al., 2016). And while there tends to be more evidence on Jacobs externalities there are still many studies with the opposite results and numerous studies produce insignificant results.

Hence, the academic debate on whether specialisation or diversification is beneficial to economic performance remains lively and unresolved (Content & Frenken, 2016). Or as Kemeny and Storper (2015) point out the question is perhaps ill-placed: the search could be in vain since this dichotomisation is not in correspondence with what we see happening in the economy and with the broader picture of how regional system as a whole functions. Instead, they suggest that both diversified and specialised industrial structures could be beneficial, but in different time periods, for different regions etc.. There have been also other calls to stop overlooking the systemic nature of how regions influence each other and the impact of general developments in the economy (Henning et al., 2016).

2.3 Relatedness

Relatedness has acquired a solid place among the key concepts of EEG. It is actively used in empirical research and its measurement has seen several novel improvements in past decade. At the same time, the theoretical unpacking and crystallising of the concept has lagged behind. It is used as a fuzzy term representing both similarities and complementarities between different activities, actors, resources etc. Most users remain open about the exact meaning, others specify it depending on the empirical case at hand. Some scholars even argue that ‘few measurement procedures have been more heavily criticised than those used to capture relatedness’ (Lien & Klein, 2009:1099).

Historical roots of relatedness concept

The concept of relatedness was first employed at firm level – Penrose (1959) suggested that firm growth is a process of related diversification and a few years later Chandler (1962) proposed to use it for assessing the impact of firm's diversification strategies on its performance. The body of work that followed in management literature tested the hypothesis that firms with portfolios of related products perform better than firms undertaking unrelated activities (Ramanujam & Varadarajan, 1989; Rumelt, 1974; Rumelt, 1982; Teece, 1982). The assumption was that the combinations of related activities generate economies of scope (i.e. synergies) in production (Teece, 1982).

Early empirical studies focused on assessing the benefits generated by the similarity of products and markets (Robins & Wiersema, 1995). This approach produced mixed results and was in the 1990s replaced by resource-based view of technological relatedness (Bryce & Winter, 2009). Soon afterwards, some authors started instead referring to knowledge relatedness (Breschi, Lissoni & Malerba, 2003). This seemed a natural development since already by technological relatedness concept it was often not the technology itself that was emphasised, but knowledge and skills about these technologies.[13] However, both concepts remain in use. In essence, both aim to group technologies that 'share a common or complementary knowledge base, rely upon common scientific principles or have similar heuristics of search' (Breschi et al., 2003:70).

Since the 1990s, two parallel strands of literature engage with similar topics to relatedness research. First, research in business studies using concept *absorptive capacity* (Cohen & Levinthal, 1990) – firm's ability to absorb new knowledge – deals implicitly with the connection between relatedness and knowledge diffusion. According to this approach, firm's ability to absorb new knowledge is a function of its prior level of related knowledge. For example, successful collaboration between firms requires its prior technological knowledge to be similar to new knowledge on the basic level, but different to a certain extent on the specialised level. Here basic knowledge means general understanding of a scientific discipline's techniques, whereas specialised knowledge refers to the specific knowledge used by actors in their everyday business activities. Empirical studies indeed find that two organisations with

[13] Term *technological relatedness* is also used to denote various technological production system interdependencies and producer-user relationships (Boschma & Frenken, 2011).

greater technological relatedness in basic knowledge have greater mutual absorptive capacity (Cohen & Levinthal, 1990; Lane & Lubatkin, 1998).

Simultaneously, a second strand of literature on *proximity* and innovation also engaged with similar questions. Its origins are more geographical. Namely, French school of proximity dynamics contributed to innovation literature by arguing that besides geographical proximity other non-spatial dimensions of proximity (i.e. similarity, familiarity) are key for learning and innovation (Gilly & Torre, 2000). In his seminal article Boschma (2005) distinguishes between five forms of proximity (geographical, cognitive, social, organisational and institutional). While this analytical clarification resulted in several empirical studies, introduction of dynamic perspective later on complicated empirical investigations due to linkages between changes in various proximity dimensions (Balland, Boschma & Frenken, 2015). In fact, Ferru and Rallet (2016) argue that the consequent need to simplify the form of non-spatial proximity was the reason behind introduction of relatedness concept. Was it so or not, in its conventional use relatedness does correspond to cognitive proximity. However, some scholars continue using terms proximity or relatedness as broader concepts that cover a range of non-spatial proximity dimensions (e.g. Hidalgo et al., 2007). Unsurprisingly, other researchers applying relatedness concept also recognise that synergy potential between local economic activities can span over other similarity features besides knowledge (e.g. markets, institutions) (Tanner, 2014) and some call for multi-dimensionality of relatedness concept (Boschma, 2017). This would essentially revert the earlier move of narrowing down in dimensions and increase the overlap between the concepts of relatedness and proximity.

Inter-industry relatedness

Literature on regional development predominantly uses indicators that capture relatedness between industries. In the 1990s, rigorous works emerged aimed at measuring the degree of technological relatedness between industries in a quantitative manner. For example, Teece et al. (1994) counted the number of times a combination of two sectors was found at multi-sector firms. Next Farjoun (1994) used occupational data to develop a relatedness indicator by calculating the degree of similarity in human capital of different sectors. The term related was also used to represent vertical trade relationships between industries (e.g. related sectors in cluster literature (Porter, 1990)) whereby relatedness is measured by input-output linkages (Fan & Lang, 2000).

In the 2000s, search for even finer indicators continued resulting in several novel approaches. Hidalgo et al. (2007) developed *product relatedness* indicator measuring the proximity between pairs of products based on the probability that countries export both products. Breschi et al. (2003) measured knowledge relatedness between patent classes by joint classification of individual patents across those classes. Neffke and Henning (2013) developed a *skill relatedness* measure based on labour flows between industry-pairs.

The result has been a multitude of indicators to measure relatedness, but this has not brought clarity in the meaning of the concept. The two key open issues are:

- What dimensions of industry features relatedness encompasses?
- Does it represent similarity, complementarity or both?

Relatedness – one or many dimensions

Relatedness is used in relation to several kinds of industry features (technological, product, skill, market etc.). Moreover, similarly to strategic management literature (Pehrsson, 2006) the multi-dimensional nature of relatedness has become more emphasised (Boschma, 2017) and some researchers argue that all these dimensions (e.g. institutional and market relatedness) are important for regional development (Tanner, 2014). No single measure of relatedness is likely to capture equally all these dimensions (Boschma, 2017). The conventional view, however, continues to interpret relatedness as based on cognitive proximity between industries (Boschma, 2017; Content & Frenken, 2016). Hence, two industries are considered related when they require similar knowledge. To provide focus, the dissertation follows this definition and considers knowledge the core dimension of relatedness. In this context, similarity between institutional framework, or market rules and market access of industries are considered to be in most cases secondary (perhaps sometimes necessary, but not sufficient to provide synergies). Therefore, these are rather regarded as supporting or constraining factors for realising the potential of core (knowledge) relatedness.

Complementarity and similarity

Majority of authors are not clear whether they mean similarity or complementarity by relatedness (Boschma, 2017; Makri, Hitt & Lane, 2010). Most define it as encompassing both. This ambiguity complicates the interpretation of research results, since the concepts represent an opposite relationship between activities. For example, in case of resources and activities at firm level, similarity refers to the degree of shared resource usage in two activities, while complementarity refers to the synergy resulting from combining resources from two (or more) different activities. In the latter case, relatedness arises due to differences and need of joint usage, not due to similarities.

Concerning regional development, the focus in EEG has not been such ‘coordinated complementarity’ of (unrelated) activities at firm level. Instead, the term *complementarity* has been often used in relatedness literature to denote knowledge combination potential between two industries sharing a knowledge base (Frenken et al., 2007). This clearly follows the cognitive proximity (Boschma, 2005; Nooteboom, 2000) and absorptive capacity (Cohen & Levinthal, 1990) arguments that emergence of knowledge spillovers and realisation of complementarity potential require a degree of knowledge similarity between activities. Hence, the dominating feature of relatedness is similarity that in empirical work has served as a proxy for assessing complementarity (potential). For example, studies assessing the impact of related variety on regional innovation level, typically measure relatedness as similarity between industries (and not as complementarity), and then assume that high relatedness implies high complementarity potential between the industries. While recognising the risk of not capturing some interdependencies/complementarities between activities if these are not explicitly assessed by chosen relatedness indicator the dissertation applies the view of relatedness as similarity. Future research on relatedness should aim at disentangling its two facets (Boschma, 2017) since, as explained below, distinguishing between the two is essential in understanding and capturing how relatedness influences regional development.

Two main strands of relatedness literature – on related variety and related diversification – put different emphasis on these two facets of relatedness. Related variety literature focuses on learning through knowledge spillovers that rely on complementarities between industries. Another mechanism for benefits from local related sectors is providing better matching opportunities that facilitate labour reallocation and productivity. These in turn require only similarity between industries. In management literature, a further distinction is made between intra- and inter-temporal similarity (Lüthge, 2020). The latter is called redeployability[14] and represents a possibility to reuse resources for similar (or related) activity in later time, while the former denotes synergies from concurrent sharing of resources by two activities (i.e. economies of scope). For example, labour reallocation represents redeployment of resources.

[14] Helfat and Eisenhardt (2004) refer to the value derived from redeployability as *inter-temporal economies of scope*.

Research on regional diversification (mainly focusing on diversification to new-to-the-region activities) also typically uses relatedness to represent the degree of similarity between two industries. In most cases, one expects these diversifications to represent redeployment of resources, but diversification can also be driven by benefits from sharing of formerly underused resources. Relatedness as complementarity can also induce diversification since vertically linked industries might gain from co-locational synergies. There is a long tradition of theories of local (agglomeration) benefits from this kind of backward and forward linkages in economic geography literature (e.g. Marshall, 1920; Myrdal, 1957; Porter, 1990).

Dynamic nature of relatedness

Linked to the similarity and complementarity debate is the issue that relatedness is a dynamic phenomenon. That relatedness is dynamic has been suggested earlier (Boschma, 2017; Boschma & Frenken, 2011; Castaldi et al., 2015; Desrochers & Leppälä, 2011), but empirical work takes predominantly static perspective. This is surprising since the employed knowledge and other resources – the sources of similarity – change over time.

Several developments can cause the rearrangement of relatedness network.

1. First relates to the diversification of world economy as new industries emerge, others die out. This can be caused either by creation of new technologies changing the very nature of production process changes (this involves combining different bits of knowledge and is innovation-based) or by Smithian specialisation that breaks up production processes of an industry into several new ones (this involves splitting an industry up and can be called specialisation-based) (Saviotti, Pyka & Jun, 2020). The most fundamental reorganisation of the whole relatedness network stems from development of new general purpose technologies that are complementary to many other industries (Bresnahan & Trajtenberg, 1995) and alter the very nature of production processes in large part of the economy.

2. Second, relatedness can change by various forms of broadening of knowledge bases of firms (from search activities to multi-firm cooperation to changes in educational system) (Kuusk & Martynovich, 2021). Central mechanism here is firm-level search activity. Search tends to be local and involve familiar knowledge bases (Fleming, 2001). Once firm exhausts the potential of useful local recombination

> or search is unsuccessful, it changes into an explorative mode which likely includes search in other industries (March, 1991). If inter-industry exploration results in firm-level successful innovation that is of industry-wide interest, then these tend to diffuse to other firms. Widespread diffusion and active knowledge exchange between firms in two industries may lead to emergence of new knowledge similarity, i.e. relatedness (see Ingstrup and Menzel (2019) for an example). Other actors can also lead or coordinate such search activities. For example, Tanner (2014) describes the role of universities in the construction of relatedness.

These developments may result in destruction of established relatedness linkages and emergence of new ones between previously non-existing or unrelated industries. Thereby the whole network of related industries is reorganised. For example, the arrival of information technology led to a rise of many new industries producing equipment using this technology or components for production of such equipment. It is likely that such new industries are related to each other, but also to several old industries that redesign their production process to make use of these new innovations. At the same time, existing relatedness ties between the industries switching to new technology and those relying on older ones, are likely to disappear because the knowledge profiles of these industries diverge. Since relatedness network arises through autonomous and self-reinforcing dynamics at the micro-level it can be considered an emergent semi-stable meso-level property of economy (Ingstrup & Menzel, 2019; Kauffman, 1993).

The same emergent forces simultaneously lead to adjustments in the structure of economic activities at global, national, and regional levels. Thus, in the long-term relatedness network is co-evolving with broader economic structures and processes. However, since most recombination efforts are likely to pick up local maxima from the vast knowledge recombination opportunities landscape (Kauffman, 1993) inter-industry relatedness is necessarily a dynamic phenomenon.

The dynamic nature of relatedness network means its ties have different ages – some are emerging, some on the way to disappear, and some stay stable over long periods (Kuusk & Martynovich, 2021). The nature of these tie types differs fundamentally. For instance, emerging linkages can generate complementarities between industry-pair. However, unless at least one of these industries is dynamic and innovative, continuously updating its knowledge profile, then over time potential for beneficial knowledge spillovers may be depleted (Boschma, 2017). Thus, mature ties may instead merely signify that the industries use similar knowledge. Hence, the capacity of different ties to provide growth benefits at regional level and the mechanism how they do it are not the same. In case of labour flows between related industries, mature and disappearing ties may instead work by facilitating structural adjustment (Frenken et al., 2007) through better matching at labour market (Duranton & Puga, 2004).

To sum up, relatedness concept has been around for some time, but has gotten lots of attention in economic geography in the past 15 years. Its measurement techniques have made great progress during this time, but conceptually clarity is lacking. It is defined as both similarity and complementarity, and used to measure relationships between industries, products, patents, skills etc. This fuzziness makes it hard to synthesise and interpret the cumulative results of studies using the concept. Conventionally, relatedness is used to represent cognitive (or knowledge) similarity between economic activities and the dissertation follows that approach.

2.4 Related variety and regional growth

A key idea in evolutionary economic geography is that benefits from local (knowledge) variety are central to the feedback mechanisms and path dependencies defining regional economic development patterns (Frenken & Boschma, 2007). Frenken et al. (2007) suggested in their seminal article that not any local knowledge diversity, but regional presence of industries with related knowledge profiles – *related variety* – is best to generating knowledge spillovers and local learning that initiate these positive feedback mechanisms.

Frenken et al. (2007) defined related industries as those having similar knowledge base. They argued that the more variety there is across related industries in the region, the more local learning opportunities there exist and knowledge spillovers are more likely to occur. Therefore, they saw the existence of related variety as an indication that region is likely to generate relatively more Jacobs externalities, which leads to innovation and employment growth.

The concept quickly gained popularity and related variety is typically considered beneficial to regional economic performance. Related variety has found to enhance productivity (Boschma & Iammarino, 2009; Bosma, Stam & Schutjens, 2011; Quatraro, 2010), support employment growth (Bishop and Gripaios, 2010; Boschma & Iammarino, 2009; Cortinovis & van Oort, 2015;

Firgo and Mayerhofer, 2018; Frenken et al., 2007; Hartog et al., 2012; Kublina & Fritsch, 2018; van Oort et al., 2015) and value-added growth (Boschma & Iammarino, 2009; Boschma, Minondo & Navarro, 2012), and encourage innovation (Aarstad, Kvitastein & Jakobsen, 2016; Castaldi et al., 2015; Miguelez & Moreno, 2018). Some recent studies demonstrate a positive link between entrepreneurship and related variety (Colombelli, 2016; Content, Frenken & Jordaan, 2019; Ejdemo & Örtqvist, 2020; Kublina & Fritsch, 2018; Tavassoli & Jienwatcharamongkhol, 2016).

However, these effects are not always universal. Benefits from related variety vary by industries (Bishop & Gripaios, 2010; Hartog, Boschma & Sotarauta, 2012; Innocenti & Lazzeretti, 2019) and regional types (Firgo & Mayerhofer, 2018; Kuusk & Martynovich, 2021; van Oort et al., 2015). The relationship is stronger in more knowledge- or technology-intensive industries and regions (Cortinovis & van Oort, 2015; Hartog, Boschma & Sotarauta, 2012). This is expected since more knowledge should spill over between industries that are knowledge-intensive to begin with. It is also in line with the empirical results from earlier studies on agglomeration externalities showing that agglomeration effects are stronger in knowledge- and technology-intensive industries (Henderson, 2003). The evidence is less settled about regional differences – for instance van Oort et al. (2015) show that only regions with smaller cities benefit from related variety while national capitals, while other studies reach the opposite conclusion (Davies & Maré, 2021; Kuusk, 2021).

While initial work on related variety focused exclusively on knowledge spillovers and learning, then more recent work highlights another mechanism how it supports regional development. Namely, in times of crisis and regional renewal related variety provides labour reallocation opportunities for workers from declining sectors (Eriksson & Hane-Weijman, 2017; Eriksson et al., 2016; Hane-Weijman et al., 2018; Jaax, 2016). Although it was initially proposed that unrelated variety provides such portfolio effect protecting regions against adverse external shocks, recent evidence shows that industry-specific shocks do not coincide with relatedness (Diodato & Weterings, 2014; Morkutė et al., 2017). This means, first, related industries are well suited for smoothing regional economic growth patterns. Second, that related variety works also through matching mechanism (Duranton & Puga, 2004).

The rise of other mechanisms besides learning complicates the interpretation of the relationship between related variety and regional growth. On the one hand, the mixed results can at least partly depend on the fact that no standardised research design has yet emerged for studying related variety. Researchers use various relatedness measures (industries, products, exportimport, skills), spatial levels (NUTS2, NUTS3, national, local labour market), methods to draw a line between related and unrelated industries (e.g. using a cut-off value of continuous relatedness indicator instead of industry classification), growth measures (employment, value added, productivity, GDP per capita). Therefore, there is a call to move towards standardised research design to gather comparable data for uncover the historical evidence on the relationship between relatedness and economic growth (Content & Frenken, 2016).

However, a better grasp of related variety's benefits is likely to also require a more context-sensitive re-theorisation of related variety (Gong & Hassink, 2020). Agglomeration externalities literature suggests that these forces differ by sectors and are time dependent for different kind of regional types (see meta-analysis by de Groot et al., 2016). Studies on related variety point in the same direction – that the impact of related variety on economic performance is heterogeneous.

2.5 Regional related diversification

Researchers and policymakers increasingly recognise that existing local capabilities constrain which new economic activities will be feasible to develop in region (Boschma, 2017; Hidalgo et al., 2007). Seminal works behind this view were put forward almost in parallel by Boschma and Frenken (Boschma & Frenken, 2011; Frenken & Boschma, 2007) working on a regional scale and Hidalgo et al. (2007) addressing developments by countries. Both explained how new local and national industries emerge by recombining knowledge and resources from local industries in a path-dependent manner (Frenken & Boschma, 2007; Martin & Sunley, 2010).

Frenken and Boschma (2007) propose the concept of *regional branching* to describe this process. This concept sees regional economic development as a step-by-step evolutionary branching out in relatedness network to new industries which are related to region's current industry mix. It is based on the assumption that products and services from a specific related sector are more likely to share similar characteristics and require similar capabilities for production than products and services from an unrelated sector (Saviotti & Frenken, 2008). Since knowledge needed to diversify into related industry already exists in the country or region, it reduces the costs and risks compared to unrelated diversification. Therefore, related diversifications are more likely and more beneficial (Frenken et al., 2007). For instance, regions manufacturing cars are more likely to start producing motorcycles than growing cacao beans. Related diversification can also be more beneficial to regional economic performance because the region has better matching resources (e.g. knowledge, skills) to succeed in the new related activities, but also via increased innovation potential both in new and old related industries due to inter-industry knowledge spillovers.

Empirical studies indeed find that regions tend to diversify into activities that are related (i.e. require similar knowledge and resources) to their current industry mix (e.g. Alonso & Martín, 2019; Antonietti & Boschma, 2020; Boschma et al., 2014; Essletzbichler, 2015; Neffke, Henning & Boschma, 2011; Rigby, 2015). Related diversification is less likely in high-income countries, in regions with advanced innovation capacity or with more sophisticated production (Coniglio et al., 2018; Galetti et al., 2021; Petralia, Balland & Morrison, 2017; Xiao et al., 2018; Zhu, He & Zhou, 2017). This ability to break away from their past and jump further in relatedness network can be explained by their better general innovation capabilities and by the fact that they have few diversification options. This latter idea was suggested by Hidalgo et al. (2007) who argued that at national level the number of diversification options has an inverted U-shaped relationship with income level – both less developed and the richest countries have fewer related diversification options than middle-income nations. The former since they host fewer industries themselves and that means fewer connections to other industries in relatedness network. The latter since they already host most industries. Middle-income countries, in turn, have the best diversification potential – they tend to host large(r) number of industries which are related to many potential new industries. Similar inverted U-shaped pattern between related diversification potential and regional size is expected to exist at regional level.

Even though the literature has focused on related diversification, have scholars increasingly acknowledged the role of unrelated diversification as a source for new knowledge and new development paths for regions (Grillitsch et al., 2018; Saviotti et al., 2020). They argue that unrelated diversification can allow regions to absorb external shocks in short-run via portfolio effect by spreading risks across industries with different exposure to the shock (Frenken et al., 2007). In addition, unrelated industries can serve as a basis to develop new growth paths in long-run and protect regions against potential lock-in (Grabher, 1993). Hence, both diversification types bring their specific benefits. This has led to a more explicit recognition that new industries might often draw on mixture of both related and unrelated local resources. Accordingly, the binary treatment of diversification as either related or unrelated has received critique (Whittle & Kogler, 2020). As a first step in this new direction, the use of continuous relatedness measure is suggested (Boschma, 2017).

To sum up, regions tend to diversify into industries that are related to their current industry mix. These tend to be less costly and more beneficial to both firms and regions. Empirical studies also find that related diversification is more likely. However, regions have different opportunities for related diversification – core and small regions have few diversification opportunities, while medium-sized and large regions have the highest potential for related diversification. In recent years, the importance of unrelated diversification is becoming more recognised.

3 Data and methodological choices

3.1 Data

The dissertation uses Statistics Sweden's employee and plant level annual data from the Longitudinal Integrated Database for Health Insurance and Labour Market Studies (LISA) for the years 1991–2010. For each individual registered in Sweden the database covers variables about the person (e.g. age, education, place of residence) and her/his main employment (e.g. industry, plant location, wage). Due to the focus on labour market developments, the analysis includes only working age population (16–64-year-olds).

During this period, Statistics Sweden used two industry classifications – SNI92 (for 1991–2001) and SNI02 (for 2002–2010) (Table 1). These Swedish national classifications (SNI) are identical to European Union's NACE classifications (*Nomenclature statistique des Activités économiques dans la Communauté Européenne*) up to the 4-digit level. SNI92 and SNI02 correspond to NACE Revision 1 and 1.1, respectively. The two SNI-classifications were merged at the 5-digit level to ensure consistency over time. As SNI02 introduced only minor changes, an unambiguous conversion was possible. The merged classification was aggregated into 505 4-digit industries, which were included in the analysis.

Table 1. Comparison of two SNI-classifications

	SNI92	SNI2002
Sections (1-digit)	17	17
Divisions (2-digit)	60	62
Groups (3-digit)	223	224
Classes (4-digit)	505	514
Sub-classes (5-digit)	755	774
Period	1991-2001	2002-2010

3.2 Methodological considerations

Although inter-industry relatedness is conceptualised as a network of industries, the dissertation does not directly apply network science methods. Rather, it follows more conventional quantitative estimation techniques. Before turning to method choices specific to relatedness literature, two choices of more general nature are explained: the choice of time periods and spatial units.

Choice of time periods

The investigated 20-year period (1991-2010) is divided into several sub-periods to allow relatedness to change over time. The choice of sub-periods does not reflect any economic periods of fundamentally different nature, but is rather a result of dividing the total period into sub-periods of equal lengths. Articles 1 and 2 use 4-year sub-periods (1991-1994, 1995-1998, …, 2007-2010). Article 3 uses instead rolling 6-year periods (1993-1998, 1994-1999, …, 2003-2008). This latter choice is driven by the aim to increase the length of sub-period because diversification events are expected to be rare.

Choice of spatial units and regional levels

Related variety and related diversification can be studied at various spatial scales. Empirical studies have used units ranging from national to sub-national (NUTS2-4) levels to local labour market regions (Content & Frenken, 2016) or even neighbourhoods within city (Andersson, Larsson & Wernberg, 2019). In principle, the choice of scale should reflect which mechanisms and channels associated with related variety and related diversification are more important for the research question at hand. For example, if labour mobility is considered the key channel, then labour market regions should be preferred.

In this dissertation, the main spatial units are 90 local labour markets (LAs) as classified by Statistics Sweden (SCB, 2010). Their boundaries are defined by intensity of commuting flows between municipalities. This means that most interactions between workers seeking jobs and employers seeking labour occur within LAs (SCB, 2010). Hence, LAs are appropriate as spatial units for linking the supply and demand in labour markets to study regional labour market performance, which is one focus of the dissertation. They are also more generally considered the most suitable unit for agglomeration analysis (Frenken et al., 2007; Mameli et al., 2008). Over time, several Swedish labour markets have been merged and their number has decreased. To make the spatial units comparable, the dissertation uses LAs based on Statistics Sweden's classification in 2000.

The LAs were grouped into four regional types reflecting their development capabilities following the classification by the Swedish Agency for Economic and Regional Growth: core regions (Stockholm, Göteborg, Malmö), large (20 LAs), medium-sized (23) and small (44) regions (NUTEK, 2004). Average population of these regions is respectively 1,5 million, 160, 50 and 17 thousand inhabitants. All non-core LAs with universities belong to large regions, whereas some small regions represent expansive, low population density LAs in North-Sweden. Most of the high-tech industries are concentrated in core regions, while in several small regions main employer is public sector. Regional hierarchy level approach was chosen for two reasons. First, region's position in national regional hierarchy represents better its capabilities to make use of growth potential provided by related variety or related diversification opportunities. Regions at the top of a regional hierarchy host emerging and innovation-intensive industries where knowledge spillovers play an important role. In addition, core regions have better general capabilities (incl. institutions) to innovate, adopt innovations made by others and develop these further. In these knowledge-intensive settings firms engage in cutting edge innovation activities. Second, growth pattern of Swedish regions varies considerably by hierarchy levels (Henning et al., 2016).

3.3 Measuring relatedness

To study related variety and diversification it is necessary to measure the degree of relatedness between economic activities (e.g. industries, products). The increasing number of empirical studies on relatedness and its impact on economic growth have led to new ways of measuring it. While the first studies were based on industry classifications and allowed dividing the economy to only two categories – related and unrelated – the availability of more detailed data has allowed more sophisticated approaches to be used that aim measuring also the degree of relatedness. The three most common approaches are:

1. Majority of studies uses inter-industry relatedness based on the structure of standard industrial classification system. For instance, industries sharing a 2-digit code are often considered related. Validity of this approach has been criticised due to the lack of theoretical justification that classifications really measure relatedness (Neffke,

Henning & Boschma, 2011). More recently studies have also used classification systems for occupation and education (Wixe & Andersson, 2017).

2. The most direct link with economies of scope is based on similarities in resources (e.g. skills, technologies, materials etc.) used in different industries. For example, some authors have turned to using linkages of industries derived from input-output tables (Fan & Lang, 2000). While other studies look at similarities in occupational profiles or labour mobility between industries (Hane-Weijman, Eriksson & Henning, 2018; Neffke & Henning, 2013). Neffke and Henning (2013) argue that theoretically all these approaches have a downside because strategic relevance of various resources varies by industry. For example, material-based measures will better capture the production of goods than services. But they also maintain that human capital can be expected to have the least bias because nowadays it is the key determinant of success in most industries.
3. Third approach is co-occurrence analysis (e.g. Bryce & Winter, 2009; Hidalgo et al., 2007; Teece et al., 1994). It measures how often two products or industries occur in the same country, region, firm or plant. The limitation of these measures is that they are based on outcomes. Hence, they first assume that country's product or industry portfolio is coherent and from this they infer that this co-occurrence reflects relatedness (Neffke & Henning, 2013). In other words, while resource-based indicators measure the potential origins of economic scope, co-occurrence indicators measure its consequences (Neffke & Henning, 2013). This approach captures relatedness in its multi-dimensionality since it is not possible to measure relatedness based on a single dimension (e.g. skills).

The dissertation engages with labour market development and therefore uses skill relatedness measure (i.e. resource-based approach) proposed by (Neffke & Henning, 2013). It captures relatedness in terms of similarities of workers' skill requirements which are assessed based on cross-industry labour flows working under the assumption that industries with similar skill needs typically have larger mutual labour flows. Neffke, Otto and Weyh (2017) show that it is a robust measure of inter-industry relatedness.

Following Neffke and Henning (2013), for each pair of four-digit industries *i* and *j* ($i \neq j$) an expected industry flow $\widehat{F_{ij}}$ was calculated based on industry size, growth and wage using the zero-inflated negative binomial model. Skill relatedness is calculated as the ratio of observed to expected labour flow:

$$SR_{ij} = \frac{F_{ij}}{\widehat{F_{ij}}}$$

where F_{ij} – the observed labour flow between industries i and j; F_{ij} – expected labour flow between the same industries. Two industries were considered related when observed labour flows exceed predicted flows, i.e. if SR_{ij} > 1 (at 5% significance level). Because the study covers 20 years, skill relatedness was calculated for five sub-periods (1991–1994, 1995–1998, 1999–2002, 2003–2006, 2007–2010) to allow changing over time. A more detail discussion of this methodology is presented in Appendix 1.

Relatedness is measured at 4-digit industry code level. At this level of detail, firms registered under the same industry code could still be engaged in economic activities that differ in nature (Kemeny & Storper, 2015). While this might introduce some noise in measurement of relatedness, so would using the most detailed level of 5-digit industry codes because estimates for smaller industries are less precise (Neffke & Henning, 2013). Given the small size of labour flows between most industry-pairs in Sweden already at 4-digit level, the latter was considered a larger drawback.

In Article 3, a simplified version of this indicator is used to calculate skill relatedness (Neffke et al., 2017). Skill relatedness between industries i and j is measured as the ratio of their observed mutual labour flows to respective expected labour which are based on aggregate mobility rates in these two industries.

$$SR_{ij} = \frac{F_{ij}}{(\sum_j F_{ij} \sum_i F_{ij}) / \sum_{ij} F_{ij}}$$

where F_{ij} – is observed labour flow between industries i and j. Based on annual labour flows SR_{ij} is calculated for each year. It is then normalised using the following formula:

$$normalised\ SR_{ij} = \frac{SR_{ij} - 1}{SR_{ij} + 1}$$

Next, mean of normalised SR_{ij} over 6 years is calculated for each sub-period (SR_{ijt}). Industries i and j are considered related if SR_{ijt} > 0. The result is a

504x504 relatedness matrix. Again, matrices were calculated separately for all sub-periods to allow for changes in relatedness over time.

Spatial scale of calculating relatedness

While classification-based relatedness indicators lack any spatial dimension, many others can be calculated at various spatial scales – global (Hidalgo et al., 2007), multi-national, national (Hane-Weijman et al., 2018; Neffke, Henning & Boschma, 2011; Neffke et al., 2017), regional etc. Global indicators have several plusses compared to national ones. First, they cover all world industries and not only those present nationally. Second, they tend to be less noisy since they are based on larger number of observations. This means they likely capture better the pure knowledge, technological etc similarity whereas moving down to national and regional level gradually includes more of the aspects of local context and actual local economic relationships. Global indicators also allow estimating more precisely relatedness for small industries which in small countries is influenced most by noisiness at national level estimates (Neffke & Henning, 2013).

For diversification studies, using global level relatedness indicators is preferred since otherwise related diversification options are constrained by the list of national industries. On the other hand, if these global level indicators are not at a detailed industry classification level, then variation in economic activities within industry classes (Kemeny & Storper, 2015) might lead to problems when using these indicators in different context. For example, relatedness matrices for developing and developed world countries might differ since their economic activities within detailed industry classes, but also in general, are different.

Again, the choice of scale should preferably be made based on research question. Most relatedness research aims to capture the potential for economic benefits beyond the current state of affairs (e.g. from whom can the industry gain new knowledge, or in which new activities could it make use of its knowledge and resources) and this would gain from looking at least to some degree beyond the established local context, patterns and relationships. This would suggest measuring relatedness at a broader scale than the indicator will be used (e.g. using global or national relatedness to study regional development). However, in empirical studies the choice often depends on the availability of data and cannot be based on theoretical grounds. In this dissertation, relatedness is calculated at a national level since the author does not have access to nor is aware of microdata on labour flows at a global level.

3.4 Estimation techniques

3.4.1 Measuring regional related variety

Regional related variety (RV) is conventionally measured by entropy following the initial approach by Frenken et al. (2007). This indicator uses relatedness based on the structure of official industry classification. Commonly 4-digit industries belonging to the same 2-digit industry class are considered related and industries belonging to different 2-digit industry classes are considered unrelated.

$$RV_r = \sum_{g=1}^{G} Q_{gr} H_{gr}$$

where

$$H_{gr} = \sum_{i \in S_g} \frac{q_{ir}}{Q_{gr}} \log_2 \left(\frac{1}{q_{ir}/Q_{gr}} \right)$$

Here, each 4-digit industry i belongs to a 2-digit industry class S_g, where $g \in \{1,2,\dots,G\}$. Q_{gr} is the share of regional employment in each 2-digit industry class S_g. It is calculated as a sum of employment in its 4-digit sub-classes q_{ir}: $Q_{gr} = \sum_{i \in S_g} q_{ir}$.

Fitjar and Timmermans (2017) propose an alternative measure to capture regional related variety – regional skill relatedness (RSR) indicator. They find that it captures industrial structure of many Norwegian manufacturing regions better than an entropy-based indicator.

$$RSR_r = \frac{(\sum_{i=1}^{N} \left(\frac{d_i}{2}\right) \sqrt{P_{ir}})/N_r}{(\sum_{i=1}^{N} \sqrt{P_{ir}})/N_r}$$

where d_i is number of incoming and outgoing related ties for each industry i present in region r; P_{ir} is share of industry i in regional employment; N_r is number of industries present in region r. RSR was calculated for 90 LAs in all sub-periods.

Using RSR instead of the more common entropy-based related variety indicator has several advantages. First, it has a straightforward interpretation as a (weighted) average number of local related ties per industry. In network theory, this represents an average degree. To give a simplified example – if RSR is equal to two, then a local industry is on average related to two other local industries.[15] Second, compared to a system-wide entropy indicator a network-based measure allows to focus on industry-pairs and labour flows between these two industries. Third, RSR is not limited to using classification-based relatedness. This is important because many skill relatedness linkages are between 2-digit industry classification groups (Henning, 2019; Kuusk & Martynovich, 2021). RSR-indicator is strongly correlated with the entropy-based related variety indicator. The correlation coefficient (0,9) (Kuusk, 2021) is comparable to the one found in Norway (0,8) (Fitjar & Timmermans, 2017).

One downside of RSR is that it weights ties essentially by the mean size of industry-pair they connect. Therefore, ties to some very small industries might be given an unduly high weight. Another drawback is that it does not directly capture the full potential from combining knowledge from more than two industries simultaneously. An alternative indicator might sum all the potential related industry combinations (i.e. pairs, combinations of three industries etc.) For interpretational simplicity and given the processes studied in the dissertation (i.e. labour flows between industry-pairs), applying pairwise industry combinations is perceived as a sound approach. The use of square roots as weights has a twofold impact. First, sum of weights is smaller for regions with a more unequal size distribution of industries given the total number of industries. Second, regions with larger number of ties related to several smaller industries instead of one large industry having many ties have higher RSR. The overall outcome of these weights depends on the combination of these two effects.

A closely related concept is closeness of industries and regional coherence (Neffke, Henning & Boschma, 2011). This is another network-based measure for related variety. Closeness is defined as number of related ties industry *i* has to other local industries. Coherence in turn is defined as employment-weighted average closeness of industries in region *r* at time *t*:

$$RC_{rt} = \sum_{i} emp_{irt} IC_{irt}$$

where emp_{irt} is the employment share of industry i in region *r* at time *t* and IC_{irt} is closeness of industry i in region *r* at time *t*. RC- and RSR-indicators

[15] This is a simplified example since RSR uses square roots as weights. The effects of this choice are explained later in the text

are strongly correlated (0,99). The dissertation applies both of these network-based measures to capture related variety.

3.4.2 Assessing the relationship between related variety and regional employment growth

The relationship between various related variety indicators and regional employment growth is estimated through a fixed-effects model. Such model estimates how change in region's related variety is associated with change in its employment growth. Its main advantages is controlling for unobservable differences between LAs that might bias the results. Firgo and Mayerhofer (2018) demonstrate the risk of such bias in a similar study on Austrian regions. The concern is relevant in the Swedish case since labour markets vary considerably in size, physical geography, economic activities etc. Hausman test also suggests using fixed-effects model.

$$\Delta EMP_{rt} = RSR_{rt}\alpha + (RTYPE_r RSR_{rt})\beta + X_{rt}\gamma + \delta_r + \theta_t + \varepsilon_{rt}$$

where ΔEMP_{rt} – annual employment growth (defined as ln(EMPrt+3/EMPrt)/3) in region r during each sub-period $t \in \{1991, 1995, 1999, 2003, 2007\}$; RSR_{rt} – related variety indicator for region r; $RTYPE_r$ – matrix of regional type dummies (large, medium, small; reference: core); X_{rt} – matrix of control variables (including constant). Term δ_r controls for time-invariant unobservable regional characteristics (regional fixed effects), θ_t represents region-invariant time effects and ε_{rt} represents the error term.

Regression includes control variables often used in growth models in related variety literature (Firgo & Mayerhofer, 2018; Frenken et al., 2007; Kublina & Fritsch, 2018; van Oort et al., 2015):

Specialisation: captures employment effects of intra-industry agglomeration externalities (i.e. localisation economies) arising from regional specialisation. Degree of regional specialisation is measured by the Theil index (sum of location quotients of the SNI 2-digit industries weighted by their share in regional employment). This follows the approach taken by van Oort et al. (2015) and Firgo and Mayerhofer (2018).

Population density: controls for general effects from the spatial agglomeration of economic activity (i.e. urbanisation economies) as higher density enhances growth by enabling better interaction (Puga, 2002).

Wage: median wage level in region controls for general economic convergence because regions with lower levels of economic development (and hence also lower wage levels) are expected to have higher employment growth.

Manufacturing: employment share in manufacturing captures the effects of regional specialisation in manufacturing on growth. Bishop and Gripaios (2010) suggest that spillovers might differ between services and manufacturing due to tradability level.

Human capital: captures human capital effects on regional employment development. It is measured as a share of workers with higher education amongst workers older than 25 years.

Competition: controls for regional level competition between firms. It is measured as the inverse of number of employees per plant, but should be interpreted with care because it might also reflect mere scale factors (Bishop & Gripaios, 2010).

Labour flow[16]: controls for general level of labour flow in region as these are likely to vary depending on growth perspective of regional economy (Andersson & Tegsjö, 2006). It is measured as a percentage of intra-regional skilled job switches to skilled employment.

To assess regional differences in the contribution of related variety, regressions include interaction terms between regional type and various RSR-indicators. All explanatory variables are in logarithm form (except those representing shares and in Article 2 also RSR-indicators) and calculated for the first year of sub-periods to minimise potential endogeneity problems.

3.4.3 Measuring diversification potential

Measuring related diversification potential requires first identifying diversification options (i.e. industries that are related to the current regional industry mix, but not yet present in the region). Next, proximity of each diversification option to the overall regional portfolio needs to be calculated. Several methods have been suggested. Hidalgo et al. (2007) proposed a density measure which has been widely used afterwards:

$$density_{ir} = \frac{\sum_j SR_{ij}\, 1\{emp_{jrt} \geq 10\}}{\sum_j SR_{ij}}$$

[16] Included only in Article 2.

Diversification potential (DP) can then be calculated as a sum of densities for all diversification options.

$$densityDP_r = \sum_i density_{ir}$$

Employment weighted average proximity is an alternative measure to assess diversification option's proximity to regional industry portfolio (Coniglio et al., 2018). The dissertation uses this as the main approach to calculate diversification potential (DP) since it is analogous to the regional coherence indicator. The difference with the latter is that instead of related ties to industries present in the region ties to industries not present in the region (but related to the region's current industry mix) are used. In other words, industries one step away from region's current industry mix, or adjacent possible (Kauffman, 1993), are considered its most likely related diversification options.

$$DP_{ir}^t = \sum_{j=1}^{N} DO_{ir}^t w_{ir}^t$$

where w_{ir}^t is regional employment share of industry i

$$w_{ir}^t = \frac{emp_{irt}}{\sum_{i=1}^{N} emp_{irt}}$$

and DO_{ir}^t is the sum of diversification options j related to industry i (o_{ijrt} is an indicator that equals 1 if industry j belongs to region r diversification options set and 0 otherwise) weighted by their mutual skill relatedness (SR_{ijt}).

$$DO_{ir}^t = \sum_{j=1}^{N} o_{ijrt} SR_{ijt}$$

There are two main limitations with this approach to calculating diversification potential. First, national skill relatedness indicator captures only the diversification options to industries already present in the national economy. Global level relatedness indicator would allow to broaden the list of potential diversification options. Second, DP treats all diversification options equally with no consideration for their future growth potential. Yet actors are more likely to start companies in industries they perceive as more profitable. Hence, DP underestimates the potential in regions with relatively many such diversification options.

3.5 Limitations of the study

As with any study, it is important to address some of its many limitations. This discussion is organised in three themes: theoretical issues, methodological issues and scope of the analysis.

Theoretical issues:

- Relatedness is a fuzzy concept that is used to represent both similarity and complementarity, and different features of economic activities (e.g. skills, technology, knowledge, products). For the purpose of this study, relatedness is defined as cognitive or knowledge similarity, which is measured as skill relatedness. Therefore, the results of this dissertation might not be generalisable to other definitions of relatedness. In addition, similarity in skills does not capture all aspects of knowledge similarity, but only the component represented by (or correlated with) skills.

Methodological issues:

- Measurement of relatedness is still a new research topic, and the methods are under development. Although, the progress has been fast, current methods of measuring relatedness can result in noisy estimates. This is especially critical when analysing changes in relatedness over time – it is hard to distinguish real, meaningful relatedness dynamics from estimation noise and general economic dynamics. Common steps used to decrease noisiness (e.g. making SR-indicator symmetric, using mean of annual SR-indicators over several years) risk losing valuable information since relatedness is asymmetric (Kuusk & Martynovich, 2021), and weak ties or ties connecting small industries might remain undetected in annual measurements averaged over several years. While the method used in Article 1 measures relatedness not annually, but over 4-year periods to allow capturing emerging ties and ties between smaller industries, it is at the same time susceptible for other kind of noise (e.g. identifying random small inter-industry labour flows as relatedness). Acknowledging this risk, the potentially noisiest part of identified relatedness ties (i.e. contingent ties) is not included in the analysis that drives the main conclusions about dynamics of relatedness ties.
- Since inter-industry labour flows are measured at a national level, then large flows in core regions dominate skill relatedness calculation. This

could bias estimates if relatedness differs between core and non-core regions. Small labour flows in Swedish non-core regions make it hard to check if this is the case. In addition, national level relatedness network includes only those industries that are present in the country as potential related diversification options.

- The goal with estimating skill relatedness is to use it for measuring local knowledge variety. Knowledge relevant for business purposes has likely more dimensions than industry experience. Individual's occupation, education etc. can be sources of differences in knowledge (Jara-Figueroa et al., 2018; Wixe & Andersson, 2017). To estimate local knowledge variety, one should break individuals into as similar groups as possible before estimating potential for different combinations of knowledge by members of these groups (van Dam, 2019). Since the data takes into account only individual's industry affiliation, related variety indicator used in the study likely underestimates the actual regional knowledge variety. However, this would not be a problem if actual and estimated variety are strongly correlated.

Scope of the analysis:

- 15-20 years is not a long enough period to capture all the dynamics of relatedness linkages and their interplay with regional development. It is more likely that the study captured one snapshot of dynamic characteristics of relatedness and not a full lifecycle of relatedness dynamics (i.e. emergence and disappearance of specific relatedness pairs). While this does not change the main conclusion of the exploratory study demonstrating that relatedness is dynamic, it suggests that future studies can advance our understanding by covering longer periods, focusing on more detailed investigation of relatedness changes at industry-pair level.
- The dissertation uses one spatial scale – local labour markets. Thus, it is best suited to capture economic phenomenon at that spatial scale. However, mechanisms generating agglomeration economies (including those associated with related variety) can vary in scale of their spatial effects – some act over small distances, others over longer ones (Andersson et al., 2019). Less-aggregated data at local government level is also available. However, since the study focuses on labour market developments, local labour markets was considered

the most suitable scale (Mameli et al., 2008) since it is well-suited for capturing relationships and patterns of interest.

4 Swedish economy and regions 1991-2010

Employment in Sweden grew 9% during these 20 years, but the growth rate varied considerably over time and space (Table 2). The country experienced two large crises during this period. In the beginning of the 1990s there was an economic contraction related to the banking crisis that spread to the whole economy. In the end of next decade, the economy slowed down as a result of the global financial crisis of 2007-2008, but the growth performance was not as weak as during the first crisis. This is partly related to the Swedish economy undergoing a transformation during the 1990s when it started the shift towards more knowledge-intensive production. Consequently, manufacturing employment declined substantially in both large and small regions (Eriksson & Hane-Weijman, 2017). This period was also characterised by a strong divergence process between regions and industries (Henning et al., 2016) – while core regions succeeded in transforming their economies and enjoyed high employment growth, many smaller regions struggled to find their role in the new economy. The employment growth in non-core regions picked up again during the 2000s and the national growth pattern amongst regions was much more equal (Henning et al., 2016). However, in many places this improved growth performance was not enough to compensate for the earlier years of sluggish development in non-core regions. The overall employment growth during the whole period was still negative for many of these regions.

Table 2. Change in average employment between the periods

Regional type	1991/1994-1999/2002	1999/2002-2007/2010	1991/1994-2007/2010
Core	9%	9%	19%
Large	-1%	4%	4%
Medium	-3%	2%	-1%
Small	-7%	0%	-7%
Sweden	3%	6%	9%

5 Findings and conclusions

5.1 Findings

Article 1

Kuusk, K., & Martynovich, M. (2021). Dynamic Nature of Relatedness, or What Kind of Related Variety for Long-Term Regional Growth. Tijdschrift voor economische en sociale geografie, 112(1), pp. 81-96.

Article 1 investigates the evolution of relatedness ties between Swedish industries during five sub-periods between 1991 and 2010. It makes a two-fold contribution to the literature. First, it demonstrates that the network of related industries is considerably reorganised over time. Thus, it finds support to the speculations that inter-industry relatedness is dynamic (Boschma, 2017; Castaldi et al., 2015; Desrochers & Leppälä, 2011). The article distinguishes between three main tie types: emerging, stable and disappearing ties. In line with two earlier notable studies (Kogler et al. (2017) on patents and Hidalgo (2009) on export products) that analyse the evolution of relatedness it finds that density of relatedness network has increased over time (number of related ties increased by 20% over 20 years). The results also suggest that emergence and untangling of ties are unidirectional (i.e. one link of the pairwise tie forms or is lost first.)

Second, the article shows that related variety based on either emerging, stable or disappearing ties provides different growth benefits at regional level. These differences in impact seem to rise from a need for match between the qualitative characteristics of ties and regional settings. Co-location of related industries generates no new growth unless mechanisms at work for this type of ties are combined with supportive regional settings. For example, if emerging industry linkages work through complementarity-based knowledge spillovers and (product) innovation, then it is not surprising that only large dynamic regions with their technology-intensive settings are able to benefit. Disappearing ties, linked to large mature industries, may facilitate adjustment to national structural changes through labour matching. Alternatively, large mature industries that benefit from specialised peripheral environments can be expected to create growth through mechanisms important for economic activities in this kind of regions (Neffke, Henning, Boschma, et al., 2011). This need for region-tie-age match may, at least partly, explain why the impact of related variety based on different kinds of ties varies by regional hierarchy level.

Furthermore, the findings suggest that relatedness linkages have a 'best before date': their impact on regional growth depends on their how long they have existed in relatedness network. The article argues that the impact of emerging, stable, and disappearing ties differs, at least partly, since the complementarity potential between related industries becomes depleted over time. In this respect, it is not only emergence and disappearance of relatedness linkages that may have implications for growth potential of regions, but also exhaustion of knowledge spillover potential between industries which remain related (Boschma, 2017). For long-term growth studies this means that we should challenge the practice of assuming that related variety is converted to growth only via knowledge spillovers and consider simultaneously easier structural adjustment through better labour market matching (Frenken et al., 2007).

Article 2

Kuusk, K. (2021). Regional differences in how related variety 'works': the case of labour mobility. European Planning Studies, pp. 1-23.

The article investigates the role of labour mobility in converting related variety into growth in Swedish regions in 1991-2010. It argues that the expected growth benefits of related variety remain potential benefits unless channels (e.g. labour flows, inter-firm cooperation) and regional capabilities are in place to convert them into actual growth.

The article introduces a concept of realised related variety to measure the part of this potential that can be linked to some channel. For example, if there was a labour flow between two firms from related industries the link between the two is classified as 'realised'.

The paper demonstrates that in terms of labour flows core and large regions realise their related variety potential to a higher degree than smaller ones. Small regions partly make up for this through inter-regional labour flows – these more than double region's plant level new related knowledge accessed via labour mobility, but this is not sufficient to compensate the difference in intra-regional flows. Furthermore, most firms and industries in small regions must rely on channels other than labour mobility to convert potential benefits of related variety into growth.

In line with previous research, related labour flows are positively associated with regional employment growth. Core and large regions also benefit from related variety realised via other channels. At the same time, the study found no evidence that other channels are on average beneficial in smaller regions. Thus, from an evolutionary perspective, related variety of industrial structure and local related knowledge interactions tend to trigger broader positive feedback mechanisms in large regions and uphold existing regional hierarchies. The results also indicate that market-mediated knowledge flow channels like labour mobility might be underestimated compared to pure knowledge spillovers via unintended interactions. Hence, they support the argument that growth benefits of related variety are not simply ‘in the air’ (Fitjar & Rodríguez-Pose, 2017).

From a general methodological perspective these two articles agree with the conclusions by Firgo and Mayerhofer (2018) that empirical studies need to pick spatial units carefully because the relationship between related variety and growth varies considerably by regional type. Therefore, using smaller spatial units with coherent regional character (e.g. labour market regions) is preferred to the use of broad geographical areas (e.g. NUTS2). The latter often consist of both urban and smaller non-urban regions which host different kinds of economic activities. This means that their potential regional growth benefits from related variety might also differ. Using spatial units of consistent character is essential to capture such potential heterogeneity of economic impacts by regional type (Firgo & Mayerhofer, 2018).

Article 3

Kuusk, K. Related diversification potential and pattern of Swedish regions in 1993-2008 (an unpublished manuscript).

Article 3 examines related diversification potential and pattern of Swedish regions in 1993-2008. During this period the average related diversification potential for all regional types remained the same. The article demonstrates that related diversification potential has an inverted U-shaped relationship with regional size. The highest potential is in large and medium-sized regions, whereas for core regions only a few related diversification opportunities remain. Core regions partly compensate their poor related diversification potential by better general development capabilities and rich non-local linkages that facilitate breaking with the past and pursuing unrelated diversifications. Indeed, relatively more unrelated diversifications occurs in core regions, which is in line findings that unrelated diversification is more likely in regions with high innovation capacity or sophisticated production (Petralia et al., 2017; Xiao et al., 2018).

In addition, the article discusses how waves of radical innovations (Schumpeter, 1961) result in reorganisation of relatedness network. This creates new related diversifications options for regions, most importantly for core regions which had very few before.

Number of related diversification events in region tends to follow the related diversification potential patterns – fewer related industries enter small and core regions than medium-sized and large regions. The article also highlights how in all regions, except the small ones, entry of new industries leads to decrease in related diversification potential. This means that only small regions gain new diversification options due to related industry entries.

Next, the study introduces a framework that connects growth potential based on local industry structure to various types of regional development paths introducing varying degrees of novelty (continuity vs change) in regional economy. It demonstrates how large and medium-sized regions have best potential to pursue both path renewal (continuity) and path branching (change). Path branching (Frenken and Boschma, 2007) corresponds to related diversification. Small regions, on the other hand, would benefit from non-local linkages and resources to introduce novelty to their economy (Isaksen, 2015) to avoid lock-in (Grabher, 1993). The article also examines how likely are rivalrous relationship between paths if a region pursues more than one path simultaneously. The results do not raise major concerns about this situation.

Finally, the paper emphasises that realising growth potential provided by related variety requires innovation capabilities, while related diversification involves a less risky entrepreneurial discovery of local production costs (Rodrik & Hausmann, 2003). This means that it can become harder and harder over time for growing large regions to find ‘easy’ growth opportunities by imitating others, since their related diversification potential keeps falling as they keep acquiring new local industries. To continue growing and reinventing the local economy they need to upgrade their innovation capabilities to benefit from their growing knowledge diversity.

5.2 Conclusions and outlook

Conclusions

The dissertation aims to advance our understanding about the role of local industry structure in regional economic development. More specifically, it explores how relatedness between local industries contributes to and constrains regional economic development. It first investigates how relatedness itself is co-evolving with broader economic developments and engages then with two main strands of evolutionary economic geography (literatures on related variety and related diversification) that explore the role of relatedness in economic evolution of regions.

While inter-industry relatedness has a prominent role in narratives explaining the evolution of regional economies, the meaning of the concept itself has remained fuzzy and relatedness concept would gain from further investigations of its nature. By challenging the current static view of relatedness, the dissertation demonstrates relatedness has a dynamic nature (Article 1) and finds empirical support to respective past speculations (Boschma, 2017; Castaldi et al., 2015; Desrochers & Leppälä, 2011). It also argues that this dynamism influences the regional growth benefits from related variety. First, growth contribution of emerging, stable and disappearing relatedness linkages is different and varies by regional context. Second, the findings suggest that over time relatedness linkages between industry-pairs tend to deplete their potential to spur complementary-based knowledge spillovers and support innovation. At a more general level, the dissertation argues that relatedness network is co-evolving with broader economic structures and processes, and calls for studying the role and evolution of inter-industry relatedness as part of broader structural change processes.

Despite its weaknesses, the concept of relatedness has brought a new perspective into the old debate on whether specialisation or diversity of local industry structure is more beneficial to regional economic development (Beaudry & Schiffauerova, 2009; de Groot et al., 2016; Glaeser et al., 1992; Henderson et al., 1995; Storper et al., 2016). This has allowed revisiting this classic topic on agglomeration economies in new light.

While the original explanation about the benefits of related variety focused on learning through knowledge spillovers (Frenken et al., 2007), later studies have demonstrated that it also facilitates local reallocation of resources (Eriksson & Hane-Weijman, 2017; Eriksson, Henning & Otto, 2016; Hane-Weijman et al., 2018; Jaax, 2016). Based on the insights on agglomeration economies in urban economics literature (Duranton & Puga, 2004), the dissertation (Article 2) puts forward matching mechanism – that related variety supports higher quality matches at local labour market – as the explanation for these benefits from labour reallocation. This means that related variety is associated not only with benefits from diversity in the form of Jacobs externalities (learning), but also with those typically connected to specialisation (matching).

Furthermore, the importance of these two mechanisms – learning via combining knowledge and matching via labour reallocation – likely varies depending on the nature of time period, both from the global, national and local economic perspective. First, labour reallocation opportunities are especially important during economic restructuring. Their availability and attractiveness to local inhabitants vis-à-vis opportunities outside the region depend on whether the crisis was trigger by global economic rebalancing or slowdown, or by specific local events. For example, available reallocation opportunities might be better after small-scale local events than in aftermath of global recession which influences large part of the economy. Second, since innovation activity tends to happen in waves (Schumpeter, 1961), local potential for knowledge combination and learning also fluctuates over time and is more important during high innovation activity periods.

Although, the dissertation's findings do not cast doubt on the role of learning in converting related variety potential into growth, they resonate with the research that questions the importance of local buzz and pure knowledge spillovers, and instead emphasises the role of market-mediated knowledge flows like labour mobility (Breschi & Lissoni, 2009; Fitjar & Rodríguez-Pose, 2017; Power & Lundmark, 2004). Hence, the results underline the importance of not assuming that the benefits of related variety are *in the air* and contribute to economic growth the same way in all regional settings (Article 2).

In support of this latter claim, the dissertation (Article 1 and 2) adds to the stock of empirical evidence that not all regions benefit equally from related variety (Firgo & Mayerhofer, 2018; Hartog et al., 2012; van Oort et al., 2015). It contributes to the literature by suggesting two explanations for these differences. First, it argues that the heterogeneous impact of related variety on regional growth, comes not only from differences in regional settings *per se*, but also from the qualitative characteristics of the relatedness ties between industries (Article 1). Core regions benefit from emerging relatedness ties, while in smaller regions employment growth is associated with disappearing ties. Hence, it is the match between regional context and nature of relatedness ties that is also important. Second, core and large regions which tend to host knowledge-intensive industries and have more advanced innovation systems are able to gain from variety of mechanisms and channels (Article 2). Swedish peripheral regions, however, might be too small for diversity-based development dynamics to emerge (Eriksson & Hansen, 2013), but they do benefit from related labour flows that support higher quality matching at local labour market (Article 2). Therefore, the dissertation suggests that studies about related variety should pay more attention to specific mechanisms at work and to regional context.

At a more general note, the role of related variety and related diversification in regional development paint a picture that it is highly path dependent. Related variety supports incremental innovation that contributes to regional path extension and renewal (i.e. innovation trajectories within the existing local industries) (Isaksen et al., 2018) introducing rather continuity than change in local economy. Related diversification represents only gradual change via regional branching (Boschma & Frenken, 2011). However, since only a handful of local related ties are realised (Article 2), knowledge diffusion patterns are not pre-determined because most potential local related knowledge combinations are not explored. Consequently, related variety's contribution via local learning leaves plenty of room for chance and purposeful activities by local agents (i.e. micro-level selection). Likewise, medium-sized regions have a range of related diversification options (Article 3) that entrepreneurs can imagine, pursue and experiment with to see if these are a good fit with the local context (Rodrik & Hausmann, 2003). This means that while we can afterwards observe that related diversification is more likely (Boschma, 2017), it is difficult to foresee which exact branch in relatedness network the region ends up following. This interplay between memory (in the form of existing local assets and capabilities) that supports continuity and selection by local agents means that even gradual regional development trajectories are characterised by third-order emergence – by selectively sampling the influences of macro-and meso-structures (like agglomeration economies, related diversification options) micro-level agents do not simply amplify historical micro-level patterns, but also create heterogeneity and divergence within and between the regions (Deacon, 2008; Martin & Sunley, 2012). As a result, the unfolding of economic landscape is path dependent, but also unpredictable.

Outlook

The dissertation highlights three broad avenues for future research on the role of relatedness of local industry structure in regional economic development.

First, continuous work is needed on the relatedness concept itself if we expect to acquire a more nuanced understanding of its role in regional development. In past decade, great contributions have been made in exploring various techniques to measure relatedness (e.g. Hidalgo et al., 2007; Neffke & Henning, 2013). However, we also need more conceptual clarity about what relatedness means and how it behaves. This concerns its use interchangeably as similarity and complementarity, but also other areas like capturing its dynamic nature (Article 1) or exploring its multi-dimensionality (Boschma, 2017). For instance, more detailed investigation of relatedness changes at industry-pair level from the emergence of a tie to its disappearance would contribute to our knowledge on the length and nature of full life-cycle of ties. In this respect, case studies such as recent work by Ingstrup and Menzel (2019) would be much appreciated to advance our understanding on what drives the emergence of and sustains inter-industry relatedness.

Second, while related diversification represents one type of regional path development, most research has focused on testing empirically whether related or unrelated diversification is more likely and under which circumstances (e.g. Neffke, Henning & Boschma, 2011; Xiao et al., 2018). Only few studies have looked at related diversification together with other types of regional development paths (e.g. Grillitsch et al., 2018). Hence, there is lack of quantitative empirical work on the combinations of development paths regions follow and on national distribution of various types of regional development paths, and the role related and unrelated diversification play in these developments at regional and national level.

Third, more context-sensitive re-theorisation of related variety is a promising topic to explore further (Gong & Hassink, 2020). The dissertation argues that such re-theorisation(s) should pay close attention to specific mechanisms and channels converting related variety into improved regional performance in various regional contexts. Article 2 has made some progress in that direction by introducing mechanisms associated with agglomeration economies in urban economics literature (Duranton & Puga, 2004). However, a comprehensive framework combining relatedness literature with insights from urban economics literature on agglomeration economies would be an interesting avenue to pursue.[17] Especially, theoretical explorations about the importance

[17] For example, when it comes to learning, related variety literature focuses on knowledge generation (e.g. product innovations), but there is little or no discussion on knowledge diffusion and accumulation. In addition, while in the dissertation all aspects of benefits from labour flows have been classified under matching mechanism, some can also be categorised as (risk) sharing in terms of labour pooling. Various benefits have been

of different mechanisms (learning, matching, sharing) in converting related variety into growth in different times and for different types of regions. This could also contribute to the unresolved debate about the superiority of specialisation vs diversity in local industrial structure, which Kemeny and Storper (2015) have suggested would benefit from a similar introduction of temporal and spatial context.

In addition, with few exceptions (e.g. Fitjar & Timmermans, 2019) related variety and related diversification are perceived as universally positive. Thus, the field would gain from engaging with critical questions about potential asymmetries in their benefits (e.g. similar to asymmetries in knowledge sharing and interaction identified in cluster literature (Giuliani & Bell, 2005)), and about their role in competition over local resources as demonstrated by Fitjar and Timmermans (2019) or explored in regional development path literature (Frangenheim, Trippl & Chlebna, 2020).

Finally, in recent years, theoretical developments in relatedness literature have lagged behind the empirical work and the application of relatedness ideas in policymaking. We can expect the policy world and empirical research to continue actively using relatedness concept in a near future. One can hope that future theoretical developments will help to catch up with these ambitions to apply the concept, and rather inform empirical work than vice versa.

assigned to labour pooling, but one of them involves firms sharing the risks of employment adjustment in response to firm-specific shocks. Hence, these benefits are associated with labour reallocation events. Both firms and employees can gain from labour pooling. So far, related variety literature has mainly focused on gains to employees in response to crises and plant closures (e.g. Hane-Weijman et al., 2018; Jaax, 2016).

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Appendix 1. Estimating inter-industry skill relatedness

This appendix[18] describes the procedure of estimating inter-industry relatedness. For illustration purposes, the procedure for the first sub-period (1991-1994) is used as an example.

Data and definitions

The data contains information on all individuals registered in Sweden for each year between 1991 and 1994. An individual is defined as a worker if she (1) is in working age (16-64 years old), (2) has a non-zero income from employment and (3) is affiliated with an establishment that has a registered industry code. Establishments are assigned to 4-digit industries according to the merged classification scheme explained in section 3.1 Data. Industries with average annual employment lower than 250 persons are excluded from the analysis as they are too small to generate or absorb significant labour flows.

Inter-industry labour flows consist of the sum of individual job switches between industries. A change in an industry of employment is registered if a worker moves to another establishment at another firm in another industry between two years. Requiring change in both the firm and establishment of employment lowers the risk to include spurious flows when an establishment is reassigned to a different industry.

The estimation of related ties between industries can be more accurate if the analysis is limited to individuals who likely have industry-specific skills. Therefore, all flows of individuals earning lower than median wage in their industry are excluded. The assumption here is that firms provide higher wages to employees with skills important for competitive advantage of the firm. Wage of individuals with few skills critical in the industry will be low relative to the industry's overall wage level. This does not necessarily imply that

[18] This appendix is largely based on Neffke and Henning (2013).

individuals with low wages have no industry-specific skills. Rather, they are excluded to reduce the noise in relatedness estimates. A drawback with such cut-off is that some high earners work as managers with mostly general skills. However, since occupation is not available for the full period, it was not possible to exclude workers based on occupation.

Estimating related ties between industries

It is logical to expect that labour flows between two industries depend not only on whether industries are related or not, but also on some general characteristics of these industries. In other words, some industries may exhibit substantial in- and outflows of labour regardless of their relatedness to other industries. Therefore, it is necessary to use a measure of expected labour flows that takes into account those additional factors. Three such variables the chosen: employment size of industries, employment growth and average wages in industries.

Since labour flows are an over-dispersed count variable with majority of observations being zero (i.e., there are no labour flows between most industry-pairs), it is appropriate to use a zero-inflated negative binomial (ZINB) model. The ZINB regression equation has two components: a regime selection equation and a count data component. The former determines whether there will be any flow at all. The latter estimates the size of flows, assuming that a non-zero regime is selected.

In order to raise the efficiency of estimates labour flows and employment were aggregated across 1991-1994. Following (Neffke & Henning, 2013), the model uses variables in levels for the regime selection equation and log-transformed variables for the count data equation:

$$E\left(F_{ij}\middle|v_i, w_j, \varepsilon_{ij}\right) = \left[1 - \pi_0\left(\gamma + \delta_i emp_{i,1991-1993} + \delta_j emp_{j,1992-1994}\right)\right] \cdot$$
$$f\left(\alpha + \beta_{1i}\log\left(emp_{i,1991-1993}\right) + \beta_{2i} log\left(wage_{i,1991-1993}\right) + \beta_{3i} growth_i \right.$$
$$+$$
$$\left. + \beta_{1j}\log\left(emp_{j,1992-1994}\right) + \beta_{2j} log\left(wage_{j,1992-1994}\right) + \beta_{3j} growth_j\right)$$

with i the industry of origin of a flow and j the industry of its destination, π_0 – the probability that a flow can, in principle, take place, $emp_{k,t}$ – the sum of employment in industry k in period t, $wage_{k,t}$ – the average wage in industry k in period t, and $growth_k$ – employment growth in industry k across the observed years.

Using the point estimates of the parameters in the equation above, the expected labour flows ($\widehat{F_{ij}}$) for all pairwise industry combinations was calculated. Inter-industry relatedness is obtained by comparing the expected flows to the observed labour flows (F_{ij}) between the same industry-pair:

$$SR_{ij} = \frac{F_{ij}}{\widehat{F_{ij}}}.$$

SR_{ij} over 1 indicates a related tie between industries.

Determining the significance levels of skill-relatedness estimates

Majority of industry-pairs experience no observed labour flows, and in these cases predicted labour flows are often negligible as well. This leads to large change in skill relatedness when the observed labour flow increases from zero to one individual while $\hat{F}_{ij}$ is less than one. Therefore, skill relatedness is not estimated with equal precision for all industry combinations. In order to reduce the potential noisiness of skill relatedness measure, confidence intervals for estimates were constructed and two industries are considered related only if their *SR* >1 and statistically significant at 5% level.

To do so, all employees are assumed to have the option to move to a new job in a new industry. If *N* denotes the number of industries present in national economy, each individual faces *N* independent choices: one is staying in the current industry, and the other *N-1* choices are moves into the rest of the industries. This job switch choice can be modelled as a Bernoulli experiment where the probability of success is equal to p_{ij} and the corresponding aggregate labour flow from i to j, F_{ij}, is the outcome of a binomial experiment $BIN(n, p)$ where n is equal to the employment in industry i and p is equal to p_{ij}:

$$F_{ij} \sim BIN(emp_i, p_{ij}).$$

This allows assessing how likely it is to observe labour flow F_{ij}^{obs} merely by chance. Let $\hat{p}_{ij}$ be the expected counterpart of p_{ij}:

$$\hat{p}_{ij} = \frac{\hat{F}_{ij}}{emp_i}.$$

Assuming that $\hat{p}_{ij}$ represents the real probability that an individual will move from industry i to industry j one can test whether F_{ij}^{obs} is exceptional or not. If $SR_{ij} > 1$ then the p-value of the corresponding one-sided test can be calculated as follows:

$$P\left(x \geq F_{ij}^{obs} \middle| p_{ij} = \hat{p}_{ij}\right) = 1 - \sum_{r=0}^{F_{ij}^{obs}-1} \left[\hat{p}_{ij}{}^{r} \cdot \left(1 - \hat{p}_{ij}\right)^{emp_i - r} \binom{emp_i}{r}\right].$$

At statistical significance level of 5%, SR_{ij} is significantly larger than 1 in 6167 industry combinations in 1991-1994. Given that 500 industries were present in the Swedish economy during those years and 27549 pairwise industry combinations contained non-zero observed labour flows, related ties correspond to 2,5% of possible ties and 22,4% of observed ties.

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Kadri Kuusk studies Human Geography at Lund University. She has academic background in Economics, Economic History and Public Policy studies. In addition, she has professional experience and interest in program and policy evaluation. Her research interests are in the areas of economic geography, innovation policy, network studies and complex systems.

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