Regional Skill Relatedness:

Towards a New Measure of Regional Related Variety

Rune Dahl Fitjar (corresponding author)
Professor of Innovation Studies
UiS Business School
University of Stavanger
4036 Stavanger
Norway
e-mail: rune.d.fitjar@uis.no
tel: +47 51831562

Bram Timmermans
Associate Professor / Senior Researcher
Department of Strategy and Management / Innovation Department
Norwegian School of Economics / Agder Research
Helleveien 30
5045 Bergen
Norway
e-mail: bram.timmermans@nhh.no
tel: +47 55959534

Acknowledgements

This work was supported by the Research Council of Norway under the programmes Demosreg, grant no. 209761, and VRI, grant no. 233737. The relatedness matrix and regional industrial statistics were analysed in the former project based on data from Statistics Norway, and the relatedness matrix developed in this project is available in Fitjar and Timmermans (2015). The regional skill relatedness method was further developed in the latter project. Earlier drafts of the paper have been presented at workshops in Stavanger and Oslo. The authors are grateful to all participants at these events for their helpful comments and suggestions.

Regional Skill Relatedness:

Towards a New Measure of Regional Related Variety

Abstract

This paper proposes a novel index of regional skill relatedness and calculates this measure for all Norwegian labour-market regions. Studies of related variety at the regional level have hitherto relied on measures building on the industry classification hierarchy. However, the growing literature identifying similarities in knowledge and competences across industries demonstrates that these classifications fail to identify a great deal of actual skill relatedness, and that measures based on revealed relatedness are therefore required. The regional skill relatedness measure builds on labor mobility flows across industries to develop a relatedness matrix for Norwegian industries. It further uses social network analysis to identify the number of other regional industries to which each industry in a particular region is related. Comparing this measure to the traditional related variety index, the analysis shows that the two measures are highly correlated, but that the regional skill relatedness index is able to identify much more of the relatedness across industries in Norwegian regions. The related variety index also tends to produce low scores for regions with high shares of manufacturing employment, which is not the case for the regional skill relatedness index. Consequently, the regional skill relatedness index represents a promising new tool for identifying relatedness in regional systems.

Keywords

Related variety; skill relatedness; regions; knowledge spillovers; urban and rural regions; Norway

Introduction

Since Frenken et al (2007) introduced the concept of related variety in the regional studies literature, scholarly and policy interest in the approach has rapidly gained momentum. The core idea in this literature is that related variety, which means the extent to which industries in a particular region build on closely related skills and competences, leads to more local knowledge spillovers across industries. Ultimately, this will enhance regional growth and employment. In its wake, a range of studies have confirmed the positive effects of related variety on employment growth (Frenken et al., 2011; Boschma and Iammarino 2009; Boschma et al., 2012), resilience (Diodato and Weterings 2015) and innovative performance (Tavassoli and Carbonara, 2014; Antonietti and Cainelli 2011; Castaldi et al, 2013), demonstrating the utility of this approach.

However, most studies of related variety at the regional level have so far applied the original measure of Frenken et al. (2007), which relies on the hierarchical structure of the NACE industry classification system. This measure has its limitations as it does not capture relatedness between all industries nor all relatedness between industries (Neffke and Henning 2013; Essletzbichler 2015). Co-classification of two industries within the NACE system does not necessarily imply that these build on related knowledge, as the classification hierarchy is not based on considerations of the type of knowledge used in different industries. Furthermore, and more commonly, industries in completely different industry classes might be related even though they are not classified in the same industry class. Reflecting these problems, recent research has proposed better measures of relatedness across industries, focusing on co-occurrences, similarities, or flows between industries on input and output factors (e.g. traded goods, labor, machine, technologies, products) (Neffke and Henning 2013; Essletzbichler 2015). The underlying argument of these approaches is that relatedness across industries reveals itself in high levels of co-occurrence, similarity and/or resource flows between industries, which will only occur consistently over time if these industries are related. Compared to the hierarchical approach, these measures allow for the identification of relatedness between industries that are categorized in different higher-level industry classes, as well as for the possibility that co-classified industries may not always build on related knowledge. The strength of this method has been demonstrated in studies of regional industrial dynamics, which have found a consistent relationship between entry and exit of industries and, for example, the skill-relatedness of regional industries (Neffke et al 2011; Boschma et al 2013; Essletzbichler 2015). However, studies of skill relatedness have mainly focused on the industry level and have so far not been extended to a region-wide measure of relatedness across all regional industries.

Consequently, studies at the regional level have been limited to the related variety measure based on co-classification as the only available approach. This paper addresses this shortcoming by proposing a novel regional skill relatedness measure based on revealed skill relatedness across industries, using social network analysis to develop an index of the overall level of relatedness across all industries in each region.

The empirical setting of the study is Norway, where we construct both the traditional measure of related variety and a new regional skill relatedness measure to analyse relatedness at the level of Norwegian regions. To identify the industrial composition of Norwegian regions, we rely on register data from Statistics Norway. This database also allows us to identify longitudinal employer-employee linkages, which can subsequently be used to identify industry affiliation and intra-industry mobility rates. The data on industry affiliation is used to calculate related variety, while labor mobility is used to measure skill relatedness across industries. The data on intra-industry mobility and industry affiliation is further combined in a novel measure of regional skill relatedness of Norwegian economic regions.

Comparing the related variety and regional skill relatedness measure, we find that the two measures are strongly correlated. However, the second approach identifies a lot more relatedness across industries in Norwegian regions than the traditional related variety measure would have us believe. A visual inspection of the two measures provides an indication that regional skill relatedness might better illustrate the industrial relatedness structure of a region compared to the traditional related variety measure. Furthermore, the related variety measure tends systematically to underestimate relatedness in certain types of regions, in particular those specialized in manufacturing industries. Notably, the related variety index is negatively correlated with the share of employees in manufacturing industries, while the regional skill relatedness index is not correlated with the region's share of manufacturing employment.

The remainder of this paper is structured as follows. In the next section, we start with a literature review presenting an overview of studies that have used the concept of related variety to explain regional economic performance and the shortcomings of this measure. Afterwards, we present an alternative method of regional skill relatedness that can address some of these shortcomings. The empirical strategy will be presented in more detail in the method section after which we present the results, comparing the related variety concept with the regional skill relatedness measure separately for large, medium-sized and small city regions, as well as for rural regions. The last section concludes.

Related Variety, Skill Relatedness, and Regional Economic Growth

Overview of the Literature

There has been a longstanding interest in understanding the link between the industry structure of a region and regional economic performance. Two ideal types of industry structures have dominated this line of research (van der Panne, 2004). On the one hand, agglomeration externalities that emphasize the importance of regional specialization, often referred to as Marshall-Arrow-Romer (MAR) externalities (Glaeser et al 1992). Such regional specialization leads to thick and specialized labor markets, access to specialized suppliers and large markets, and promotes regional knowledge spillovers as firms rely on similar knowledge, skills and competences. Conversely, a different school of thought emphasizes agglomeration externalities as the result of diversified regional structures, i.e. Jacobs externalities (Jacobs 1969). In such a regional structure, diversity is the trigger of new ideas, which would lead to new economic activities and subsequent regional economic growth. Empirical research has demonstrated positive and negative effects of both types of externalities on innovation performance and activities (Audretsch and Feldman 1999; Paci and Usai 1999; Shefer and Fenkel 1998).

Frenken et al (2007), by introducing the concept of related variety, provided a more nuanced perspective on how specialization and diversity affect regional economic performance. They positioned themselves in between the two schools, arguing that knowledge spillovers that are useful for innovation mainly take place across industries which are different, but also not completely unrelated. Knowledge spillovers are not expected between all sectors, as some level of complementarity in competences is required or at least beneficial for knowledge spillovers. However, too much proximity potentially hampers interactive learning and innovation as well (Nooteboom 2001; Boschma 2005; Fitjar et al. 2016). Consequently, neither regional diversity nor regional specialization are beneficial for innovation and regional development per se. Interactive learning, innovation and regional development will most likely occur when knowledge flows between sectors that are technologically related, but not identical. Thus, related variety leads to more knowledge spillovers, which will enhance regional growth and employment. On the other hand, unrelated variety, which means that there are no apparent or only limited complementarities between sectors, may have a portfolio effect that protects regions against the impacts of economic shocks, mitigating unemployment growth. However, more recently, studies have argued that such portfolio effects might also be achieved in a setting of related variety if the related sectors are subject to different business cycles (Boschma 2015, Diodato and Weterings 2015).

The concepts of related and unrelated variety have lent themselves well to empirical testing. Over the last couple of years, many studies of the effects of related and unrelated variety in industry structure have emerged. These studies have investigated how related and unrelated variety affect a range of regional economic performance indicators, including employment and unemployment growth, productivity, value added growth and regional innovation capabilities (Frenken et al 2007; Boschma and Iammarino 2009; Bishop and Gripaios, 2011; Falcıoğlu 2011; Boschma et al 2011; Hartog et al 2012; Tavassoli and Carbonara, 2014; van Oort et al 2015). Others have used these concepts to explain national growth rates (Saviotti and Frenken 2008) and more recently firm level performance, using indicators such as innovation and productivity growth (Antonietti and Cainelli 2011, Aarstad et al 2016).

Frenken et al (2007), upon introducing these concepts, investigated the impact of related and unrelated variety on regional economic development in the Netherlands. The paper examined whether there was a potential spillover effect of related variety, which would create jobs, and a portfolio effect for unrelated variety, i.e. unrelated variety was better able to sustain economic shocks and therefore dampen unemployment. This study concluded that related variety positively affects employment growth, which was corroborated in studies in Italy (Boschma and Iammarino 2009) and Spain (Boschma et al, 2011). Despite the general character of the theory, there is considerable heterogeneity between sectors in the size of this effect (Bishop and Gripaios, 2011). In particular, the effect is typically stronger for high-tech industries (Hartog et al 2012). Furthermore, there was an additional positive effect when the region had high levels of related trade variation, i.e. when it interacted with regions whose industry structures can be characterized as related, rather than similar or unrelated (Boschma and Iammarino, 2009). Meanwhile, unrelated variety had a negative or non-significant effect on regional employment growth (Frenken et al 2007; Boschma et al, 2011). However, unrelated variety tends to dampen unemployment growth (Frenken et al 2007), although these results are not robust for a wider set of European regions (Van Oort et al 2015).

Measuring Related Variety

In order to measure related variety, research tends to rely on the hierarchical structure of the industrial classification system (Neffke and Henning 2013; Essletzbichler 2015). Industrial classification systems like NACE and SIC have various levels of aggregation that are utilized to measure related variety. The underlying assumption is that all lower-level categories within a higher-level category are related. To illustrate, the low-level industry class “manufacturing of batteries and accumulators” is considered related to the low-level industry class “manufacturing of electricity distribution and control apparatus”

since these classes are both part of the higher-level industry category “manufacturing of electrical equipment”. However, these industries are not related to the manufacturing of fluid power equipment, which belongs to a different higher-level industry category (“manufacturing of machinery and equipment not elsewhere classified”). This approach has several properties that make it an interesting approach for research. First, these classification systems are internationally harmonized, allowing for international comparison and thus for comparative studies of the impact of related variety (Oort et al 2015). Second, similar approaches can be, and have been, applied to other hierarchical classification systems like patents (Castaldi et al 2013), education (Østergaard and Timmermans, 2016), occupations and product classes. Third, the aggregated nature of the data needed to investigate this form of relatedness is often readily available from statistical offices.

However, the downsides of this approach are also obvious, as e.g. Neffke and Henning (2013) and Essletzbichler (2015) stress. The classification of industries is not based on considerations of relatedness across them, meaning industries that have little in common are sometimes grouped together. For example, “manufacturing of medical and dental instruments and supplies” is part of the same two-digit category as “manufacturing of games and toys”, and “transportation via pipelines” is part of the same category as “taxi operation”. In addition, and perhaps more commonly, it also fails to capture apparent relatedness across the higher-level categories. For example, one might argue that industries within the same supply and value chain (e.g. “manufacturing of computer, electronic and optical products” and “computer programming, consultancy and related activities”) are related, as they both rely on the same skills, competences, and technologies. But given that these are in different two-digit industry classes, this type of relatedness is not identified using the traditional co-classification measure.

The Concept of Skill Relatedness

Some of these shortcomings of using the hierarchical method of related variety can be dealt with by measuring relatedness based on flows of resources between different types of industries. Common approaches are to look at input-output tables to identify the presence of strong trade linkages between industries, or, in an approach developed more recently, and which this paper applies, at labor mobility flows (Neffke and Henning 2013; Neffke et al 2011; Boschma et al 2013; Timmermans and Boschma 2014; Fitjar and Timmermans 2015). Labor mobility flows provide an indicator of relatedness because workers are more inclined to move to employers who value their skills and competences and reward them according to their human capital. Thus, workers tend change to employers either in the same industry or in industries that rely on similar skills and competences. We thus expect mobility between

industry pairs to be more frequent when skills and competences are transferable to another industry. Consequently, higher levels of mobility between industry pairs is a sign that these industries are more related. This measure has been used to predict the entry and exit of new industries, i.e. regional branching, in Sweden (Neffke et al 2011), Spain (Boschma et al 2013) and the United States (Essletzbichler, 2015). Furthermore, this indicator of relatedness has also proven useful to explain resilience of Swedish shipbuilding industries (Henning et al 2013) and labor productivity growth of Danish plants (Timmermans and Boschma 2014).

Overall, this measure provides useful information on how individual industries, or firms within a particular industry, are related to other firms and industries in a particular geographic context. Skill relatedness measures have mainly been used to explain industry dynamics and labor market dynamics of particular industries in conjunction with their related industries and individual firm or plant performance. However, as far as we could identify, this industry skill relatedness measure has not yet been aggregated to a regional level and as such has not been compared to the measure of related variety.

Method

Data

This study investigates the link between regional skill relatedness and related variety as introduced by Frenken et al (2007) in the context of Norway. We calculate relatedness across regional industries for Norwegian regions using two measures: Frenken et al's (2007) measure of related variety, and the novel regional skill relatedness measure which we develop in this paper. Both measures are created based on data from the Norwegian registers. The data contains detailed universal and longitudinal information on the workplace, industry and work location of individuals for the period 2008-2011. From this register, we first build a data set of the number of workers per industry in each economic region of Norway. Industries are identified at the five-digit NACE level. Second, we build a separate data set of inter-industry mobility across industry pairs in Norway, which we subsequently use to construct our skill relatedness measure. Finally, the two data sets are combined to create the regional skill relatedness measure, to which we will return shortly.

We calculate the measures of related variety and skill relatedness for labour-market regions, which in Norway correspond mostly to the statistical category economic regions. Economic regions are officially

defined by Statistics Norway (2000) and represent NUTS4 regions[1] at the level between the counties and municipalities, which are the official political and administrative units[2]. However, we merge integrated labor markets on the basis of Gundersen and Juvkam's (2013) analysis of labor market flows[3]. This gives a total of 78 regions, which we further classify as large cities, medium-sized cities, small cities, and rural regions, again following Gundersen and Juvkam's (2013) classification based on population size and availability of services.

Regional Related Variety

To measure regional related variety, we follow the same approach as Frenken et al (2007) of analysing the industrial structure in each region, making a distinction between the higher (two-digit) and lower-level (five-digit) NACE industry classification. All five-digit industry classifications *i* fall under a two-digit industry classification S_g, where g=1,…,G. The share of employees in each two-digit industry class (P_g) can be calculated by summing the five-digit sub-disciplines (p_i). Summing all employment shares in the various industries within a region will add up to 1. The level of unrelated variety in the region is calculated as an entropy of the distribution of industry classes. This measure is calculated as follows:

$$URV = \sum_{g=1}^{G} P_g \log_e \left(\frac{1}{P_g}\right)$$

Related variety is calculated as the weighted entropy index for lower-level five-digit NACE industry classes in each of the two-digit industry classes, indicating the diversity within the lower levels.

$$RV = \sum_{g=1}^{G} P_g H_g$$

[1] Norway, with its population of 5.2 million inhabitants, is among the most sparsely populated countries in Europe. Consequently, economic regions are highly dispersed in both geographic size and population size, and the NUTS3 regional classification is relatively large. Smaller Norwegian NUTS 3 regions are often the same size as NUTS2 regions in other European countries, while regions located in the north are similar in size as the countries of Denmark, the Netherlands, or Belgium. Hence, NUTS 4 regions is the best equivalent of functional economic regions. As we question the validity of these knowledge spill-overs dynamics in regions which cover very large areas, we rely on NUTS 4 regions in our analyses.

[2] However, many economic regions are also represented by organisations such as regional councils or regional development agencies, which are normally joint ventures by several neighbouring municipalities with responsibilities especially for development policy.

[3] The following economic regions are identified as part of the same labor market by Gundersen and Juvkam (2013) and are therefore classified as one region: Oslo, Follo, Bærum/Asker, Lillestrøm and Ullensaker/Eidsvoll; Drammen and Sande/Svelvik; Tønsberg/Horten and Holmestrand; Skien/Porsgrunn and Kragerø; Kristiansand and Lillesand; Stavanger/Sandnes and Jæren; Haugesund and Søndre Sunnhordland; Trondheim and Stjørdalshalsen; and Namsos and Grong.

where

$$H_g = \sum_{i \in S_g} \frac{p_i}{P_g} \log_e \left(\frac{1}{p_i / P_g} \right)$$

Regional Skill Relatedness

In order to examine the regional skill relatedness in each region, we further develop the measure of skill relatedness between industry pairs based on labor mobility patterns, as developed by Neffke and Henning (2013). To measure this relatedness, we rely on the unique person and workplace identifiers from the register data. These allow us to identify mobility patters between employers and industries. We use information on nationwide individual workers' mobility between industries to measure skill relatedness across Norwegian industries. When observing more mobility than expected between industries, these industries are considered related as they can be expected to build on similar human capital. We measure the skill relatedness between two industries *i* and *j* as follows:

$$SR_{ij} = \frac{F_{ij}/F}{(F_i/F)\,(F_j/F)} = F_{ij} \frac{F}{F_i F_j}$$

In this model F_{ij} is the total number of employees moving from industry *i* to industry *j*; *F* is the total number of employees that change employers in any given year; F_i is the number of individuals that leave a firm in industry *i*; and F_j is the number of employees that enter a firm in industry *j*. We furthermore standardize the measure to a range between -1 and +1 using the formula

$$\widehat{SR}_{ij} = \frac{SR_{ij} - 1}{SR_{ij} + 1}$$

In order to create a general measure of skill relatedness across industries, we combine data for all regions over a 4-year period. This is done to reduce the impact of random noise on the measure, so that only industry pairs which consistently across time and space display higher inter-industry mobility rates than what would be expected due to chance are considered skill-related. Consequently, we apply a four-year measure of skill relatedness in the whole of Norway to identify regional skill relatedness in one particular region at a particular point in time. Two industries are considered related if $\widehat{SR}_{ij}$ is higher than 0.25 for the period 2008 to 2011 as a whole, and higher than 0 in at least two of the four years. A more

detailed description of the method, along with the full relatedness matrix for Norwegian industries, is presented in Fitjar and Timmermans (2015).

These skill relatedness measures only provide an indication of whether particular industry pairs are related and do not provide an overall regional measure of skill relatedness as such. For this purpose, we apply social network analysis in which we combine data on regional employment and skill relatedness to construct network measures for each region. The network analysis is used to measure the number of regional industries related to each industry *i* by calculating the number of ties between *i* and all other industries *j* present in the region. As the relatedness of larger industries is of greater importance for the possibility for local knowledge spillovers, we weight the industry's number of ties by the square root of its share of regional employment. As an overall measure of regional skill relatedness, we measure the average number of weighted ties for all industries in the region[4]. This measure is further standardized by the average share of regional employment for regional industries in order to ensure that the regional skill relatedness index is determined exclusively by the number of ties and not by the distribution of regional employment (and hence by the level of specialization in the region) through the weights. The regional skill relatedness (RSR) is calculated as follows:

$$RSR_r = \frac{\frac{\sum_{i=1}^{n} \frac{d_i}{2} \sqrt{P_{ir}}}{N_{ir}}}{\frac{\sum_{i=1}^{n} \sqrt{P_{ir}}}{N_{ir}}}$$

Where P_{ir} is industry i's share of total regional employment in region r, N_{ir} is the number of industries present in region r, and d_i is the sum of ingoing and outgoing ties for industry i to other industries in region r.

Regional skill relatedness and related variety

In order to compare the regional skill relatedness measure to the traditional related variety measure, we compare the scores and rankings of Norwegian regions on the two measures. Overall, the two indices are highly correlated with a Pearson's R of 0.79. The concurrent validity of the measure is therefore high. However, there are also some notable discrepancies between the two indices. For instance, the related

[4] The analysis focuses on employment in the private sector only. Following Frenken et al. (2007), we further exclude the primary sector industries agriculture and fisheries from the analysis. We also exclude retail, hotels and restaurants, as well as temp agencies. The three former industries are excluded as they include lots of temporary workers, while the latter is excluded as it mainly acts as a channel to place workers in other industries; consequently, the knowledge and skills that are being transferred are not specific to the temp agency industry, but related to the industries in which temp agencies place workers.

variety index is significantly negatively correlated with the share of manufacturing employment in the region (R = -0.40), whereas the regional skill relatedness index is not significantly correlated with manufacturing employment (R = -0.03). This suggests that the regional skill relatedness index might be less sensitive than the related variety index to certain types of regional industrial structures, e.g. manufacturing regions.

We further examine the face validity of the regional skill relatedness measure through visual inspection of a series of network graphs, focusing on regions in each category where there are discrepancies between the indices. These graphs show the size and relatedness ties across industries in one region which ranks higher on the regional skill relatedness measure than on the related variety index, and one region where the opposite is true. Examining the underlying data on which the measure is calculated will give an indication of which types of regional industry structures would produce higher or lower scores on the regional skill relatedness measure.

The possibilities for skill relatedness are highly correlated with region size, i.e. the more economic activities there are in a region, the more regional diversity there will be, including related variety and regional skill relatedness. Hence, the bivariate correlation between employment size and regional skill relatedness is 0.59, while the correlation between employment size and related variety is 0.46. To account for this, we conduct the comparisons both across the two indices and across regions which differ in their rankings on the two measures separately for regions of different sizes, looking in turn at large cities, medium-sized cities, small cities, and rural regions.

Large cities

It is not surprising that the largest city regions are among the regions with highest level of regional skill relatedness and related variety, and that Oslo tops the regional ranking for both measures (see Table 1). The three remaining large city regions are more comparable to each other. However, the ranking of the three is reversed in the regional skill relatedness index compared to the related variety index. In the former, Stavanger is second with Bergen close behind, while Trondheim clearly has a lower score. In the related variety index, Trondheim ranks second, followed closely by Bergen, while Stavanger is trailing by a margin. Furthermore, none of the three regions have particularly impressive scores on the related variety index. Indeed, five of the medium-sized city regions discussed below have higher scores than Trondheim on this index, and twelve out of sixteen medium-sized city regions have higher scores than Stavanger. This raises the question: Are Norway's large cities outside the capital region characterized by

related variety, as the regional skill relatedness measure would suggest, or are they not, as suggested by the related variety index?

Table 1 about here

Figure 1 demonstrates the differences between Trondheim and Stavanger in greater detail. The network graphs show all relatedness ties between industries. The size of the nodes indicates the share of regional employment in this industry. Both regions have dense networks, reflecting that Stavanger and Trondheim are among the regions with the most regional skill relatedness in Norway. Both regions are, however, also specialized in some industries that are not related to any other industries in the region, shown as isolated nodes to the right.

The Stavanger region, which is heavily reliant on the oil and gas industry, has an industry structure that could be characterized as more specialized. However, the oil and gas industry is composed of various sub-industries specializing in different aspects of the production of oil and gas (e.g. extraction of oil and gas, oil and gas services, and various manufacturing and service industries), and the complete value-chain within the upstream part of the industry is represented in the Stavanger region (Fitjar and Rodríguez-Pose 2011). Hence, the region also has a fairly diversified industry structure within oil and gas. Arguably, this is precisely what the concept of related variety is meant to capture – a series of different industries that are connected through a common knowledge core, in this case engineering knowledge, particularly in fields such as chemistry, geology and construction. However, as the oil and gas industry is spread over several two-digit industry codes, covering mining, manufacturing and services, a lot of the relatedness across different sub-sectors of the oil and gas industry is not picked up by the traditional related variety index. The related variety score is therefore lower than in the other city regions.

The oil and gas industry in Stavanger is clearly presented with the two largest nodes in the map (shown in purple). These are related to each other but also to many smaller sectors in the region. Notably, several of the major manufacturing sectors (red nodes) in Stavanger are related to oil and gas and tend to cluster close to the oil and gas industries on the map. The effect of this is that larger nodes are placed in close proximity on the map, which indicates that there are relatively strong relatedness ties among larger industries in Stavanger. Conversely, the industries (including manufacturing) located further away from this cluster tend to be smaller. Compared to Stavanger, Trondheim has fewer major nodes, reflecting that the region is less specialized than Stavanger. Furthermore, the largest nodes are in some cases located on opposite edges of the network and are unrelated to each other. Scientific and technical

consultancy services (brown nodes) are located in the upper right-hand corner of the map, surrounded by many smaller manufacturing and service (pink nodes) industries. In the opposite corner of the map is a set of construction (yellow nodes) and transportation (blue nodes) industries that have a large share of regional employment, but benefit little from the region's strength in scientific and technical services (an exception is the electrical installation industry, shown as a large yellow node close in the upper right section, close to scientific and technical consultancy). The same could be said for the financial sector (orange nodes) in the upper left part of the map. Trondheim's score on the regional skill relatedness measure is therefore lower than Stavanger's.

Figure 1 about here

Medium-sized cities

Table 2 shows the ranking of medium-sized cities. In most cases, the rankings tend to be quite similar. The top three regions in the regional skill relatedness index are also the top three in the related variety index. There are also low-ranking regions on both measures, such as Molde, Bodø, Gjøvik and Lillehammer. However, there are also some discrepancies, which tend to follow along a clear geographical pattern: While the medium-sized coastal cities in Eastern Norway (Drammen, Tønsberg, Fredrikstad, Sandefjord and Skien) tend to do well on both measures, the southwestern cities Haugesund, Kristiansand and Arendal all score much higher on the regional skill relatedness than on the related variety index. Kristiansand is fourth on the regional skill relatedness index, but only tenth on the related variety index. Similarly, Haugesund and Arendal are both above the median in this category for regional skill relatedness, but occupy the two lowest places in the related variety index ranking. Conversely, another group of cities in Eastern Norway – Moss, Hamar, Gjøvik and Lillehammer – all rank higher on the related variety than on the regional skill relatedness index, as do the Northern Norwegian cities Tromsø and Bodø.

Table 2 about here

How can this be accounted for? To examine this, Figure 2 shows the skill relatedness maps for Haugesund and Tromsø, which moved in opposite directions on the two indices. The two regions are similar in size, with a population in 2008 of 99,000 and 78,000, respectively, although Haugesund has a higher share of private sector employment, translating into a private sector workforce that was 55% higher than Tromsø's in the industries considered. The industrial structures of the two regions are also quite different. As the maps show, Haugesund relies much more on manufacturing (red nodes) than

Tromsø. The two largest industries in Haugesund are both in manufacturing (shipbuilding and aluminium production). Both of these are also located quite centrally in the map and are surrounded by several smaller manufacturing industries. This includes various metal products and machine production industries, which – as they are in different two-digit categories – are not picked up by the related variety index as being related to either of the two largest industries. This is also true for other large industries in Haugesund, such as the sea freight industry (blue node at the top) and the oil and gas industries (purple nodes). The related variety index therefore fails to detect a lot of the relatedness across industries in Haugesund, while the regional skill relatedness measure picks up much more of these linkages.

The manufacturing industries in Tromsø are much smaller and also more dispersed throughout the map. Tromsø's major specialisations include the construction (yellow nodes) and transport (blue nodes) industries, which form two separate clusters in the upper right and left parts of the map, respectively. The industries within these sectors tend to be skill-related, but this kind of relatedness is to a greater extent also picked up by the related variety index, as construction and transport both cover a limited number of two-digit industries (three and five, respectively, compared to 24 in manufacturing). Being host to a research university, Tromsø also has a set of scientific and technical service industries (brown nodes) which cluster at the bottom of the map. However, as in Trondheim, these industries are somewhat disconnected from other large industries in Tromsø, although they are related to a series of smaller information and communication services (pink nodes) and financial services (orange nodes) industries in Tromsø. Overall, however, the division between two or three relatively unrelated specialisations in construction, transport and scientific/technical services translate into a fairly low level of regional skill relatedness in Tromsø.

Figure 2 about here

Small cities

Moving to smaller city regions (see Table 3), a similar pattern emerges. The top of the two rankings is once more identical, with the same two regions occupying the first two positions in both rankings. However, also in this category, there is a group of manufacturing-oriented regions with very high scores in the regional skill relatedness index, which are in the bottom places on the related variety index. This includes the third-ranking region Sunnhordland and fifth-ranking Kongsberg, as well as Egersund, Sogndal/Årdal, Halden and Mo i Rana. All of these regions are mainly specialized in one or more manufacturing industries, which tends to result in lower related variety scores due to the limited number of four-digit industries normally present within each two-digit manufacturing sector in most regions.

Conversely, several regions in Northern Norway score much higher in the related variety than in the regional skill relatedness index also in this category. This includes regions such as Alta and Kirkenes, both in Finnmark, which are third and sixth, respectively, in the related variety index, while they are nineteenth and rock bottom, respectively, in the regional skill relatedness index. Other northern regions, such as Hammerfest and Finnsnes, also move in the same direction. Much like Tromsø, these regions tend to be much more dominated by the construction and transportation services sectors.

Table 3 about here

To illustrate this, Figure 3 shows the network graphs for Kongsberg in Eastern Norway and Kirkenes in Finnmark. Kongsberg is fifth in the regional skill relatedness measure, but third from bottom in the related variety index. The opposite is the case for Kirkenes, which is sixth in the related variety index, but last in the regional skill relatedness index. The dominance of manufacturing industries in Kongsberg is clear from the large red nodes in the upper left part of the network. Kongsberg has emerged in recent years as one of the major high-technology manufacturing regions in Norway, home to the Subsea Valley oil and gas technology cluster, as well as leading weapons manufacturers (Onsager et al. 2007; Isaksen 2009). The three largest nodes in Kongsberg are shipbuilding, weapons manufacturing and instrument manufacturing, which all belong to different two-digit NACE industries, but are clearly skill-related as shown by the links between them as well as their proximity in the map. Most other manufacturing industries in Kongsberg are also located close to the largest industries, while the service industries tend to be fairly detached from this cluster. Overall, however, the relatedness ties between all three dominant industries, as well as the many ties between these and other industries in Kongsberg, lead to a high regional skill relatedness score for Kongsberg.

Kirkenes is also specialized in a manufacturing industry, in this case ship repairs. This industry also has a central position in the regional network, although with few other manufacturing industries nearby. However, the construction and transportation industries are much more important in Kirkenes than in Kongsberg, as shown by the larger yellow and blue nodes. In particular, many of the construction industries are in the two-digit category specialized construction, while many of the transportation industries are in storage or land transport, leading to a high score on the related variety index. However, particularly in the case of construction, these industries are not skill-related, as the network map shows. For instance, the large node in electrical installations is only related to one other industry in Kirkenes and is therefore on the periphery of the network, even though there are several other specialized construction industries in the region. In this case, therefore, the related variety index might in some

cases overestimated relatedness across industries in Kirkenes. Meanwhile, the largest nodes are spread out in different parts of the regional network, with large nodes in the top, bottom, right and centre of the network. Few large industries are located in the vicinity of other large industries in Kirkenes. This results in a low regional skill relatedness score.

Figure 3 about here

Rural regions

Finally, the classification for rural areas tends to show the largest discrepancies. While there are certainly many regions that are at the top or, especially, at the bottom of both indices, this is the only category where the top of the two lists looks quite different. In particular, the top-ranking region for regional skill relatedness, Ulsteinvik, is nearly at the bottom of the related variety index. Conversely, a region in Finnmark once more stands out with a much higher score in the related variety index than in the regional skill relatedness measure: Vadsø is second for related variety, compared to its twelfth place in the regional skill relatedness index. Nonetheless, there are also similarities. In particular, several inland regions in Eastern Norway, such as Hadeland, Hallingdal and Valdres, do well on both measures, while the smallest regions are at the bottom in both indices, as would also be expected.

Table 4 about here

Figure 4 shows the network maps for Ulsteinvik and Rørvik, which have similar related variety scores (0.63 and 0.60, respectively), even though Ulsteinvik's regional skill relatedness score is more than double that of Rørvik. Ulsteinvik is a heavily manufacturing-oriented region which hosts world-leading and highly technologically sophisticated shipbuilding firms (Karlsen 2005). Its largest sectors are ship-building (red node) and ship transportation (blue node). Ship-building in particular is related to a large number of other manufacturing industries in Ulsteinvik, mostly in the machine or metal products manufacturing sectors. Consequently, most manufacturing industries in Ulsteinvik are located in close proximity on the map, linked by a large number of relatedness ties. This results in a high score on the regional skill relatedness index. However, many of these linkages are not picked up by the related variety index, as ship-building belongs to a different two-digit category (manufacture of transport equipment) than machine or metal products manufacturing. Ulsteinvik's score on the related variety index is therefore much lower.

Ostensibly, the industry structure in Rørvik is similar to that of Ulsteinvik, although the region is much smaller. Its largest industries are also ship transportation – as in Ulsteinvik – and a manufacturing

industry. However, in this case, the manufacturing specialisation is fish processing, which has less to do with ship transportation than Ulsteinvik's ship-building industry. Fish processing also has fewer ties to other industries in Rørvik in general, with only a few other small food production industries related to it. The other manufacturing industries in Rørvik are located in a different part of the map, and are mostly quite small. Furthermore, ship transportation is only related to three other industries in Rørvik, whereas the same industry has seven related industries in Ulsteinvik. Despite being one of the least densely populated regions in Norway, Rørvik also has a small concentration of IT industries (pink nodes), the largest being wireless telecommunications. However, this is located in a different part of the network from the other large industries in the region. Overall, there are also considerably fewer ties across industries in Rørvik than in Ulsteinvik, as the density of linkages on the two maps illustrates. This results in a low score for Rørvik on the regional skill relatedness index.

Figure 4 about here

Conclusion

Understanding how the different industrial structures of regions create or deter opportunities for knowledge flows between industries has long been a topic of interest for academics and policy-makers. During the last 10 years, the concept of related variety, which takes into account the extent to which industries in a given region build on related knowledge, has gained momentum as an approach to explaining regional economic performance. Existing empirical research tends, with some exceptions, to support this idea. However, the empirical support for the benefits of related variety has relied mainly on studies using indices which build on the co-classification of industries in the NACE hierarchical industry classification system. In the meantime, new measures of industry relatedness have been introduced which are in many cases clearly better at identifying relatedness between industries. In particular, such measure are able to capture links between industries that build on related knowledge, but which are classified in different part of the NACE system. However, these measures tend to focus on individual industries rather than regional systems. A macro-level measure of relatedness at the regional level has hitherto not existed.

In this paper, we have created such a measure. The paper proposes a measure of regional skill relatedness based on revealed relatedness ties across regional industries as identified by labor mobility flows. We create and calculate this measure for all Norwegian regions using social network analysis, building on the comprehensive linked employer-employee data available from Statistics Norway. We

further compare the measure to the related variety measure as introduced by Frenken et al (2007). When comparing these measures, we see some notable discrepancies between them. Relatedness between industries appears to be underestimated for most regions in the related variety index. This underestimation is mainly driven by the failure of the related variety index to identify a large number of linkages between industries belonging to different two-digit NACE codes. Relying exclusively on related variety as identified by the classification hierarchy would particularly be problematic for smaller regions, where many industries are not co-located with other industries in the same two-digit NACE category. The measure of regional skill relatedness identifies these industries more clearly, thus highlighting a larger number of industries that can (potentially) benefit from being co-located in the same area. Furthermore, while the sheer number of relatedness linkages is underestimated in all regions, this is particularly a problem in manufacturing-oriented regions. The correlation analysis demonstrates a negative correlation between the share of employees active in manufacturing industries and related variety, and this is also apparent in several of the individual regions shown in the analysis. A consequence of this is that regions specializing in manufacturing tend to score lower on the related variety index than on the regional skill relatedness index in all size categories. Consequently, the level of related variety in many of Norway's most technologically sophisticated and export-oriented manufacturing regions is severely underestimated by the related variety index, including large cities such as Stavanger, medium-sized cities such as Kristiansand and Haugesund, small cities such as Sunnhordland, Kongsberg and Halden, and rural regions such as Ulsteinvik. Conversely, the proposed regional skill relatedness index picks up more of the relatedness across industries in these regions, placing many of them close to the top of the rankings in the respective categories.

Our analysis comes with some limitations. First, our proposed measure needs to be fine-tuned further as it is strongly correlated with the size of the region. A consequence of this is that it is challenging to investigate how well this measure can explain regional economic performance beyond general centralization trends. Second, the Norwegian context is one of the factors that should be considered. Our findings thus provide a call for future research to investigate the robustness of our proposed regional skill relatedness measure; not only compared to the Norwegian setting, but also to existing measures of regional industrial diversity. The oil and gas industry plays an important role in the Norwegian economy as it provides jobs for a diverse labor force, paying high wages. As such, labor mobility patterns and subsequent related variety might to some extent be affected by the strong dominance of this industry. Furthermore, Norway's main industries are in many cases distributed across different NACE categories. This is the case for oil and gas, but also for maritime industries as the

examples discussed in the paper have shown. This might lead the related variety index into greater problems in Norway than in industrial settings that conform more to the logic of the classification hierarchy. Third, relatedness based on labor mobility patterns is only one way to measure revealed relatedness. Other measures could also be aggregated into regional indices (see Neffke and Henning (2013) and Essletzbichler (2015) for a more detailed discussion on the type of relatedness measures that can be constructed). However, this paper has provided a first step towards developing an overall regional measure of relatedness which relies on revealed relatedness rather than on the classification hierarchy.

References:

Aarstad, J., Kvitastein, O. A., & Jakobsen, S. E. (2016). Related and unrelated variety as regional drivers of enterprise productivity and innovation: A multilevel study. Research Policy, 45(4), 844-856

Antonietti, R., and Cainelli, G. (2008). Spatial agglomeration, technology and outsourcing of knowledge-intensive business services: empirical insights from Italy. International Journal of Services Technology and Management, 10(2-4), 273-298.

Bishop, P., and Gripaios, P. (2010). Spatial externalities, relatedness and sector employment growth in Great Britain. Regional Studies, 44(4), 443-454.

Boschma, R. (2005). Proximity and innovation: a critical assessment. Regional Studies, 39(1), 61-74.

Boschma, R. (2015). Towards an evolutionary perspective on regional resilience. Regional Studies, 49(5), 733-751.

Boschma, R., and Gianelle, C. (2013). Regional branching and smart specialization policy. JRC technical reports, (06/2104).

Boschma, R., and Iammarino, S. (2009). Related variety, trade linkages, and regional growth in Italy. Economic Geography, 85(3), 289-311.

Boschma, R., Minondo, A., and Navarro, M. (2012). Related variety and regional growth in Spain. Papers in Regional Science, 91(2), 241-256.

Boschma, R., Minondo, A., and Navarro, M. (2013). The emergence of new industries at the regional level in Spain: a proximity approach based on product relatedness. Economic Geography, 89(1), 29-51.

Bugge, M. M., and Øiestad, S. (2015). The Micro-foundations of Regional Branching: The Case of Digitization of Publishing. European Planning Studies, 23(4), 764-784.

Castaldi, C., Frenken, K., and Los, B. (2015). Related variety, unrelated variety and technological breakthroughs: an analysis of US state-level patenting. Regional Studies, 49(5), 767-781.

Diodato, D., and Weterings, A. B. (2014). The resilience of regional labor markets to economic shocks: exploring the role of interactions among firms and workers. Journal of Economic Geography, lbu030.

Essletzbichler, J. (2015). Relatedness, industrial branching and technological cohesion in US metropolitan areas. Regional Studies, 49(5), 752-766.

Falcıoğlu, P. (2011). Location and determinants of productivity: The case of the manufacturing industry in Turkey. Emerging Markets Finance and Trade, 47(sup5), 86-96.

Feldman, M. P., & Audretsch, D. B. (1999). Innovation in cities:: Science-based diversity, specialization and localized competition. European Economic Review, 43(2), 409-429.

Fitjar, R.D., & Rodríguez-Pose, A. (2011). Innovation in the periphery: Firms, values and innovation in Southwest Norway. European Planning Studies, 19(4), 555-574.

Fitjar, R.D., Huber, F., & Rodríguez-Pose, A. (2016). Not too close, not too far: Testing the Goldilocks principle of 'optimal' distance in innovation networks. Industry & Innovation. DOI: 10.1080/13662716.2016.1184562

Frenken, K., Van Oort, F., and Verburg, T. (2007). Related variety, unrelated variety and regional economic growth. Regional Studies, 41(5), 685-697.

Glaeser, E. L., Kallal, H. D., Scheinkman, J. A., & Shleifer, A. (1992). Growth in cities (No. w3787). National Bureau of Economic Research.

Gundersen, F., Jukvam, D. (2013) Inndelinger i senterstruktur, sentralitet og BA regioner. NIBR-rapport 2013-1.

Hartog, M., Boschma, R., and Sotarauta, M. (2012). The impact of related variety on regional employment growth in Finland 1993–2006: high-tech versus medium/low-tech. Industry and Innovation, 19(6), 459-476.

Isaksen, A. (2009). Innovation dynamics of global competitive regional clusters: The case of the Norwegian centres of expertise. Regional Studies, 43(9), 1155-1166.

Jacobs, J. (1969). The Economy of Cities. New York: John Wiley.

Karlsen, A. (2005). The dynamics of regional specialization and cluster formation: Dividing trajectories of maritime industries in two Norwegian regions. Entrepreneurship & Regional Development, 17(5), 313-338.

Neffke, F., Henning, M., and Boschma, R. (2011). How do regions diversify over time? Industry relatedness and the development of new growth paths in regions. Economic Geography, 87(3), 237-265.

Neffke, F. M., Henning, M., and Boschma, R. (2012). The impact of aging and technological relatedness on agglomeration externalities: a survival analysis. Journal of Economic Geography, 12(2), 485-517.

Neffke, F., & Henning, M. (2013). Skill relatedness and firm diversification. *Strategic Management Journal*, *34*(3), 297-316.

Nooteboom, B. (2000). Learning by interaction: absorptive capacity, cognitive distance and governance. Journal of Management and Governance, 4(1-2), 69-92.

Onsager, K., Isaksen, A., Fraas, M., & Johnstad, T. (2007). Technology cities in Norway: Innovating in glocal networks. European Planning Studies, 15(4), 549-566.

Paci, R., & Usai, S. (1999). Externalities, knowledge spillovers and the spatial distribution of innovation. GeoJournal, 49(4), 381-390.

Saviotti, P. P., & Frenken, K. (2008). Export variety and the economic performance of countries. Journal of Evolutionary Economics, 18(2), 201-218.

Shefer, D., & Frenkel, A. (1998). Local milieu and innovations: Some empirical results. The Annals of Regional Science, 32(1), 185-200.

Tavassoli, S., and Carbonara, N. (2014). The role of knowledge variety and intensity for regional innovation. Small Business Economics, 43(2), 493-509.

Timmermans, B., & Boschma, R. (2014). The effect of intra-and inter-regional labour mobility on plant performance in Denmark: the significance of related labour inflows. Journal of Economic Geography, 14(2), 289-311.

Timmermans, B., & Fitjar, R. (2015). Skill Relatedness in Norway. University of Stavanger Working Papers in Economics and Finance, no. 20/2015.

Van Oort, F., de Geus, S., & Dogaru, T. (2015). Related variety and regional economic growth in a cross-section of European urban regions. European Planning Studies, 23(6), 1110-1127.

Figure 1: Large cities regional skill relatedness networks

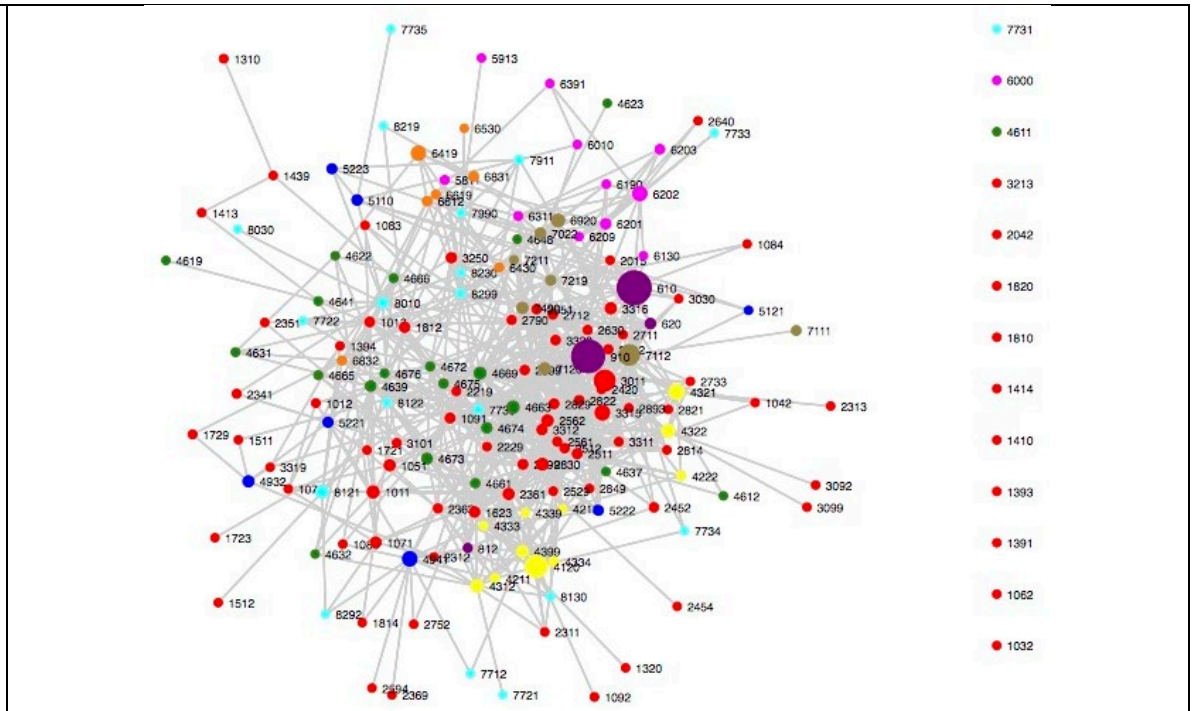
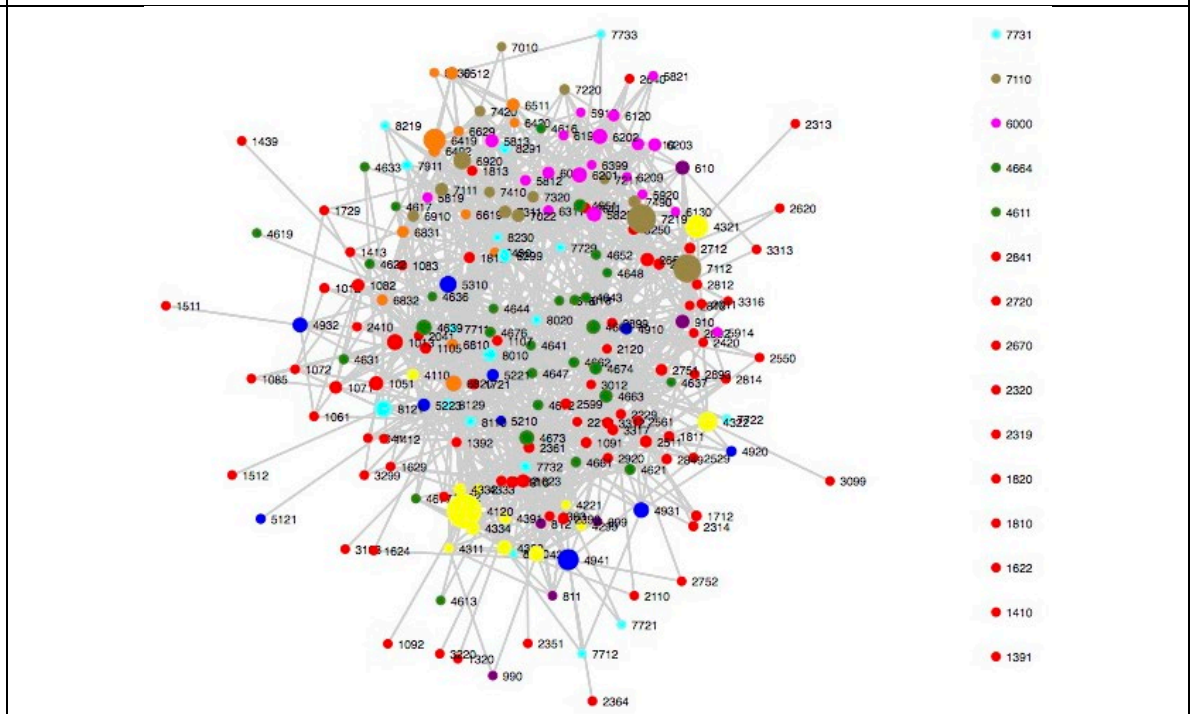
Stavanger (RSR=14.82)	
Trondheim (RSR=14.19)	

Figure 2: Medium cities regional skill relatedness networks

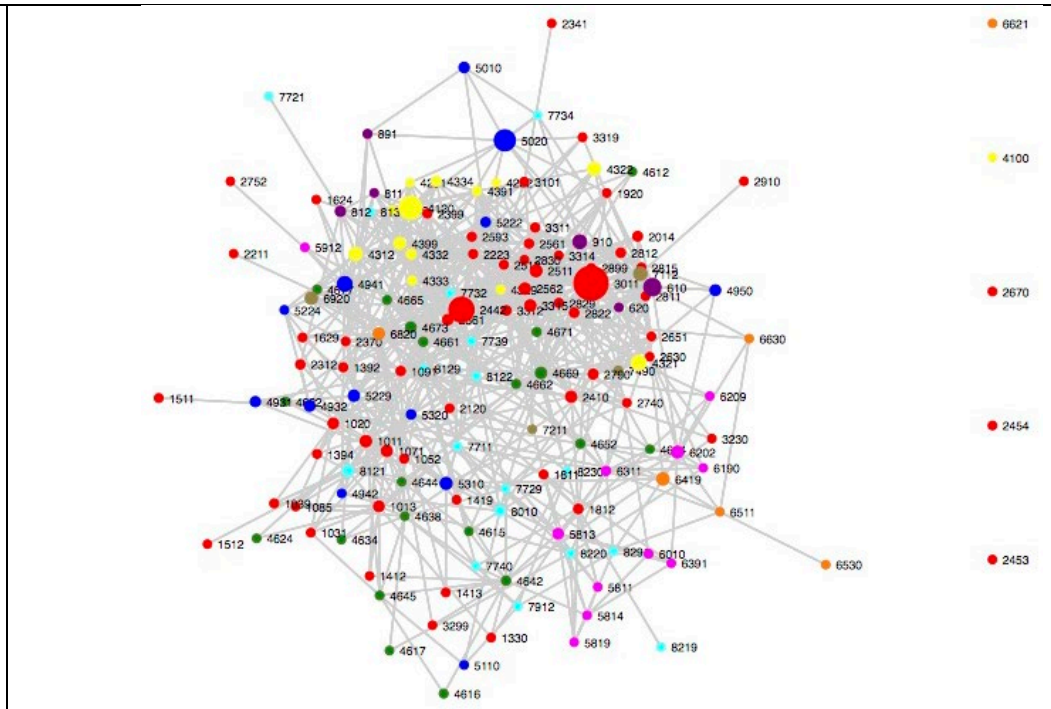
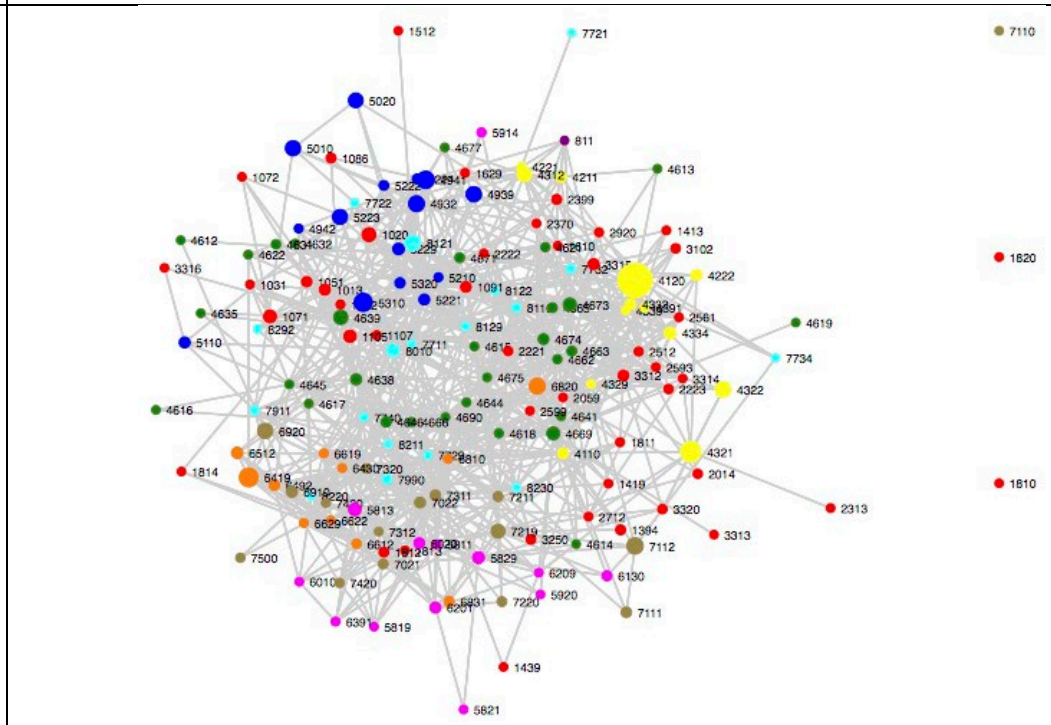
Haugesund (RSR=12.18)	
Tromsø (RSR= 10.89)	

Figure 3: Small cities regional skill relatedness networks

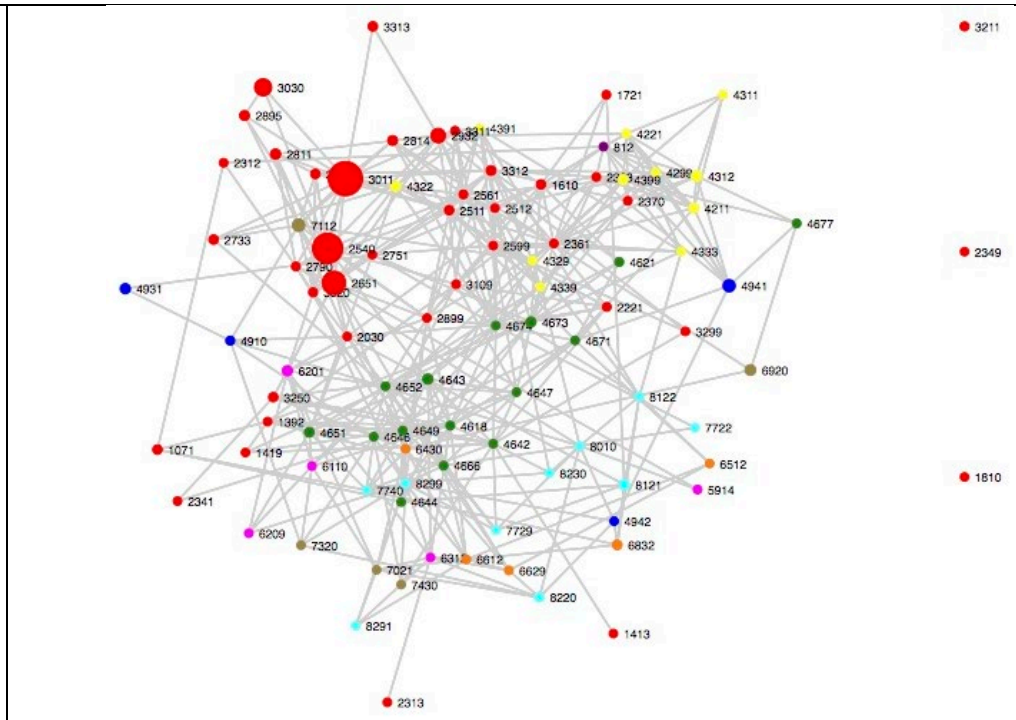
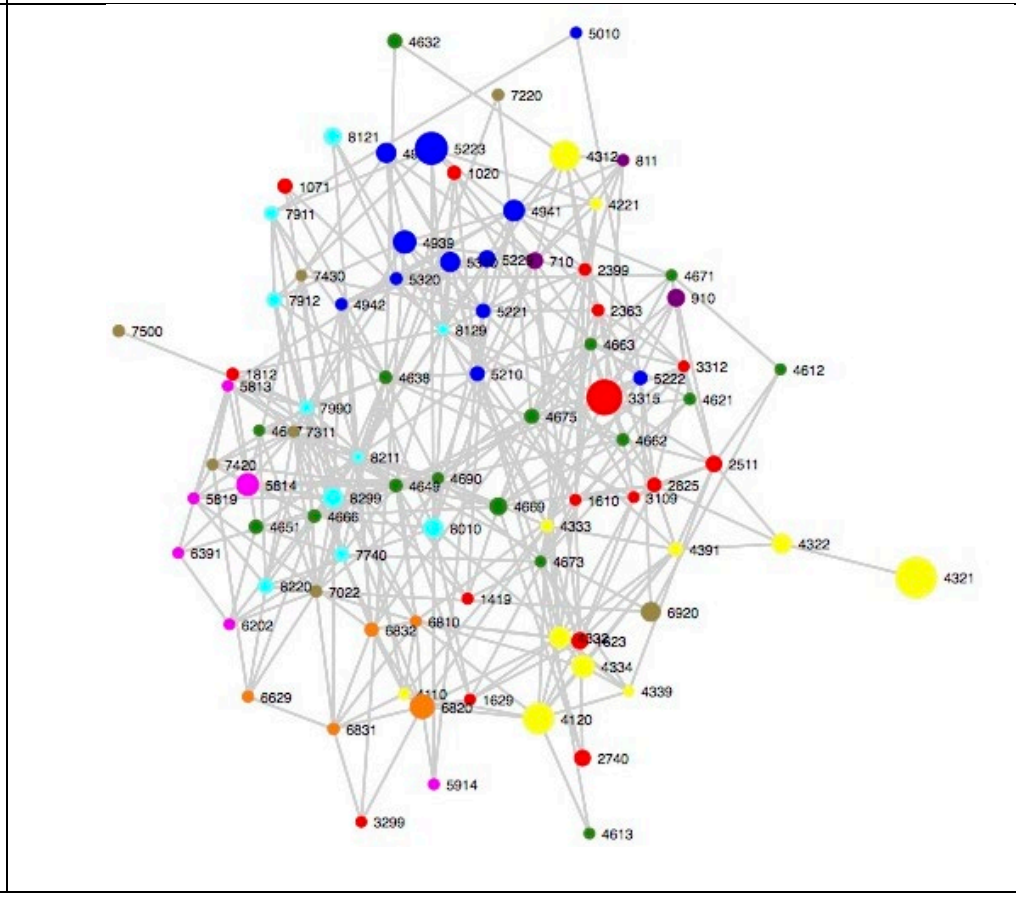
Kongsberg (RSR = 9.69)	
Kirkenes (RSR = 5.61)	

Figure 4: Rural regions regional skill relatedness networks

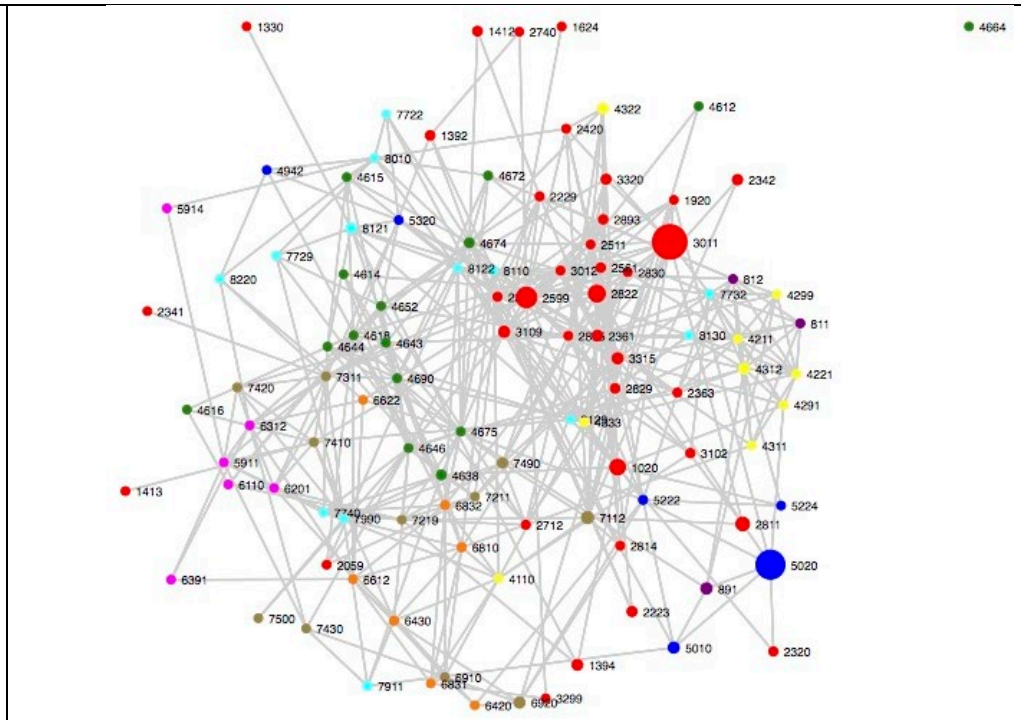
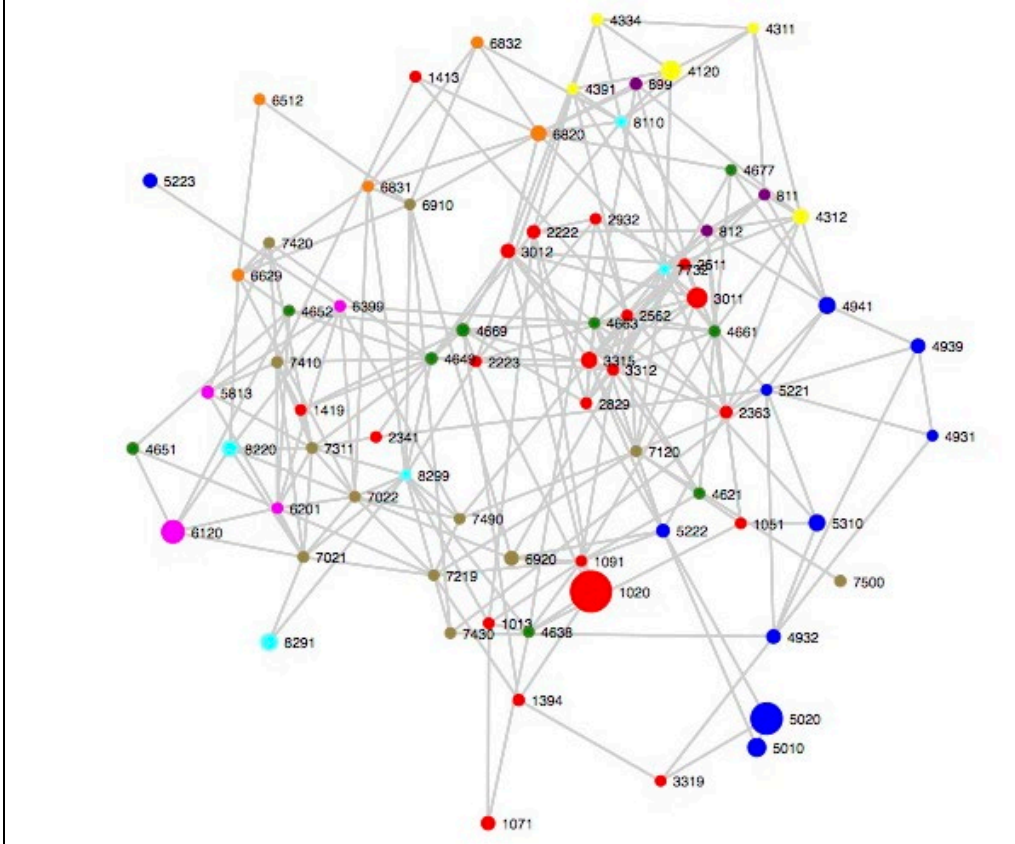
Ulsteinvik (RSR = 8.90)	
Rørvik (RSR = 4.18)	

Table 1: Large cities, regional skill relatedness and related variety scores

	RSR		RV	
	Score	**Rank**	**Score**	**Rank**
Oslo	16.69	1	1.47	1
Stavanger	14.82	2	1.02	4
Bergen	14.74	3	1.17	3
Trondheim	14.19	4	1.24	2

Table 2: Medium cities, regional skill relatedness and related variety scores

	RSR		RV			RSR		RV	
	Score	**Rank**	**Score**	**Rank**		**Score**	**Rank**	**Score**	**Rank**
Drammen	14.00	1	1.42	1	Hamar	12.00	9	1.22	6
Tønsberg/Horten	13.38	2	1.33	3	Ålesund	11.94	10	1.13	9
Fredrikstad/Sarpsborg	12.93	3	1.39	2	Molde	11.64	11	1.01	14
Kristiansand	12.86	4	1.12	10	Moss	11.60	12	1.26	5
Sandefjord/Larvik	12.72	5	1.26	4	Gjøvik	11.34	13	1.07	11
Skien/Porsgrunn	12.51	6	1.17	7	Tromsø	10.89	14	1.15	8
Haugesund	12.18	7	0.90	16	Bodø	10.85	15	1.01	13
Arendal	12.08	8	0.98	15	Lillehammer	8.83	16	1.07	12

Table 3: Small cities, regional skill relatedness and related variety scores

	RSR		RV			RSR		RV	
	Score	**Rank**	**Score**	**Rank**		**Score**	**Rank**	**Score**	**Rank**
Askim/Mysen	10.56	1	1.21	1	Orkanger	8.21	16	0.73	23
Kongsvinger	10.17	2	1.08	2	Narvik	8.19	17	0.92	14
Sunnhordland	10.02	3	0.66	28	Mandal	8.12	18	0.80	22
Hønefoss	9.75	4	0.92	13	Alta	8.11	19	1.03	3
Kongsberg	9.69	5	0.68	27	Namsos	7.96	20	0.93	11
Kristiansund	9.52	6	0.97	5	Sogndal/Årdal	7.91	21	0.65	29
Steinkjer	9.19	7	0.95	9	Mosjøen	7.23	22	0.82	20
Levanger/Verdalsøra	9.02	8	0.83	18	Lofoten	7.22	23	0.80	21
Halden	8.90	9	0.70	25	Florø	7.13	24	0.68	26
Harstad	8.85	10	0.93	10	Ørsta/Volda	7.09	25	0.83	17
Notodden/Bø	8.71	11	0.95	8	Hammerfest	6.98	26	0.88	15
Mo i Rana	8.45	12	0.82	19	Voss	6.82	27	0.93	12
Elverum	8.39	13	0.99	4	Finnsnes	6.53	28	0.87	16
Egersund	8.38	14	0.65	30	Sandnessjøen	5.90	29	0.73	24
Førde	8.35	15	0.95	7	Kirkenes	5.61	30	0.96	6

Table 4: Rural regions, regional skill relatedness and related variety scores

	RSR		RV			RSR		RV	
	Score	**Rank**	**Score**	**Rank**		**Score**	**Rank**	**Score**	**Rank**
Ulsteinvik	8.90	1	0.63	24	Surnadal	6.10	15	0.67	22
Nordfjord	8.55	2	0.95	3	Tynset	6.03	16	0.80	11
Vesterålen	8.18	3	0.91	6	Andselv	5.97	17	0.76	15
Hadeland	7.97	5	1.05	1	Odda	5.90	18	0.74	17
Valdres	7.66	4	0.93	5	Oppdal	5.70	19	0.77	12
Hallingdal	7.46	6	0.94	4	Høyanger	5.66	20	0.42	27
Nord-Gudbrandsdalen	7.19	7	0.86	10	Sunndalsøra	5.46	21	0.39	28
Lyngdal/Farsund	7.17	8	0.76	14	Røros	5.34	22	0.68	21
Flekkefjord	6.85	9	0.72	18	Brønnøysund	5.14	23	0.71	19
Midt-Gudbrandsdalen	6.83	10	0.90	7	Setesdal	4.94	24	0.74	16
Risør	6.62	11	0.86	9	Nord-Troms	4.70	25	0.76	13
Vadsø	6.34	12	0.95	2	Rjukan	4.53	26	0.64	23
Brekstad	6.34	13	0.71	20	Rørvik	4.18	27	0.60	25
Vest-Telemark	6.20	14	0.87	8	Frøya/Hitra	4.10	28	0.42	26