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Network Equilibrium and the Spread of Innovation in Technologically Cooperating European SMEs

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Abstract

European technical cooperation data from a recent large survey on small and medium enterprises (SMEs) is used to formulate a proxy network of country typical SMEs (CTSMEs) and reveal measures of centrality, bridging, density and structural equivalence. The longer established European member CTSMEs show similar structural equivalence, while the same is true for the new member states. We found that the innovativeness of a body of structurally equivalent CTSMEs is positively related to their gatekeeper role and ability to occupy balanced Simmelian as opposed to balanced ordinary bridging positions, highlighting the value of cooperation as opposed to competition in the growth of innovation. This brings enhanced understanding to organisations about areas for long term trans-regional business improvement.

Keywords: Innovation; Small and Medium Enterprises; Technical Cooperation; Brokerage; Social networks; Structure

1. Introduction

A firm's ability to recognize, absorb and apply new ideas, referred to by Cohen and Levinthal (1990) as its absorptive capacity, is enhanced by the way in which it spans organizational boundaries (Bellamy et al., 2014). If these boundaries are porous this allows scope for interaction with the environment and "open innovation" (Chesbrough, 2003) leading to the enhancement of value creation (Enkel, 2010; Lee et al., 2010). Laursen and Salter (2006) investigate the influence of search strategies for external knowledge and develop the concepts of breadth and depth as two components of the openness of individual firms' external search strategies. There is evidence within Europe that being open for innovation generally pays off provided that a suitable marketing strategy is adopted (Teichert & Bounchen, 2011; Grimpe & Sofka, 2009) together with an outgoing approach to technological cooperation in a technologically advanced environment (Sofka & Grimpe, 2010). This supports an SME's motivation for cooperation by having better access to larger markets, a cheaper supply of materials and components, but also a reduction of costs for various services and a smooth and assured meeting of client demands manifesting a network of direct and indirect ties which can enhance potential for increased prosperity (Villa, 2009).

The use of social network analysis has been applied to significant effect, from the examination of micro processes in social networks of those involved in organizational innovation in the automotive business (Obstfeld, 2005), to the way in which knowledge-sharing ties span internal boundaries in the R&D division of a global high-tech company (Tortoriello et al., 2010), to the examination of structural holes in Canadian mutual fund companies (Zaheer et al., 2005). Studies of firms' innovation output have also focussed on the structure of their supply, as opposed to their technical cooperation, networks. Bellamy et al. (2014) use social network analysis to demonstrate that supply network accessibility as well as absorptive capacity have a significant association with a firm's innovation output. Other studies include Havnes and Hauge (2004) who adopt an 'enterprise perspective' focussing on each SME's ego network as well as adopting a case study approach highlighting the cooperation development trend as steadily shifting towards more stable, long lasting, strategic and committed partnerships not withstanding a built in desire of SMEs to maintain independence and avoid the risk of disclosing sensitive information. Another study is the EIM Report (2010) summarising the internationalisation of European SMEs with details of the levels of technical cooperation and innovation with the positive contribution made to exports. Pearson and Cabras (2014) concentrate on northern European technical cooperation networks and carry out probit analysis to identify a strong link between connectivity factors and increased innovation.

Research has also been carried out showing that a country's economic structure, as well as its evolution, is influenced by the tacit knowledge available in neighbouring countries (Bahar et al., 2012). It is argued, on the one hand, that the exploitation of gaps in a network called "structural holes" (Burt, 1992) enables competitive advantage while on the other that embeddedness in a highly integrated network of equity-based collaborating partnerships enables companies to respond effectively to radical changes in their technological environment and promotes innovation through inter-firm trust (Roijakkers and Hagedoorn, 2007). Previous studies include that carried out by Amighini and Gorgoni (2013) who use social network analysis concepts of centrality, brokerage and structure to explore how the structure of the world trade (export and import) network in automotive components changed over the last decade. They also explore the roles played by each country in linking various geographical regional groupings.

One of the common tie structures associated with business activity is bridging ties. There are various types of such ties. One type has individual firms acting as bridges between other individual firms (Burt, 1992). Another has individual firms acting as bridges between groups of other firms, where the groups are defined according to geographical proximity (Amighini and Gorgoni, 2013). Some researchers have focussed on the finding that innovative and technological patent diversity of firms peaks when there is a balance between the location of newly formed ties within and outside of the main network component (Gulati et al., 2012), where the components are identified by clustering methods. They thereby demonstrate a dynamic equilibrium which evolves over time as well as uncovering an inverted U-shaped evolutionary pattern to a small world structure, whereby an increase in the smallworldliness of the system is followed by a later decline. Another type of bridging tie, known as a Simmelian tie (Simmel, 1950), with another party requires the presence of common third-party ties which enhance the collaborative aspect of cooperation. It is the sort of tie that spans organizational boundaries and is conducive to the generation of innovations (Krackhardt and Kilduff, (2002); Obsfeldt, (2005); Tortoriello and Krackhardt, 2010).

Studying the structure of technical cooperation networks leads to the concept of structural equivalence rather than geographical proximity or clustering as a determinant of group membership. Structurally equivalent actors tend to mimic each other which, for firms, means that they tend to form similar tie structures when they engage in competitive and cooperative behaviour (Friedkin, N. 1998; Mizruchi, 1990). This provides a different view of the way in which groups or 'blocks' of actors engage with each other by studying the way in which individuals act as bridges (non-Simmelian and Simmelian) between blocks of other actors. It enables the study of within and outside of block ties and enables the formulation of a hypothesis on the association between the balance between such ties and innovativeness. Another feature of this approach is the light it shines on each actor's capacity to play a brokerage role (Gould and Fernandez, 1989) within its own block and the overall block structure. Of typical importance in this view is the role played by a gatekeeper who acts as both a monitor of the environment and translator of the technical information into a form understandable to the members of its group (Tushman, 1977) and so improves the absorptive capacity of each group member for innovation (Cohen and Levinthal, 1990).

Marshall (1920) introduced the concept of a representative producer to resolve issues around market equilibrium and the governance of the supply price of a commodity. Recent developments in social capital and network theory lead us to the formulation of a related network concept, which is used for investigating issues around the balance (or equilibrium) of network structures and the spread of innovation.The actors in our study are therefore formed by averaging the economic and network characteristics of each country's SMEs in order to apply social network methodology to uncover the network structure and economic and innovation activity of typical firms whose membership ranges across all European countries. We introduce the term 'country typical SME' (CTSME) representing the typical or representative SME in a certain country who's characteristics are derived from the networking and economic details of the SMEs interviewed in each of 33 European countries in a large survey of over 9480 SMEs. We thereby construct a proxy network of 33 country typical SMEs who's economic and network behaviour are extracted from the SMEs surveyed in each country and whose characteristics build a picture of how a typical SME behaves in a particular country with regard to its innovation activity and technical cooperation links with typical SMEs in other countries. We then employ structurally equivalent blocks of CTSMEs, rather than geographically or economically defined clusters (Villa, 2009), in order to explore fundamental similarities in the way in which blocks of actors emulate each other's network behaviour as well as the balance which occurs within and outside of these blocks. Our study helps address questions about the way in which typical firms choose to cooperate with bodies in other countries as well as which countries are close with regard to technical cooperation.

Economic or knowledge-based factors also influence innovation and so are included as control variables. We might, for instance, expect growth in the workforce and turnover, as signs of healthy economic progress, to be associated with a firm's innovative activity (Freel & Robson, 2004). The age of an SME could also count since SMEs take time to absorb and accumulate the knowledge required for innovation (Cohen & Levinthal, 1990; Zaheer et. al., 2005; Obstfeld, 2005). An SME might also increase opportunities for innovation by investment abroad (EIM Report, 2010) or by the receipt of government financial or logistic support (Garcia & Mohnen, 2010; Lin & Ho, 2008). These and the above social network issues are addressed by developing a technical cooperation network using data from a survey on the internationalisation of small and medium enterprises (SMEs) carried out in 33 European countries (EIM Report, 2010).

In the following sections we describe our methods, establish our hypotheses and outline our results. We both summarise and discuss our findings and close with implications for practice.

2. Theoretical background and hypotheses development

2.1 Theoretical Background

We formulate the technical cooperation links between the CTSMEs in different European countries into a matrix which can be viewed as a valued sociogram for analysis using sociometric methods displaying features which are characteristic of network data. One such feature is the asymmetric nature of the technical cooperation matrix. For instance, the Danish CTSME's preferences for technical cooperation with the Swedish CTSME are not the same as Sweden's for the Danish CTSME. We can therefore identify ways in which power is structured in the network. We can also uncover evidence of structural holes and other network features. The scores in this matrix do not, however, refer to ties between SMEs but between CTSMEs and measure the likelihood that technical cooperation relationships such as bridges between firms in respective countries exist. The CTSME network therefore acts as an indicator or proxy for the overall technical cooperation network between SMEs in Europe. The more preferences that are expressed for cooperation with SMEs in a particular country, given that at least one tie exists for each SME expressing named preferences due to the structure of the survey, then the more likely it is that ties exist between the countries' firms[1].

2.2 Hypotheses Development

We noted above that there is evidence within Europe that being open for innovation generally pays off provided that a suitable marketing strategy is adopted (Teichert & Bounchen, 2011; Grimpe & Sofka, 2009) together with an outgoing approach to technological cooperation (Sofka & Grimpe, 2010). Formulating a preference for cooperation is, according to this view, the first step in achieving improved innovation. We therefore state our first hypothesis as:

Hypothesis 1: CTSMEs enhance their innovativeness by having a strong preference for technical cooperation measured by high network outdegree

The term 'structural hole' was introduced by Burt (1992; 2005) to describe aspects of positional advantage or disadvantage determined by the way firms are embedded in neighbourhoods. A structural hole is an absent tie or relationship between partners (nodes) in a firm's network such that firms which occupy a position which bridges structural holes are better positioned to outperform other firms which do not occupy such positions. A key part is played by 'bridges' who act as links between clusters of firms as information benefits are expected to travel over bridges. One of the tasks for a strategic firm in building an efficient technological innovation network is to focus on the maintenance of bridge ties between groups of firms in the neighbourhood (Zaheer & Bell, 2005; Soda, 2011). Bridge ties are valuable in separating non-redundant information sources so that non-overlapping innovative ideas are brought together (Reagans & McEvily, 2003; Feng et al., 2011). The structure of alliance networks, then, strongly influences their potential for knowledge creation (Schilling & Phelps, 2007) with non-redundant connections contracting the distance between firms. This leads to the formulation of our second hypothesis:

Hypothesis 2: CTSMEs enhance their innovativeness by bridging structural holes in their technical cooperation network

As a corollary it has been argued that network closure, characteristic of dense networks, does not enhance firm performance since fewer structural holes appear in such networks (Zaheer and Bell, 2005; Soda, 2011). We therefore also test the network hypothesis for density:

[1] We occasionally refer to a country typical SME by the name of the country (e.g. "Austria" instead of "Austria's CTSME").

Hypothesis 3: CTSMEs reduce their innovativeness by occupying dense technical cooperation networks

The concept of structural equivalence describes the way in which firms behave similarly with regard to their pattern of network bonds, such as symmetry, transitivity and reflexivity, even if they do not actually have ties with each other (Friedkin, N. 1998; Mizruchi, 1990). The theory of structural equivalence has developed through the use of block models (White et al., 1976) and has subsequently been used in the analysis of business networks (Burt, 1987; Todeva, 2006; Pallotti et al., 2011), where the leading assumption is that structurally equivalent actors tend to mimic each other which, for firms, means that they tend to form similar tie structures when they engage in competitive and cooperative behaviour. The structurally equivalent blocks can also be incorporated into the methods of Gould and Fernandez (1989) to categorise brokerage roles, such as gatekeeper and liaison by group membership. Of particular interest is a gatekeeper who both monitors the environment and translates the technical information into a form understandable to the members of its group (Tushman, 1977) and so improves the absorptive capacity of each group member for innovation (Cohen and Levinthal, 1990). In our context the 'group' is the structurally equivalent block in the technical cooperation network of CTSMEs. In this way the member CTSMEs benefit from the overall gatekeeping capacity of their block. On the other hand a liaison CTSME passes technical information between members of other blocks and so limits its own absorptive capacity (through limited engagement), but not necessarily the absorptive capacity of the members of its block, for the development of innovation. This leads to the formulation of the next two hypotheses:

Hypothesis 4: A CTSME reduces its innovativeness by occupying a liaison role within its structurally equivalent block

Hypothesis 5: A CTSME's innovativeness is enhanced by its block's gatekeeping capacity

Central to Cohen and Levinthals' (1990) absorptive capacity is whether a firm stands at the interface between internal subunits within the firm and the external environment. The interface function can be diffused across individuals or organizations so that, when the expertise of most individuals within the organization differs considerably from those outside of it, some group members may profitably act as gatekeepers or boundary spanners. The gatekeeper therefore monitors the environment and translates it into a form understandable to the research group. Cohen and Levinthal (1990) highlight the need for a trade-off or equilibrium between inward-looking versus outward-looking absorptive capacities. Laursen and Salter (2006) argue that poor allocation of managerial attention can lead to firms engaging in too many (or too few) external and internal communication channels and propose equilibrium between the two types of engagement. Gulati et al. (2012) argue that technological patent diversity of firms peaks when there is a balance between the location of newly formed ties within and outside of the main network component. We therefore formulate our next hypothesis as:

Hypothesis 6: A CTSME enhances its innovativeness through balanced bridging ties within and outside of its structurally equivalent block of CTSMEs in the technical cooperation network

The structural hole concept has been challenged and refined during the debate between competitiveness and collaboration as the main drivers of innovative productivity. Obstfeld (2005) introduces a 7-point *tertius iungens* (or “third who joins”) orientation scale to capture a predisposition to bring people together in collaboration and contrasts it with the *tertius gaudens* orientation emphasized in structural holes theory. He then positively relates the level of innovation to the *tertius iungens* scale as well as diverse social knowledge and dense social networks in automotive manufacture. Tortoriello and Krackhardt (2010) study the conditions under which having bridging ties that span organizational boundaries are conducive to the generation of innovations and conclude that a particular type of bridging tie known as a Simmelian tie is associated with the generation of innovations. The work relates to that of Obsfeldt (2005) and Krackhardt and Kilduff (2002) because a Simmelian tie (Simmel, 1950) with another party requires the presence of common third-party ties which enhance the collaborative aspect of cooperation together with the acquisition of innovative information. The seventh hypothesis is therefore formulated from the brokerage refinement between competitiveness and collaboration and the value of Simmelian ties in promoting innovation using the equilibrium measure formulated in Section 3.2 (Obstfeld, 2005; Tortoriello and Krackhardt, 2010; Cohen and Levinthal, 1990; Laursen and Salter, 2006):

Hypothesis 7: A CTSME enhances its innovativeness through balanced Simmelian bridging ties within and outside of its structurally equivalent block of CTSMEs in the technical cooperation network

Economic factors include: growth in the workforce and turnover, as signs of healthy economic progress, (Freel & Robson, 2004); the age of an SME, since SMEs take time to absorb and accumulate the knowledge required for innovation (Cohen & Levinthal, 1990; Zaheer et. al., 2005; Obstfeld, 2005); increased opportunities for SME innovation by investment abroad (EIM Report, 2010); the receipt of government financial or logistic support (Garcia & Mohnen, 2010; Lin & Ho, 2008; Rothwell & Dodgson, 1991). All of these factors could be associated with a firm’s innovative activity and so we treat them as control variables and apply least squares regression analysis to identify a relationship between the network and economic variables and innovativeness as dependent variable.

3. Methods

3.1 The Data

The data were extracted from a survey carried out by EIM (Business and Policy Research) of 9,480 SMEs in 33 European countries (including some countries such as Turkey which is currently outside the EU) during spring 2009. The number of SMEs interviewed in each country was in proportion to the population size of the country. 7% of the SMEs in the 33 countries surveyed had technological cooperation with enterprises abroad: the larger the company the more likely is the occurrence of technical cooperation. Initial findings were published in a report (EIM, 2010). Regarding innovativeness the respondents to the questionnaire were asked the following question:

Did your enterprise introduce any new product or service on the market in the last 3 years which is new for our sector in this country?

If the respondent answered ‘yes’ then a dichotomous variable with value 0 (no) or 1 (yes) was formulated for that SME. These scores were averaged across all SMEs in each European country, which produced a scalar variable suitable as a dependent variable for least squares regression analysis. It was not possible to determine if the companies had actually introduced any new product or service as this was self-reported innovative activity. However, we checked the figures against those published by the European Union for 2006 (Eurostat Yearbook, 2010) and found a weakly positive correlation for all countries surveyed (Spearman's rho = 0.304, *p=0.109)* while there was a strong positive correlation for countries with Simmelian ties (Spearman's rho = 0.431, *p=0.025*).

3.2 Technical Cooperation Matrix

One of the questions in the survey asks the respondent who represents the SME:

Did your enterprise in 2006 -2008 have any technological co-operation (e.g. technology transfer) with enterprises abroad?

If the answer to this question is 'yes' the survey then asks:

What are the top three countries for Technology co-operation / Technology transfer with enterprise abroad?
LIST ONLY ONE COUNTRY PER LINE

1. …………………………
2. …………………………
3. …………………………

Even though the respondent in the latter question already engages in technical cooperation with at least one country the question may indicate a preference rather than actual cooperation for some of the named countries. We use this data to construct a proxy technical cooperation matrix consisting of the country typical SMEs (CTSMEs) in Europe. The matrix entries are weighted averages of the scores given by SMEs in a particular country to their preference for technical cooperation with firms or organisations in other countries[2]. The first named country is given the highest weight (0.5) since it is the most likely country where actual technical cooperation is taking place, as we know that the SME is already engaged in some cooperation. The other named countries are given weights of 0.3 and 0.2, respectively, reflecting preferences and the lower probability that actual cooperation is happening with these countries. So, for instance, 6 Danish companies named Sweden as first choice for technical cooperation, 4 as second choice and none as third choice, giving an overall preference of Danish firms for technical cooperation with Swedish firms of 100x(0.5 x 6 + 0.3 x 4 + 0.2 x 0)/197 = 2.13, where there are 197 Danish SMEs in the survey and the score is expressed as a percentage. In this way we develop a 33x33 matrix with elements containing the weighted average of scores for SMEs in all 33 European countries. These weighted averages measure the representative score for SMEs in a particular country.

3.3. Balanced Ties

The concept of structurally equivalent block applies to a group of countries that have similar relationships with the same other countries in the technical cooperation network. We use two types of ties, ordinary and Simmelian bridging (Section 4.6 and Figures 3a and 3b) ties within and outside of structurally equivalent blocks to investigate any relationship with CTSME innovativeness. Krackhardt & Stern (1988) proposed the E-I index as a measure of homophily/heterophily relating to internal and external relationships. It is defined as:

$$\text{E-I Index} = (E-I)/(E+I)$$

where E is the number of external (between-group) relationship edges and I is the number of internal (within-group) relationship edges. Smaller values indicate homophily while larger

[2] The survey does not incorporate information on ties linking SMEs to other SMEs in the same country

values indicate heterophily. The index can be applied to the block structures containing CTSMEs so that, for instance, Sweden can be given an index value between -1 and +1 indicating the proportion of ties that lie within the Baltic Sea block of countries compared to those lying outside of this block. A score of -1 indicates that all ties are internal while a score of +1 indicates that all are external. We formulate the *balanced* E-I Index from our discussion of Hypothesis 6 (above) in order to reflect a balance between internal and external ties:
Balanced E-I Index for CTSME as a function of its E-I index =

$$\frac{1 - \mathrm{abs}(\mathrm{median}(\mathrm{E-I\ Index}) - (\mathrm{E-I\ Index})) + \mathrm{median}(\mathrm{E-I\ Index})}{1 + \mathrm{median}\ (\mathrm{E-I\ Index})} \qquad (1)$$

where the median of the E-I index is calculated across all CTSMEs with bridging ties. The balanced E-I Index has been standardised so that it has values between 0 and 1. This index reflects the equilibrium recommended by Cohen and Levinthal (1990) by reaching a maximum when the number of inward-looking ties for a CTSME within the block structure is balanced against the number of outward-looking ties according to the characteristics of the block to which the CTSME belongs.

Work by Obstfeld (2005) and Tortoriello & Krackhardt (2010) highlighted the value of Simmelian as opposed to just bridging ties. Simmelian ties are associated with greater technical cooperation in the presence of a third collaborator and are thought to provide a more stable and trusting environment for effective innovation. We therefore also formulate in a similar way the *balanced* Simmelian E-I Index in Hypothesis 7 (above) using the formula (1) where the median of the E-I index is calculated across all CTSMEs with Simmelian ties. If there are no Simmelian ties for a country (vacuous case) then it is excluded from the analysis. The index is also standardised so that its values range from 0 to 1. The maximum value of both balanced E-I indices occurs when the E-I index of a CTSME equals the median E-I index of all CTSMEs. If this median is greater than zero then the CTSMEs of all blocks are generally more outward-looking and vice-versa if the median is less than zero. For this case the median E-I index of all CTSMEs with bridging ties is 0.72 while for the 26 countries with Simmelian ties it is 0.28, indicating in both cases a generally positive outward-looking approach.

3.4. Economic Variables

We incorporate a number of economic variables as controls on innovativeness. One such factor is whether or not the CTSME is expanding which relates to economic growth (Freel & Robson, 2004). Another is whether or not a CTSME receives government support (Garcia & Mohnen, 2010; Lin & Ho, 2008; Rothwell & Dodgson, 1991), which may occur either through financial or by logistical assistance. The effects of other economic variables, such as increase in turnover, age of SME (as a sign of maturity and absorptive capacity) and investment abroad (Pearson and Cabras, 2014), were tested but found not to have any significant effect on innovation levels for our model.

4. Results

We categorise countries on the strategic and structural characteristics of the technical cooperation networks formed by their firms. We make use of the social network software UCINET (Borgatti and Everett, 2002) to calculate the measures of centrality and brokerage. We then perform regression analysis with innovativeness as dependent with explanatory network and economic variables. Country population is used as a control variable as a precaution lest the sample sizes for each country were chosen disproportionately.

4.1 Innovative Firms

Innovative activity is measured dichotomously and indicates whether the SME introduced any new product on the market in the period 2006-2008. Table 1 shows the proportion of firms in each country who have introduced such a new product. Some information was not forthcoming from the data set (or was limited in its scope). We were not, for example, able to extract precise details on the type of innovation in which the firms were engaged. Nor were we able to discover the amount of R&D carried out by the firms. Iceland, Turkey, Bulgaria, Finland, Poland, Lithuania and Norway all have high proportions (>30%) while France, Luxembourg, United Kingdom and Portugal have low proportions (<15%) with the other countries falling between the two extremes. It is noted that the survey was carried out among SMEs and not larger firms with more than 250 employees. According to the Eurostat Yearbook (2013) large enterprises tend to innovate more than SMEs so that countries with a high proportion of large enterprises such as Germany, which had the highest propensity in Europe in 2008 to innovate measured across all enterprises, do not show such high SME innovation figures.

4.2 Egonet Density

A country's ego-network includes the specific country and all the countries that are connected to it through technical cooperation (the connection could be either a link named by that country or a link from another country naming it). Table 2 illustrates the egonet density (*D*) for each country expressed mathematically as $D=2g/(n*(n-1))$, where g is the number of actual ties between all countries in the egonet and n is the number of countries in the egonet. This acts as an indication of the degree of cohesion within that country's overseas innovation network. According to Soda (2011) we would want a low density network to increase the likelihood of increased performance. We see that the countries with the largest egonets and lowest densities are Germany followed by Italy, UK, France, the Netherlands and Spain.

4.3 Centrality

The centrality of a country with respect to its firms which engage in technical cooperation abroad is most simply measured by the number of network ties surrounding the country. If this is the case then countries with the highest centrality tend to be the most powerful as information will tend to flow through them before it reaches others. The simplest measures of centrality are indegree (measured by the total of the incoming weighted ties naming SMEs in a particular country) and outdegree (measured by the total of the outgoing weighted ties named by SMEs in a particular country). For indegree we see from Table 1 that Germany has the highest (95.08) followed by Italy (34.92), UK (27.60) and France (21.88) with all other countries having measures below 18. Conversely these countries were among the lowest for outdegree while the countries with high outdegree (Iceland at 30.81) tended to be among the lowest for indegree. We also tested for the Freeman betweeness centrality but found little significant effect on innovativeness for this model.

	Innovate	EgoNet%	Density	Indegree	Outdegree	k-local Bridging
Austria	0.23	87.90	0.35	12.46	9.27	30
Belgium	0.19	84.80	0.36	11.03	7.96	20
Bulgaria	0.35	63.60	0.39	2.08	10.10	36
Croatia	0.20	45.50	0.47	1.57	10.18	22
Cyprus	0.26	27.30	0.50	0.49	9.52	16
Czech	0.28	60.60	0.43	7.25	4.67	12
Denmark	0.26	72.70	0.44	13.00	10.76	30
Estonia	0.19	51.50	0.53	2.18	13.80	32
Finland	0.34	66.70	0.45	9.78	6.75	23
France	0.11	97.00	0.31	21.88	1.82	20
Germany	0.23	100.00	0.23	95.08	3.84	30
Greece	0.22	57.60	0.44	6.02	9.22	57
Hungary	0.18	60.60	0.42	3.50	6.70	24
Iceland	0.44	54.50	0.44	0.17	30.81	65
Ireland	0.18	45.50	0.51	1.53	5.86	16
Italy	0.21	100.00	0.29	34.92	2.97	28
Latvia	0.22	54.50	0.51	2.13	16.98	34
Liechten	0.17	21.20	0.68	0.00	6.59	12
Lithuania	0.31	57.60	0.48	1.80	14.04	36
Luxem	0.12	27.30	0.66	0.24	9.32	16
Macedon	0.30	51.50	0.42	0.20	15.77	30
Malta	0.23	42.40	0.71	0.25	10.24	24
Netherlands	0.23	93.90	0.33	16.04	6.57	26
Norway	0.31	78.80	0.37	8.19	21.15	65
Poland	0.32	69.70	0.41	5.67	9.24	36
Portugal	0.15	48.50	0.46	0.68	7.17	26
Romania	0.18	63.60	0.42	2.50	12.84	36
Slovakia	0.22	60.60	0.39	2.24	13.10	28
Slovenia	0.19	54.50	0.50	2.19	10.46	26
Spain	0.18	93.90	0.34	9.53	5.30	28
Sweden	0.27	78.80	0.37	17.97	11.57	32
Turkey	0.35	66.70	0.45	7.57	8.30	34
UK	0.14	97.00	0.31	27.60	4.90	34

Table 1 Network and Brokerage Measures

4.4 Bridging

We begin with a simple measure of bridging applied across the whole technical cooperation matrix before considering the way in which CTSMEs can act as bridges between groups or blocks of CTSMEs with shared network characteristics. A feature of structural hole theory is the key part played by 'bridges' who act as links between other actors in the network as information benefits are expected to travel over bridges. A bridge therefore is an edge (i.e. a tie between two countries) whose removal disconnects the (technical cooperation) graph. A k-local bridge is an edge whose removal increases the distance of its endpoints to a value of k or more. We utilise the UCINET routine (Borgatti et al., 2002) which calculates the distance between the endpoints of each adjacent pair of vertices (countries) in the graph when the edge connecting them is deleted.

Table 1 shows the values of the k-local bridge distances for each country summed across all other countries. The top three countries (Iceland, Norway and Greece) have very high scores but also are characterised by high variability within the scores. So, while most edge scores for most countries are 2 some edge scores are much higher which leads to a greater sum shown in Table 1 as well as a higher variability. For instance, the edge between Iceland and Malta has an individual score of 33, which, as the number of countries in the network, is the maximum possible score attainable. This is because Iceland is the only country who’s SMEs express a preference for technical cooperation with companies in Malta. Similarly the edge between Norway and Iceland also has an individual score of 33, since Norway is the only country with SMEs naming a preference for Icelandic companies with regard to technical cooperation. The same applies to the relationship between Greece and Cyprus, since Greece is the only country whose SMEs name Cyprus.

4.5 Structural Equivalence

A group of countries that have similar relationships with the same other countries in the technical cooperation network form a structurally equivalent block. Structural similarity may stimulate a competitive orientation in which countries’ firms are attentive to each other’s status and interests (Burt, 1987) as well as a cooperative orientation in which they are encouraged to engage in collaborative research (Roijakkers and Hagedoorn, 2007). Accordingly the strategy for countries in the same block may be initially identified as following a joint policy of increasing innovativeness since their networks are structurally equivalent. We apply this concept to the data in this study and identify, initially two, then four structurally equivalent blocks (SE Blocks), making use of the UCINET structural equivalence optimisation routine (Borgatti and Everett, 2002). The two structurally equivalent blocks are:

1: Austria Belgium Denmark Finland France Germany Italy Netherlands Norway Poland Spain Sweden UK
2: Bulgaria Croatia Cyprus Czech Estonia Greece Hungary Iceland Ireland Latvia Liechtenstein Lithuania Luxemburg Macedonia Malta Portugal Romania Slovakia Slovenia Turkey

The results indicate that the longer established European members show similar structural equivalence, while the same is true for the new (and smaller) member states.

Further analysis identifies four blocks, which are illustrated in Figure 1 showing that certain Baltic Sea countries (Block 4) exhibit common structural equivalence. These countries also have higher innovation scores. The countries with the lowest innovation scores lie in the structurally equivalent block in mainland Europe. Many of the countries that have recently joined Europe are in the middle two blocks regarding innovation.

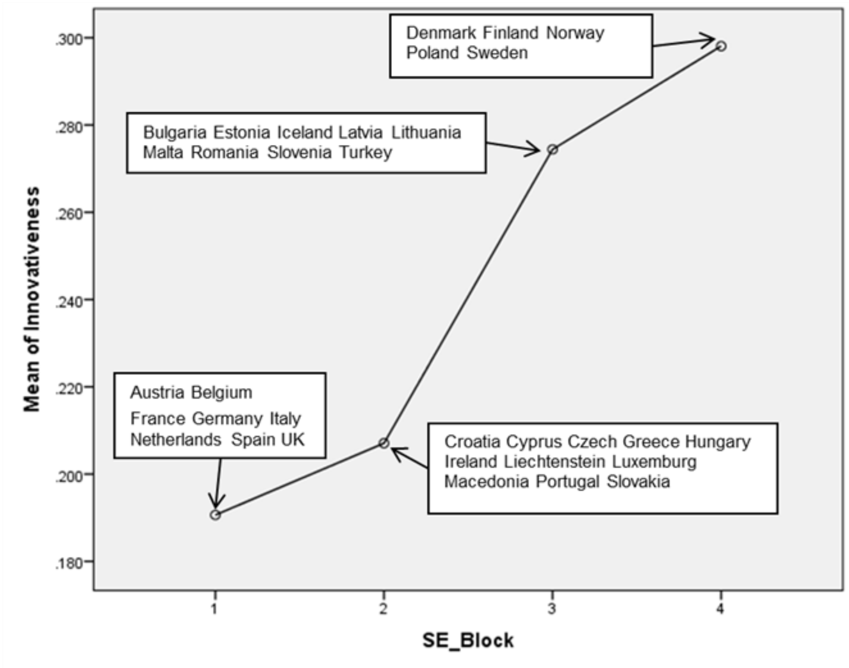

Figure 1 Means Plot for Four Structurally Equivalent Blocks

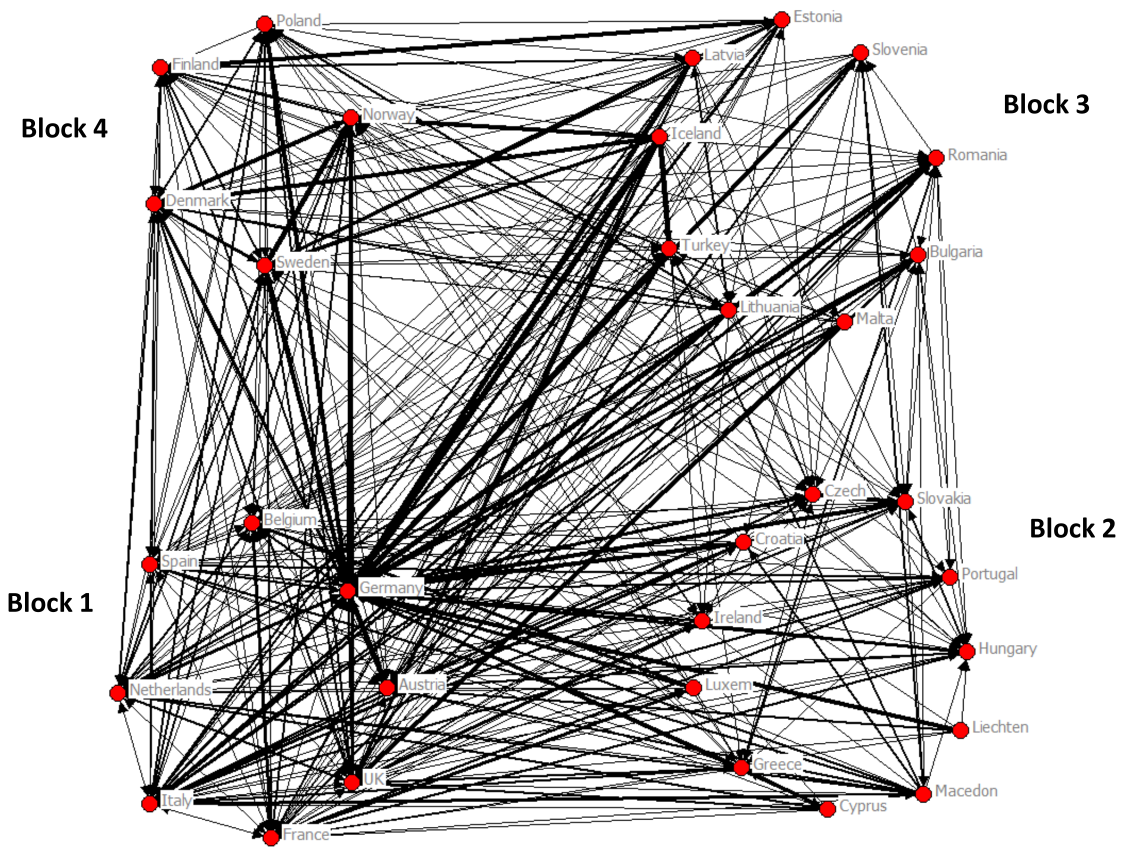

Figure 2 Digraph illustrating Structurally Equivalent Blocks
(Produced using Netdraw. Line size indicates strength of tie)

Figure 2 shows the countries covered by the survey in the European network together with the directional edges connecting them and the grouping into structurally equivalent blocks. The line sizing indicates the strength of the relationship between the countries and highlights Germany's powerful position. The blocked adjacency matrix derived from carrying out structural equivalence shows that blocks 1 and 4 (Figures 1 and 2), constituting the oldest established EU countries, attract dense ties from other blocks with the exception of block 2 which does not have as many dense ties to block 4 as to other blocks.

Brokerage Roles†	Definition	Interpretation
Coordinator A-**A**-A	A country that imports ideas* from countries belonging to its own block** and exports to countries belonging to its own block Example (coordinator in bold): Netherlands→ **Belgium**→ France	Coordinators link different countries within the same block, therefore tightening the within block technical cooperation network they belong to (in the example, bilingual Belgium engages in technical cooperation with France while also being engaged by the Netherlands)
Gatekeeper B-**A**-A	A country that imports ideas from a country belonging to a different block and exports to countries within its own block Example (gatekeeper in bold): Turkey→ **Sweden**→ Finland	Gatekeepers act as suppliers of imported ideas to countries belonging to their own block (in the example, Sweden engages with Finland while also being engaged by Turkey where the Swedish Research Institute in Istanbul (SRII) is based)
Representative A-**A**-B	A country that imports ideas from countries within its own block and exports to countries outside the block Example (representative in bold): Germany→ **UK**→ Ireland	Representatives act as exporters of ideas produced within their own block and destined to countries in other blocks (in the example, UK is engaged by Germany while also engaging Ireland with which UK has shared academic-industry collaborations)
Consultant B-**A**-B	A country that imports ideas from and exports to countries belonging to the same block, but different from its own Example (consultant in bold): Croatia→ **Italy**→ Greece	Consultants act as external players to a technical cooperation network in another block, linking countries belonging to that block from the outside (in the example, Italy is engaged by Croatia (which exports goods mainly to Italy) while also engaging Greece, which has strong trading links with Italy)
Liaison B-**A**-C	A country that imports ideas from and exports to countries belonging to other blocks Example (liaison in bold): Iceland→ **Norway**→ Germany	Liaisons link countries belonging to technical cooperation networks in different blocks by acting as both importers and exporters of ideas (in the example, Norway is engaged by Iceland, which collaborates through RANNIS, while also engaging Germany where Norway has research and energy trading links)

* 'A country that imports ideas' refers to a CTSME being named by another CTSME with regard to technical cooperation and vice versa for exports

** The term 'block' refers to the group of structurally equivalent countries with regard to technical cooperation rather than regional proximity

† A, B and C are distinct blocks

Table 2 Brokerage Roles (Gould and Fernandez, 1989; Amighini and Gorgoni, 2013)

We use Gould and Fernandez (1989) methods making use of the structurally equivalent blocks to categorise the brokerage roles, such as gatekeeper and liaison by group membership in order to investigate role relationships between the blocks. Table 2 illustrates the roles played by a broker, which in this case represents a country's typical SME (CTSME) within a block of structurally equivalent countries. The CTSME can act as a broker in five different ways. For instance a broker acting as a gatekeeper receives technical knowledge from a CTSME in a different country block and then shares this knowledge with a CTSME in another country within its own block.

	Coord inator	Gate keeper	Represent ative	Consult ant	Liaison	Total	Balanced E-I Index_All	Simmelian Ties	E-I Index Sim	Balanced E-I Index_Sim
Block										
Austria	0	0.9	5.497	10.494	16.999	33.89	0.31	50	0.32	0.97
Belgium	0.67	0.76	2.538	2.6	6.231	12.799	0.07	46	-0.65	0.27
Germany	0.368	0.95	3.593	1.042	7.363	13.316	0.43	94	-0.11	0.70
Italy	0.316	2.892	9.723	14.908	15.212	43.051	0.25	78	-0.21	0.62
UK	0.67	0.725	18.669	13.497	27.294	60.855	0.27	88	-0.20	0.62
Spain	0.1	1.851	1.982	3.428	12.544	19.904	0.33	54	0.04	0.81
Netherlands	0	0.425	5.069	4.53	14.479	24.503	0.26	70	0	0.78
France	0	1.518	4.25	8.158	18.099	32.025	0.23	46	-0.30	0.54
Average	***0.266***	***1.253***	***6.415***	***7.332***	***14.778***	***30.043***	***0.269***	***65.750***	***-0.139***	***0.664***
Cyprus	0	0	0.125	0	0	0.125	0.75	0	0	-
Croatia	0.81	0.811	0.125	0	0	1.746	0.94	0	0	-
Ireland	0.125	0.236	0.143	0	0	0.504	0.87	2	1.00	0.44
Greece	1.125	6.661	0.278	0.1	0.993	9.156	0.91	2	1.00	0.44
Hungary	1.343	1.325	4.322	1.095	2.525	10.61	0.90	26	0.85	0.56
Czech	0.643	1.135	3.311	1.944	3.583	10.616	0.89	4	0.50	0.83
Macedon	0.5	0.111	0.958	0	0.726	2.296	0.97	0	0	-
Luxem	0	0	0	0.243	0.143	0.386	0.87	2	1.00	0.44
Liechten	0	0	0	0	0	0	0.87	0	0	-
Slovakia	3	4.111	3.686	0.669	1.084	12.55	0.72	14	0.57	0.77
Portugal	0	2.381	0	0.1	1.393	3.873	0.94	12	1.00	0.44
Average	***0.686***	***1.525***	***1.177***	***0.377***	***0.950***	***4.715***	***0.875***	***5.636***	***0.538***	***0.560***
Bulgaria	0.333	2.31	0.768	1.035	2.385	6.831	0.86	20	0.20	0.94
Lithuania	0.367	2.367	0.4	0.111	0.597	3.842	1.00	8	0	0.78
Latvia	0	0.333	0.31	0.111	0	0.754	0.96	4	-0.50	0.39
Romania	1.167	5.819	1.497	1.729	4.49	14.702	0.87	36	0.56	0.79
Estonia	0	2.333	0	0.292	0.403	3.028	0.95	4	-0.50	0.39
Slovenia	0	0	1.211	1.234	2.693	5.138	0.83	0	0	-
Malta	0	0	0	0	0	0	0.85	0	0	-
Turkey	0.75	2.317	1.548	1.802	3.869	10.286	0.91	24	0.50	0.83
Iceland	0	1	0	0	0.111	1.111	0.96	0	0	-
Average	***0.291***	***1.831***	***0.637***	***0.702***	***1.616***	***5.077***	***0.910***	***10.667***	***0.029***	***0.687***
Denmark	0.403	1.869	2.101	2.002	4.919	11.294	0.69	68	0.29	0.99
Finland	0	0.492	1.98	3.808	6.746	13.026	0.81	22	0.27	0.99
Sweden	0.111	5.773	0.81	4.935	12.969	24.598	0.98	84	0.40	0.91
Norway	0	1.629	4.768	13.878	21.366	41.64	0.65	20	0.20	0.94
Poland	0	1.877	5.297	5.455	18.917	31.546	0.87	70	0.63	0.73
Average	***0.103***	***2.328***	***2.991***	***6.016***	***12.983***	***24.421***	***0.800***	***52.800***	***0.358***	***0.912***

Table 3 Brokerage Role Scores (Weighted Method) and Simmelian block measures

Tables 3 and 4 result from performing brokerage analysis using the UCINET software (Borgatti et al., 2002). In Table 3 the countries, having been previously partitioned into structurally equivalent blocks, have been given brokerage scores where each row counts the weighted number of times that each country plays each of the five roles in the whole graph. The weighting is used because, in this context, we are more interested in group relations between blocks of countries. As an example suppose that a country, B, acts as a representative between countries A and C (Table 2) while some other actor, D, is also acting as a representative between A and C then B and D would each get half the score for this role rather than the full score.

Table 3 shows that UK has the highest total score due to its brokerage activity as a representative, liaison and consultant relating mainly to countries in block 2 and to a lesser extent block 4 (see also Table 4). These countries include Ireland and Cyprus with which the UK has strong ties. The next highest scorer is Italy which again acts as a representative, consultant and liaison but also gatekeeper involving block 2 and to a lesser extent block 4. Italy has contacts with block 2 countries Greece, Portugal and Ireland as well as contacts with block 4 countries Poland and Finland. The third highest scorer is Norway which plays a central role as liaison between block 3 and blocks 1&2 as well as acting as a consultant for block 3 and representative for block 1. Table 3 also illustrates the gatekeeper block average scores for each CTSME block. So, for instance, the same block average score of 1.525 is used for Ireland, Hungary and Portugal (as, indeed, for all CTSMEs in that block) as the value of the explanatory variable in the regression model (Table 6). This is because, according to hypothesis 5, the innovativeness of each CTSME in a block is improved by the overall gatekeeping performance of the member CTSMEs.

Block 1	*1*	*2*	*3*	*4*
1	0.25	4.25	1.25	0.88
2	1.00	5.88	2.38	3.63
3	0.00	4.75	1.25	0.38
4	0.00	3.00	0.75	0.00
Block 2	*1*	*2*	*3*	*4*
1	0.00	0.45	0.36	0.09
2	0.18	0.73	0.45	0.36
3	0.00	0.73	0.18	0.00
4	0.00	0.36	0.18	0.00
Block 3	*1*	*2*	*3*	*4*
1	0.00	0.44	0.56	0.22
2	0.11	0.56	0.56	0.33
3	0.00	0.44	0.22	0.11
4	0.00	0.22	0.67	0.00
Block 4	*1*	*2*	*3*	*4*
1	0.20	1.40	4.40	0.60
2	0.40	1.20	4.60	1.20
3	0.00	2.00	4.80	0.60
4	0.00	1.00	2.00	0.00

Illustrates block 1 acting as a consultant to block 2:
2-1-2 with score 5.88
(*See also Tables 2&3)*

Illustrates block 4 acting as a gatekeeper from block 2:
2-4-4 with score 1.20

Table 4 Brokerage Block Relations (Average Scores)

Table 4 illustrates the frequency with which countries in each block are involved in relations among and within each of the other blocks. We see, for instance, that the countries of block 1 (Austria, Belgium, Germany etc.) have stronger relations with countries in block 2 than other blocks. The score 5.88 refers to the role of consultant indicating the amount of connections made by block 1 countries acting as a consultant to block two countries by connecting a member of block 2 to another member of block 2 (2-1-2). The main consultants in block 1 are Italy, UK and Austria (Table 3). The score 4.25 refers to the role of representative indicating the amount of connections made by block 1 countries acting as a representative in block 2 (1-1-2). The main representative in block 1 is UK mostly involving block 2. The UK's other significant roles are as a consultant for block 2 and as a liaison between blocks 2 and 3 and also between blocks 2 and 4. The role of gatekeeper is reflected for each block by the scores attracted from other blocks. So, for instance, block 1 attracts a score of 1.0 from block 2 due mainly to the role of Italy as a gatekeeper (2-1-1). The main gatekeepers for block 2 are Greece and Slovakia, while for block 3 the main gatekeeper is Romania. The gate-keeping role for block 4 is mainly carried out by Sweden through attracting ties from block 2 countries giving a score of 1.20 (2-4-4).

4.6 Balanced Ties

Figures 3a and 3b illustrate the inverse U-shape of the plots of innovativeness against the ordinary and Simmelian E-I indices. The shape supports the formulation of the balanced E-I indices in Section 3.3, since the CTSMEs with E-I indices close to the median have the highest innovativeness.

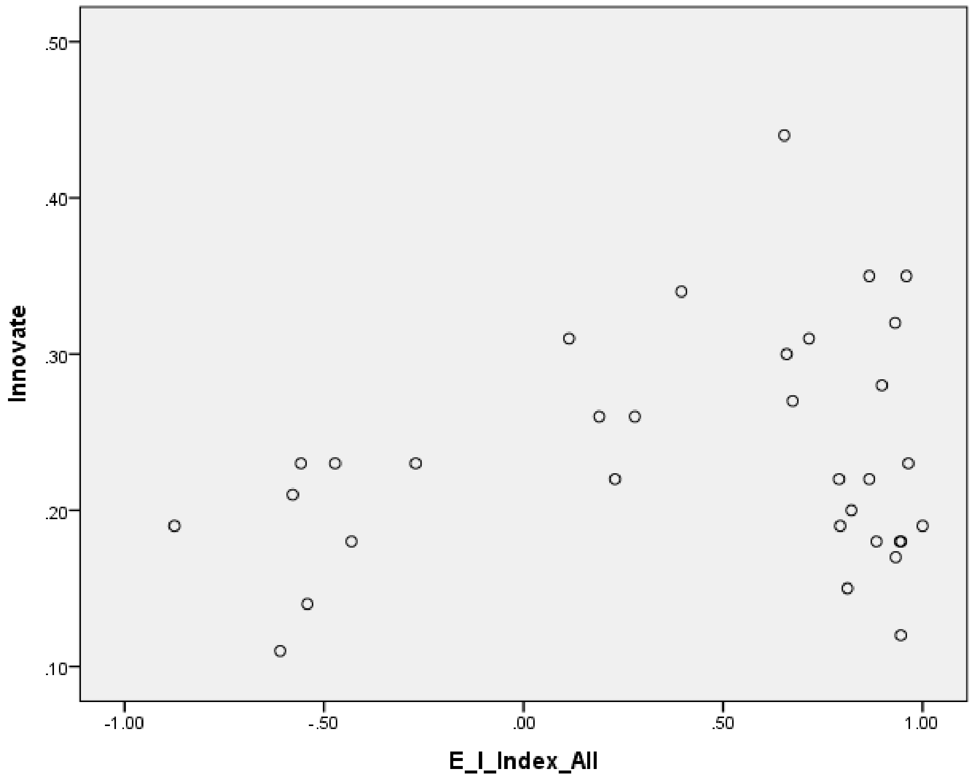

Figure 3a Inverse U-shape plot of innovativeness against E-I index

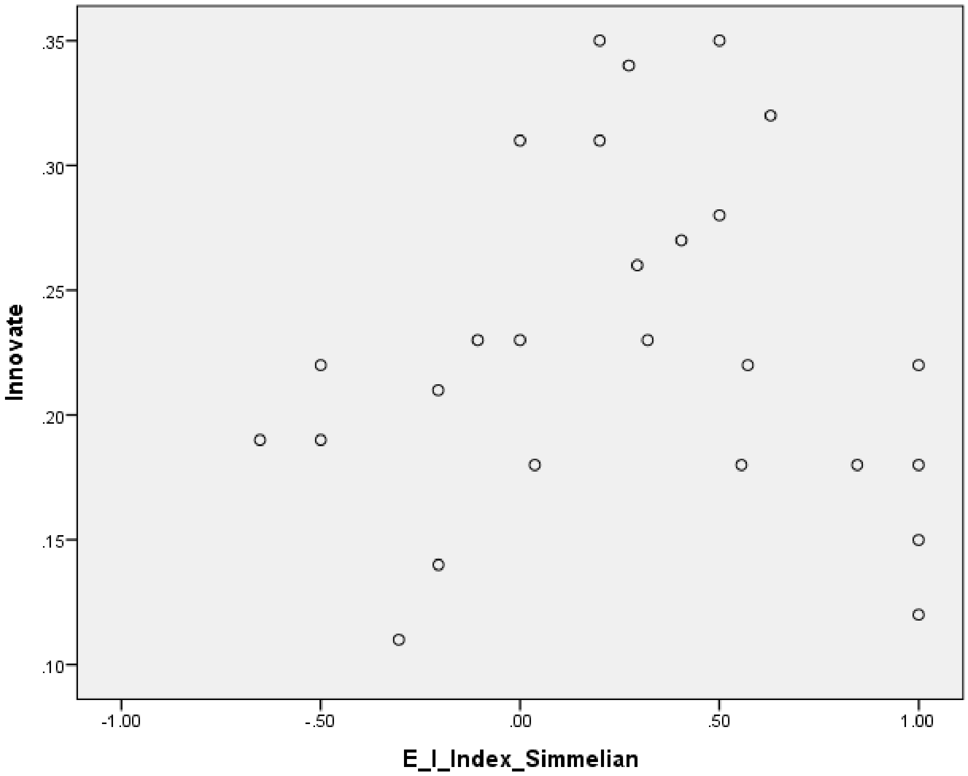

Figure 3b Inverse U-shape plot of innovativeness against Simmelian E-I index

Figures 4a and 4b further illustrate the balanced ties concept in relation to Simmelian ties. A country (A) is said to have a Simmelian tie with another country (B) if A is part of a reciprocated triad (including also C). If B is within A's block then the Simmelian tie with B is a within block tie and an outside of block tie otherwise. For instance, Figure 4a illustrates all of the Czech Republic's Simmelian ties. It has a within block Simmelian tie with Slovakia, an outside of block tie with Germany and two outside of block ties with Austria. The last three columns of Table 3 show the total number of reciprocated Simmelian ties for each country together with the E-I and balanced E-I indices. For the Czech Republic we have four Simmelian ties, one within and three outside of block giving an E-I index of 0.50 (= (3-1)/(3+1)) and a balanced E-I index of 0.83 (=(1-abs(0.28-0.5)+0.28)/1+0.28), where 0.28 is the median E-I index for all European countries with Simmelian ties. Some countries, such as Croatia and Cyprus have no Simmelian ties and so are excluded from the balanced E-I index calculation.

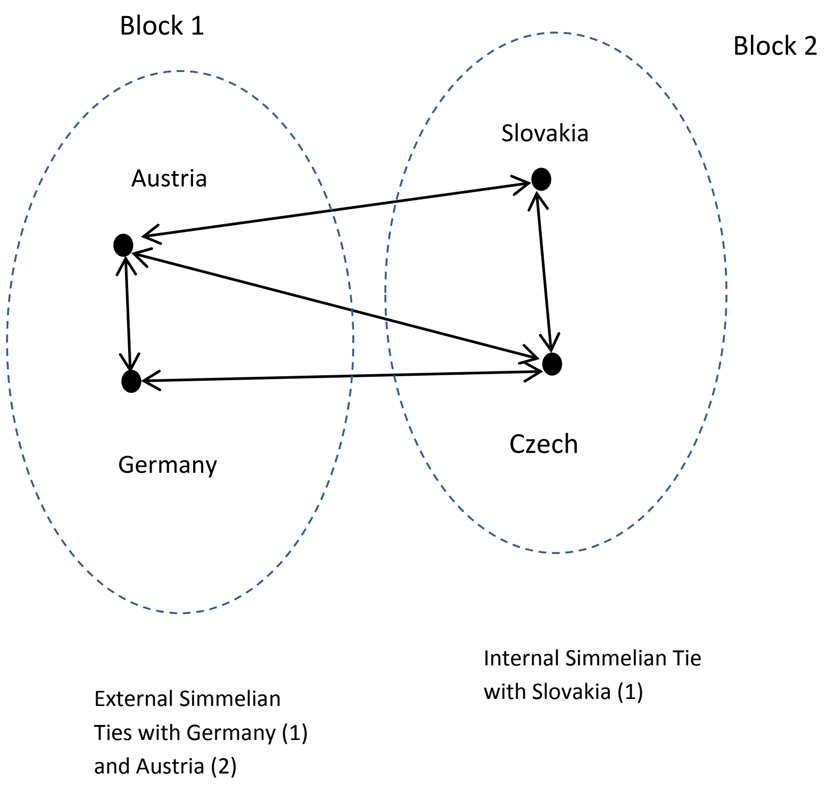

Figure 4a Illustrating all four of Czech Republic's Simmelian Ties

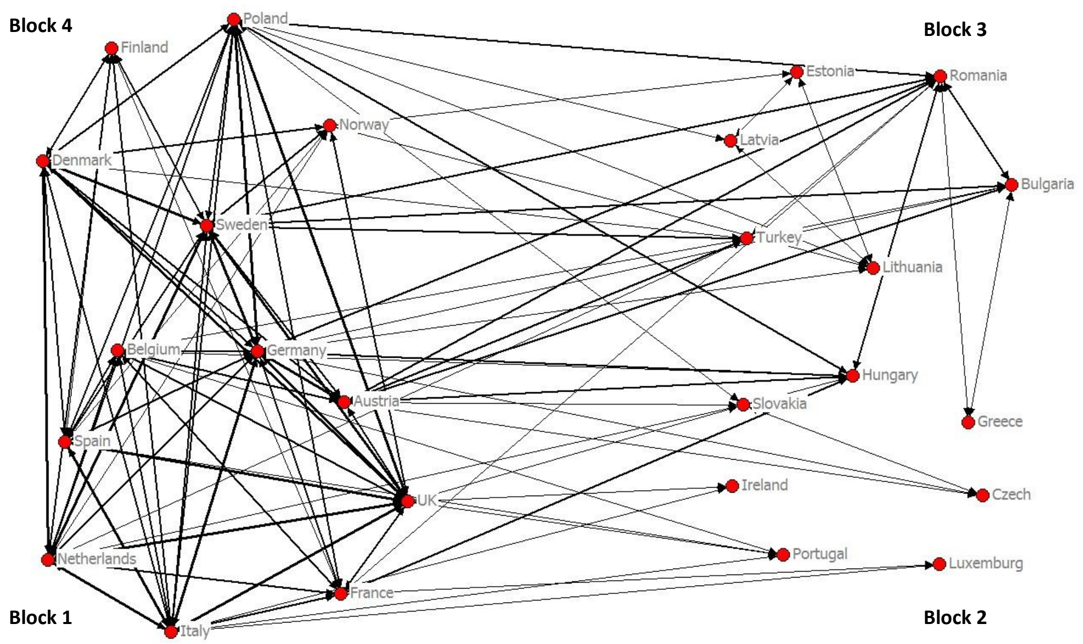

Figure 4b Digraph of reciprocated Simmelian ties in Block Structure

The countries with the highest strength of Simmelian ties are Germany followed closely by UK and Sweden. This is illustrated in Figure 4b which shows the reciprocated Simmelian tie network of countries' ties. The countries with the highest balanced E-I indices are mainly from the Baltic Sea block of countries, such as Finland, Denmark and Norway. These countries display equilibrium between within block and outside of block Simmelian ties.

5. Summary Analysis

We summarise by attending to the relationship between innovativeness and the network and economic variables outlined above. Least squares regression found little relationship between innovation and egonet size but a weak negative relationship between innovation and density which was not statistically significant (*R-Square=0.007, p=0.64).* There is a strong positive linear relationship between a country's outdegree and its innovation (*R-Square=0.327, p=0.0005*), but no significant relationship between indegree and innovation. There is a positive linear relationship between occupying a bridging position and innovativeness (*R-Square=0.275, p=0.002)*. Some values indicate mild exceptions (>1.5 Standard deviations). For instance Finland and Turkey (as well as Bulgaria, Czech Republic and Iceland) have higher innovativeness levels than predicted by their bridging positions while the UK (as well as France and Greece) has a lower innovation level than predicted.

Analysis of variance on the levels of innovativeness of countries attached to structurally equivalent blocks show that when the countries were divided into two structural blocks there is no significant difference between the innovativeness of the blocks. However when they are split into four blocks there is a significant difference (*ANOVA, p=0.007*) with the greatest difference between block 1 and blocks 3 and 4.

In Table 5 we present a correlation matrix. There is a strong correlation between innovativeness and the balanced E-I Simmelian index as well as k-local bridging and the CTSME gatekeeper block average. There is a less significant positive correlation between innovativeness and the balanced E-I index for all CTSMEs with bridging ties, while there is a negative correlation (not significant) between innovativeness and density as well as the liaison role. There are significant correlations between the balanced E-I index for all bridging ties and the density and liaison variables as well as between the density and liaison variables themselves leading to the exercise of caution concerning collinearity.

Table 6 shows the results of seven models. The first hypothesis associates high outdegree, the second the bridging of structural holes, the third a negative effect of dense networks, while the fourth associates a negative effect of occupying a liaison brokerage role. All four of these hypotheses are supported, though in the case of the liaison role significance is only achieved in model 2. The fifth hypothesis associates the average gatekeeper score of the block to which a CTSME belongs with the innovativeness of the CTSME. This hypothesis is also supported. The increase in the number of employees is the only significant economic explanatory variable for these three models.

Models 4 and 5 test hypothesis 6 and are based on data from the 33 CTSMEs which had ties both within and outside of their own country block. In this situation each CTSME behaves as a bridge both within and outside of its block and the level of balance between these types of ties is measured using the balanced E-I index as explanatory variable. In model 4, which has a poorer fit than any previous model (variance inflation factor < 4.19 and Adjusted R-Squared = 0.444), the k-local bridging variable, measured across all CTSMEs, is the only one of the network and economic explanatory variables to have significance.

	Innovate	Outdegree	k-local Bridging	Density	Liaison	Gatekeeper Block Average	Balance E-I Index All	Balance E-I Index Simm	Employee Increase	Financial Support	Logistic Support
Innovate	1	.568**	.516**	-.084	-.090	.550**	.346*	.661***	.311	-.145	-.225
Outdegree		1	.693***	.198	-.252	.466**	.451**	.142	.215	-.380*	.126
k-local Bridging			1	-.258	.202	.368*	.138	.212	.164	-.335	-.095
Density				1	-.641***	.256	.616***	-.299	-.076	.273	-.017
Liaison					1	-.052	-.663***	.303	.130	-.120	.170
Gatekeeper Block Average						1	.571**	.446*	.077	-.040	-.223
Balance E-I Index All							1	.035	.042	.052	-.241
Balance E-I Index Simmelian								1	.164	.030	-.150
Employee Increase									1	-.190	.136
Financial Support										1	.012
Logistic Support											1

**p<0.05; ***p<0.01; ****p<0.001 (Two-tailed) (all based on 33 CTSMEs except Balanced E-I Index Simmelian which is based on 26 CTSMEs)*

Table 5 Correlations

Dependent Variable Innovativeness	Hypo-thesis	Model 1		Model 2		Model 3		Model 4		Model 5		Model 6†		Model 7†	
Explanatory Variable††		Coeff	SE	Coeff	SE	Coeff	SE	Coeff	SE	Coeff	SE	Coeff	SE	Coeff	SE
Social Network															
Constant		.202***	.029	.210***	.029	.198***	.028	.212**	.060	.208***	.044	.089**	.030	.105***	.022
Outdegree	1	.024	.019			.033*	.013	.023	.020			-.018	.014		
k-local Bridging	2	.006	.017	.024	.012			.007	.018	.027*	.012	.020	.011	.020**	.007
Density	3	-.034*	.015	-.027	.014	-.035*	.013	-.033	.016			.001	.015		
Liaison	4	-.022	.014	-.027*	.013	-.020	.013	-.024	.019			-.014	.010		
Gatekeeper Block Average	5	.033*	.012	.036**	.012	.032**	.011	.035*	.015	.024	.013	.020	.010	.017**	.005
Balanced E-I Index All	6							-.014	.072	.023	.046				
Balanced E-I Index Simmelian	7											.139**	.039	.123***	.025
Economic															
Increase in employees		.012	.007	.025*	.011	.025*	.010	.012	.007	.025	.012	.021**	.005	.033***	.005
Govt. financial support		.142	.140	.032	.134	.109	.134	.141	.143	-.024	.140	.306**	.097	.290**	.074
Govt. logistical support		-.079	.156	.069	.191	.100	.182	-.082	.160	.023	.205	-.417*	.148	-.287*	.108
Increase in employees x Govt. logistical support				-.156	.118	-.192	.114			-.180	.127			-.260**	.068
Variance Inflation Factor		*<3.95*		*<4.16*		*<4.30*		*<4.19*		*<4.20*		*<4.02*		*<3.64*	
R-Squared Adj.		*0.466*		*0.469*		*0.520*		*0.444*		*0.394*		*0.800*		0.881	

** p<.05; **p<.01; ***p<.001;*

† Models 6 & 7 are based on data from the 26 CTSMEs which had Simmelian ties. All other models use data from 33 CTSMEs.

†† Explanatory variables are standardised with values between 0 and 1 where appropriate to accommodate interaction analysis.

Table 6 Results of Regression Analysis

Interactions between all the explanatory variables were then tested with little or no improvement to the model fit. Model 5 excludes the outdegree, density and liaison variables while keeping the bridging variable together with an interaction between the increase in employees and government logistical support variables. The only significant explanatory variable is the k-local bridging variable offering some support to hypothesis 2. When interactions were tested the models were either not any more significant or suffered from high variance inflation factors due to collinearity between the balanced E-I index and other variables such as the density, liaison and outdegree variables.

Models 6 and 7 test hypothesis 7 and are based on data from the 26 CTSMEs which had within and outside of block Simmelian ties and include the balanced E-I index as explanatory variable. In model 6, which has an improved fit to all previous models (variance inflation factor < 4.02 and Adjusted R-Squared = 0.80), some of the network and economic explanatory variables have significance. These are the balanced Simmelian bridging, economic growth as in the increase in the number of employees, government financial support (positive effect) and government logistical support (negative effect). Interactions between all the explanatory variables were then tested and model 7 re-introduces the k-local bridging variable together with an interaction between the increase in employees and government logistical support economic variables. All of the explanatory variables are significant in this model which supports hypotheses two, five and seven demonstrating an effect of the k-local bridging, gatekeeper block average and balanced Simmelian bridging social network factors. We also tested other explanatory variables such as the increase in SME turnover, the age of the SME, whether or not the SME invested abroad and the population of the country to which the SME belonged and found no significant results for this data set.

The regression analysis showed significant network effects associated with the block structure of the CTSMEs. We therefore summarise the main structural characteristics for each block as follows:

SE Block 1. The countries in this block have high brokerage totals with strong scores for representative, consultant and liaison roles (Table 3). They are representatives for block 2 and 3 countries as well as liaisons (2-1-3 and 3-1-2) and consultants and gatekeepers for Block 2 countries (Table 4). The main gatekeeper is Italy which attracts ties from block 2. The block 1 countries are homogeneous with regard to bridging (Table 1) with the exceptions of France (low bridging level) and the UK (high bridging level). The countries in this block have a high number of Simmelian ties which are mostly within block (negative E-I index average).

SE Block 2. The countries in this block have the lowest brokerage totals. They are consultants and representatives for block 3 as well as coordinators for block 2 and gatekeepers for blocks 1 and 3. The main gatekeepers are Greece and Slovakia. The block 2 countries have medium to low scores for bridging capacity (with the exception of Greece which has a high score and Czech Republic and Liechtenstein with very low scores) as well as medium to low scores for innovativeness with the exceptions of Macedonia and the Czech Republic which have high scores. The countries in this block have a low number of Simmelian ties which are mostly outside of the block (positive E-I index average).

SE Block 3. The countries in this block have low brokerage scores. They are gatekeepers for blocks 2, 3 and 4 as well as consultants for block 2 (Table 4). The main gatekeeper is Romania which maintains ties with all other blocks. The block 3 countries have high scores for bridging capacity (with the exception of Malta and Slovenia) as well as medium to high scores for innovativeness (with the exceptions of Romania, Estonia and Slovenia) which have lower scores. The countries in this block have a below average number of Simmelian ties which are both within and outside of the block (E-I index average close to zero).

SE Block 4. The countries in this block have high brokerage scores. They are gatekeepers and consultants for blocks 2, 1 and 3 as well as liaisons (1-4-3, 2-4-3) and representatives for block 3. The main gatekeeper for this block is Sweden, which attracts ties mainly from block 2 countries. The countries in block 4 have high scores for innovativeness as well as medium to high scores, with the exception of Finland, for bridging capacity. They also have a high number of homogenous Simmelian ties which lie both within and outside of the block but are skewed to outside ties. The balanced E-I index is close to one showing optimal balance.

6. **Conclusion** (including implications for practice)

We introduce the concept of country typical SME (CTSME) in order to construct a proxy network with each node representing the economic and networking behaviour of a firm representing its country within Europe. We then observe the structure of CTSMEs' technical cooperation networks and thereby enhance our understanding of their ability to absorb and engage in innovation with CTSMEs in other European countries. By adopting structural equivalence (that is, CTSMEs that have similar relationships with the same other CTSMEs) rather than regional proximity we identify blocks of country typical SMEs with similar network features. Our research then demonstrates increased innovativeness through adopting a cooperative, as opposed to just competitive, bridging strategy. That is, while the conventionally measured outgoing ability to form bridges across less densely connected firms has significance, this is outweighed by the balanced cooperative (Simmelian) bridging capacity of a CTSME acting within its associated block of countries. In the long term, and for suitably located firms, cooperative structure may outweigh individualistic competitive brokerage. Another feature of structure is that the role of gatekeeper, seen as averaged over the CTSMEs in a block, is positively associated with the innovativeness of each member CTSME, emphasising the value of environment monitoring and the translation of technical information into a form understandable to the business community of the block membership.

The inverse U-shape of the plots of CTSME innovativeness against their E-I and Simmelian E-I indices strikes a resonance with the earlier work of Gulati et al. (2012), which identified an inverted U-shaped pattern of a small world system's evolutionary dynamics over a period of time. The shape of the development was explained as being due to three factors. Firstly, in terms of the reduced ability of actors to form bridging ties as the intensity of such ties increases. Secondly, due to the increasing homogenization of the social system which makes it less attractive to new actors which in turn limits the formation of bridging ties to outside clusters. And thirdly, due to fragmentation and the inability of the system to retain current clusters. In our study, which is not dynamic, we capture a snapshot of the structure of technical cooperation networks and confirm that dense structures mitigate against the growth of innovation but further investigate both conventional and Simmelian bridging mechanisms and the balance between relationships within and outside of block structures. Interestingly, although both types of bridging mechanisms display an inverted U-shaped relationship with CTSME innovativeness, it is the balanced Simmelian bridging that is most strongly associated. The conclusion we reach is that Simmelian tie formation adds a special new dimension to the relationship enabling a more cooperative, trusting and long term environment for the development of innovation, but that it is also important that the formation of new within and outside of block relationships are balanced to maintain performance.

Specific examples of CTSMEs are worthy of note. Belgium's CTSME, for instance, does not, allowing for the limitations of our study, display this equilibrium with regard to Simmelian ties, since it has very few such ties outside of its own block (E-I Index = -0.65, Table 1). Firms in Belgium could consider forming such ties with countries in another block such as Finland, the Czech Republic or Slovenia. For CTSMEs currently without Simmelian ties (Croatia, Cyprus, Iceland, Liechtenstein, Macedonia, Malta and Slovenia) attention might be given to the formation of such ties. Firms in Iceland, for instance, might consider forming reciprocal technical cooperation ties with countries in their own block such as Estonia, Latvia and Lithuania while also improving ties with longer established CTSMEs in the Baltic Sea block such as Denmark, Finland and Sweden since most of these countries already have strong Simmelian ties. Countries who's CTSMEs display a strong Simmelian balance, such as Denmark, Finland, Austria and Sweden, would do well to keep track of the dynamic structure of the European technical cooperation network including the entry of new countries and form new relationships accordingly.

Further strategic considerations follow from closer inspection of the structurally equivalent blocks. The countries in these blocks should be more sensitive about following a joint policy of harmonising innovation and balanced Simmelian bridging capacity due to the similarities in their network structures. The practical implications vary depending on the block to which the country belongs. Block 1 CTSMEs in older and larger European countries who are so good at forming within block Simmelian ties could seek for more of these ties outside of their own block which may open up new opportunities for collaborative innovation. For the same reason they might adopt gatekeeper roles, since they already have strong network links with blocks 2 and 3. They might also extend their brokerage influence by greater technical cooperation with block 4 countries in the Baltic Sea. For blocks 2 and 3 similar strategies could be adopted. This might involve the formation of more Simmelian ties both within (especially those who currently have no Simmelian ties) and outside of own block. A further improvement could be the enhancement of gate-keeping with other blocks. In contrast, block 4 countries have both a high number and optimal equilibrium of (within and outside of block) Simmelian ties. They might, however, increase their brokerage strength by extending gate-keeping opportunities to attract ties from blocks 1 and 3.

A firm's innovative activity is also influenced by economic factors such as growth, maturity, government support and the involvement in overseas investment. Our findings show that, while growth in employment levels is associated with innovative activity, growth in turnover is not. This may indicate that the increase in current employment levels is a better indicator of recent innovative engagement than increase in prosperity. The study, which is not longitudinal, is not able to reveal the effect of growth at an earlier stage to innovative activity at a later stage (or vice versa). With regard to maturity this is positively, but not significantly, associated with innovativeness. This is partially accounted for by the fact that firms in countries which are new entrants to the European Union have lower maturity and yet have quite high reported innovation levels. Firms in the other countries with higher maturity have higher investment abroad and stronger liaison roles neither of which is associated with innovative activity. Another finding is that, while innovativeness increases with government financial support, the reverse is true for logistic support. Zeng et. al. (2010) report similar findings for Chinese firms. A possible explanation is that governments may be more likely to give financial support to growing firms already engaged in innovative activity while only offering logistic support to those not already so engaged. There may also be a time lag between support and the achievement of innovation. The type of support may, however, be crucial and Rothwell and Dodgson (1991) highlight the need for carefully adapted strategic policies throughout the innovation chain. Investment abroad is not significantly associated with CTSME innovativeness. In fact there is a small negative effect. It could be that firms face a competitive choice between allocating resources to their own innovative activity and overseas investment rendering the activities to some degree mutually exclusive.

The methods used in this study have some limitations. The use of brokerage theory in the context of preference for technical cooperation with European countries abroad imposes the limitation that, since each firm names only a country and not another firm, the brokerage and other scores do not actually reflect relationships between firms. In this sense the technical cooperation network is a proxy network of country typical SMEs (CTSMEs) and this must be taken into account when evaluating its impact. We argue that the brokerage scores of CTSMEs do measure the likelihood that technical cooperation relationships such as bridges between firms and equivalence between structural blocks exist, since the more preferences that are expressed for cooperation with a particular country then the more likely it is that ties exist between the countries' firms, given that only firms with actual technical cooperation ties abroad were asked to name country preferences. Another limitation is that the respondents in the IEM Survey (2009) were asked if they had introduced any new product or service in the market in the last three years but the nature of the innovation was not specified. Their innovation was therefore self-reported although reference to other survey data (Eurostat Yearbook, 2013) generally confirms its validity. There was not therefore a formal evaluation of the knowledge and technology transfer activities of the firms involved in the survey (Tsekouras et al., 2010).

To conclude, our research revealing the structure of the European technical cooperation network, economic factors and the association with the spread of innovation offers concrete assistance to the formulation of effective SME, government and European policy.

Acknowledgements

The authors wish to thank the EIM Business Policy Research Unit (presently part of Panteia Ltd), Amsterdam, Netherlands for access to the EIM, 2009, survey data as well as DG Enterprise and Industry of the European Commission. They also wish to thank the North Sea Supply Connect project and the Interreg IVB European Union funders for making it possible to carry out the research.

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