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STRUCTURAL AND AGENTIC ANALYSIS OF SUPPLY-CHAINS: A SOCIAL NETWORK ANALYSIS APPROACH

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ABSTRACT

This research adds to a body of work exploring the role of Social Network Analysis (SNA) in the study of both relational and structural characteristics of supply chain networks. Two contrasting network cases (food enterprises and digital-based enterprises) are chosen in order to elicit structural differences in business networks subject to divergences in local embeddedness and the relative materiality of the goods and services produced. Our analysis and findings draw out differences in network structure – evidenced by metrics of network centralization and cohesion, the presence of components and other sub-groupings, and the position of central actors. We relate these structural features both to the nature of the networks and to the (qualitative) experiences of the actors themselves. We find, in particular, the role of customers as co-creators of knowledge (for the Food network), the central role of infrastructure and services (for the Digital network), the importance of ICT as a source of codified knowledge inputs, along with the continuing importance of geographical proximity for the development and transfer of tacit knowledge and for incremental learning.

Introduction:

Over recent decades fundamental political change has created the conditions to support a 'globalisation era' with far reaching consequences. In tandem rapid advances in Information and Communication Technology (ICT) has created a new set of 'technological separabilities'. Such 'separability' has prompted much discussion around notions such as the "death of distance" and the "end of geography" (Castells, 1996; Sassen, 2001; Graham, 1998) and thus the role of forces of agglomeration and dispersal. It also engages with debates on policy and practice, for example redefining "footloose industries" and FDI-led economic growth.

Within the past few years there has been a growing interest in bringing the techniques and perspectives of Social Network Analysis (SNA) to bear on the study of Supply-Chains (Kim et al. 2011; Sloane & O'Reilly 2010; Borgatti & Li 2009; Choi & Wu 2009; Choi & Kim 2008). While Social Network Analysis has become widely-accepted in research, and even quite widely adopted in policy studies, most work to date has concentrated on one network, or less frequently on multiplex networks – a set of distinct relations on the same set of actors. Comparison across networks of distinct actors in terms of network structure is a relatively new and active area of research e.g. (Entwistle et al. 2007; K. Faust forthcoming). This research paper describes the application of SNA to two contrasting network cases chosen in order to elicit structural differences in business networks subject to divergences in local embeddedness and the relative materiality of the goods and services produced.

The paper builds on previous work (Sloane and O'Reilly, 2010) that adopted a SNA approach. This previous work found that a mixed methods approach that includes SNA facilitates greater insight into social processes of both structure and agency ((Kelle 2001): making clear, for example, that relations are conceptual and cognitive entities; that actors actively construct the network; that the network serves as a resource to actors; and conversely that their actions are shaped by the structure of the network. The earlier work focused on a network with strong local embeddedness and thus largely ignored the increasing importance of global interactions along supply networks. This paper considers two networks that ex-ante might be considered a sharp contrast between local and global

orientation. The paper begins with a brief overview of the context and methodology as we devote most the paper to illustration and discussion of our comparative work. We conclude with some observations regarding the impact of social embeddedness and the role of networks relations and structure in knowledge creation and dissemination.

Background and Methodology:

The objective of this paper is to investigate the insight that various SNA techniques may offer into the relational and structural nature of two contrasting networks - a network of food enterprises and a network of digitally-based enterprises. The former network was presented in Sloane and O'Reilly (2010) which also provides an overview of the SNA research design and describes the methodology adopted. In this paper we provide some context for the comparative study and a brief overview of the methodology.

In the mid to late 1990's there was a surge of speculation and futuristic prediction on the likely consequences of society's adoption of new technologies of computing and communication, fuelled particularly by emergent popular awareness of the "world-wide web". More specifically, journalists, government policy analysts and academic researchers proposed, with varying degrees of certitude, that the new age would bring about a "death of distance" (Cairncross 1998) or the "end of geography" (O'Brien 1992). The "digital revolution" would even "reshape the landscape" (Kotkin 2000).

In this new era the established locational constraints on economic activity, whether in terms of production tied to local resources and tradition, or on labour tied to the location of production or the location of consumption (in the case of services), were supposed to be weakened and possibly entirely removed. E-commerce, e-services, e-government were the bywords of the "information age". Much of the initial enthusiasm has been tempered in the succeeding years, and an awareness has developed that the interactions of the social, the spatial and the technological (not to mention the economic and the political) are "multi-layered, interrelated and complex" (Collins 2007).

These developments have rekindled interest in economic and social processes underlying the processes of agglomeration and dispersal, within the context both of Marshall's original insights and those of modern scholars, including those in the "Italian School" (Becattini et al 1990), the "California School" (Scott 1993, Saxenian 1994), "GREMI" (Aydalot and Keeble 1988) and in Scandinavia (Lundvall & Johnson 1994, Maskell and Malmberg 1999). These studies have pointed out the central structuring role played by knowledge, innovation and the development of competitive advantage. Thus this paper considers the types of knowledge; how knowledge is elaborated and communicated; and the role of spatial or social proximity in these processes. We characterise the nature of these two networks along two conceptual axes: one determined by social embeddedness, and the other by the relative proportions of tacit or codified knowledge involved in the production process.

We collected data on samples of businesses operating in two contrasting economic sectors within a single geographic area. We utilised the techniques of "quantitative interviews" (Johnson & Turner 2002) and "expanding selection" (Doreian & Woodard 1992) to concurrently collect network data and semi-structured qualitative data. We built a multiplex network graph, incorporating five distinct relations: customer, supplier, service, competitor and ally. Our analysis then combined quantitative network analysis with qualitative analysis within a "Concurrent Mixed Method" research design, using alternating and iterative strands of deductive and inductive inquiry. We adopted purposive sampling, followed by concurrent qualitative and quantitative (SNA actors, relations, attributes) data collection and analysis. Thus, in the typology of "Mixed Methods" research designs, it is a "Concurrent Nested Design" (Creswell et al. 2003).

Findings:

Network Overview

Figure 2 and Figure 3 below show graphs of the “complete” networks for both the “Food” and the “Digital” networks[†]. In these graphs we have aggregated the five distinct relations and additionally have symmetrised the ties. While aggregation and symmetrisation necessarily results in a loss of information, it also makes the networks more dense and the analytical procedures more robust. We could view this composite relation as a more abstract and general representation of “has business tie to” or flows of business-relevant knowledge. In particular our argument is that the aggregation of the five individual relations comprises the network of business relations within which firms determine strategy and from which they draw as a resource.

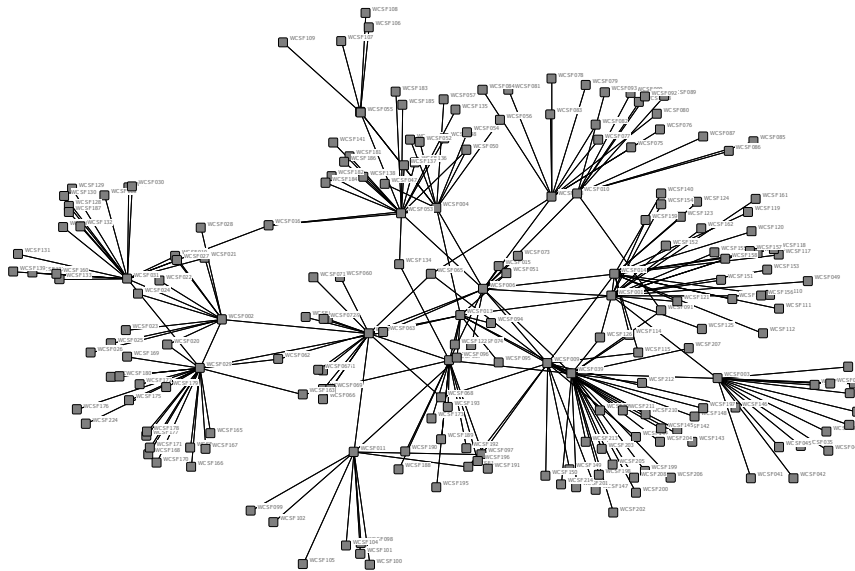


Figure 2. Food – “Complete” Network

An initial visual inspection of the two graphs suggests much in common, but with a few obvious divergences. The layout algorithm used is a “spring-embedder”, which results in clusters of mutually connected nodes being placed close together, the most connected nodes at the centre, and “pendants” (nodes of degree 1) around the periphery. Both graphs have many such pendants but this is a side-effect of our method of data-collection: the pendants are firms which were mentioned as ties, but which lie outside the network boundaries (i.e. outside the geographic area or in a different business sector) and which were not themselves surveyed. In subsequent analysis we remove the pendants, and extract the “core” networks, which are comprised of the firms surveyed together with any others who were mentioned more than once.

The removal of these pendants highlights structural differences between the two networks, in that the Food network is a single connected component, whereas there are three components to the Digital network. In addition, there seems to be less of a clearly defined “centre” to the digital network.

[†] All of our analyses were carried out with the software Ucinet and graphs were drawn with its visualization component NetDraw (Borgatti et al. 2002)

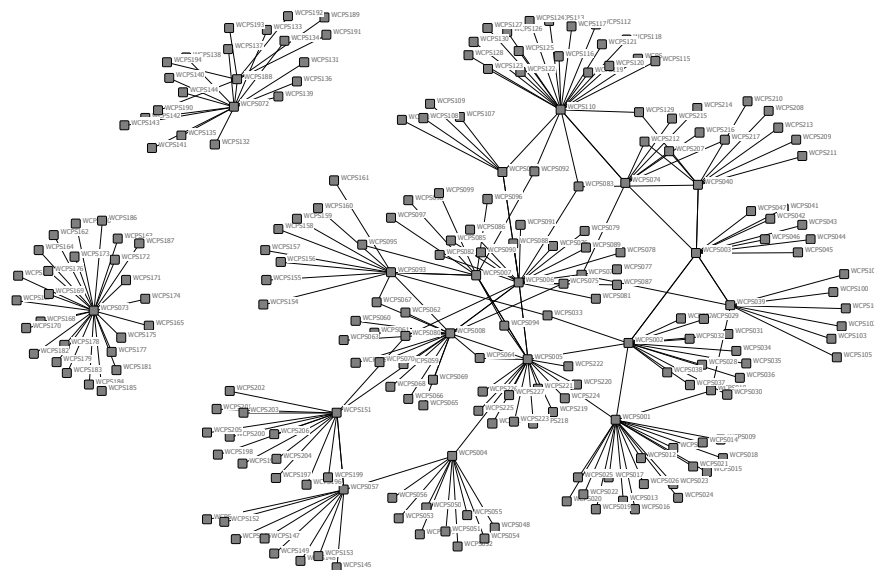


Figure 3. Digital- "Complete" Network

Chains and Networks

In discussion of supply-chains it has been conventional to visualise the relations between firms in a layout where the supplier in each dyad is placed on the left and the buyer on the right, and the resulting set of relations connected together in horizontal layers. When constructed in such a manner we identified those actors who seem, by visual inspection, particularly "important" or "well-connected". In the Food network two actors (both local retailers) appeared central, whereas in the Digital network, three actors appeared central (these included two of the wireless broadband suppliers in the area). Both observations seem to make intuitive sense, although in the Food case it is shared customers who are important, while in the Digital case it is suppliers of a common infrastructure.

Social Network Analysis provides a number of definitions for whether an actor is "important", "well-connected" or "influential", mostly categorized under the concept of "centrality". Therefore we explored how network visualisation software might make the notion of centrality more amenable to visual interpretation, and how using formal definitions of centrality allows us to be more precise in identifying, quantifying and specifying the nature of an actor's "importance" in the network structure.

Network Centrality

The literature on Social Network Analysis provides a large number of formal definitions of centrality. Some go back to the beginnings of the discipline, and new ones are still being proposed (Bavelas 1948; Everett & Borgatti 2010). In our discussion here, and in our application of the techniques to our data, we will follow two influential syntheses of these ideas (Freeman 1978; Borgatti & Everett 2006). Freeman identified three principal types of centrality: degree, betweenness and closeness. He comments that each of these implies a different underlying model of communication process and of "how centrality might affect group processes" (Freeman 1978, p.238), with degree measuring "activity", closeness measuring "independence" and betweenness a measure of "control"

In our study degree is not an appropriate choice because of the way in which our data was collected: subjects were asked to name their "top suppliers", "top customers" and so on (this is called a "name generator" question in SNA). The number of alters enumerated varied hugely – from zero to ten or more, but it would not be reasonable to infer that a subject who listed ten alters was more "important" than one who listed two or three – the response would be dependent on so many other factors.

A popular measure of centrality based on (weighted) closeness is “eigenvector” centrality (Bonacich 1972). For this measure to be appropriate it is necessary that criteria be met on the relative variation accounted for by the eigenvectors and on the relative magnitudes of the eigenvalues. These criteria are not met for the Food network, and are only partially met in the Digital network. Betweenness measures however are a good fit both analytically and conceptually for our networks. The most central node, by the measure of “node betweenness” (Freeman 1977, Freeman 1980), is the one that falls on the greatest number of shortest paths (geodesics) between all other pairs of nodes in the network. This is a natural definition of “importance” if the network represents flows of information or exchange relations that are dependent on intermediaries. Freeman noted that such a network position is important for the maintenance of communication in the network and also as a coordinating role in group processes (Freeman 1978, p.221). All of these interpretations are important in our conception of business relations and networks.

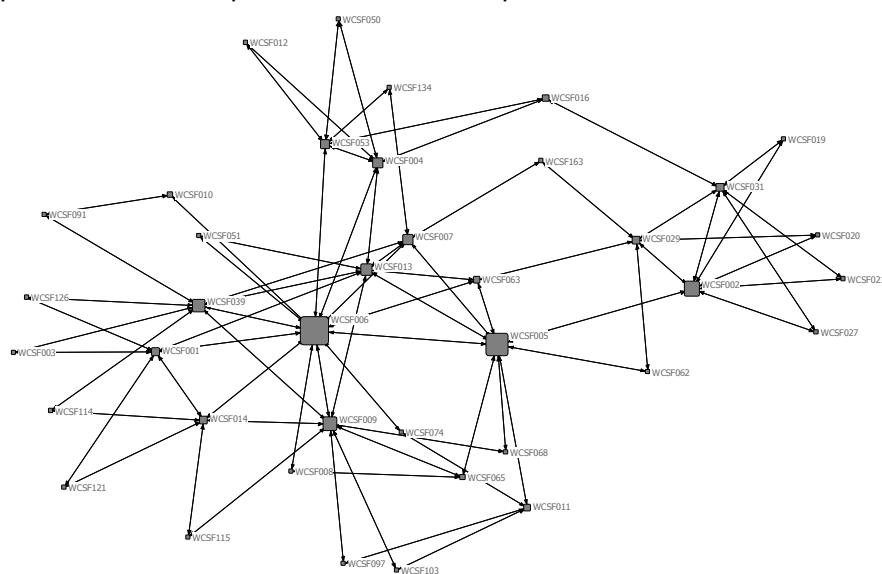


Figure 4. Food - Betweenness Centrality

The graph in Figure 4 picks out the two retailers, together with an actor who (drawing on the qualitative data) is often cited as a “role model” for firms who aspire to grow bigger, having moved from small-scale home production to a purpose-built production facility and international distribution. In the Digital network, none of the methods seem to fit well. The underlying reason for this is that the main component of the network (i.e. excluding the two smaller components) is really two separate groups, each with its own “centre”.

Borgatti & Everett devised a typology of centrality measures based a cross-categorization into medial/radial and volume/length (Borgatti & Everett 2006, p.476). Within this typology degree, eigenvector and power centrality are all radial-volume methods, while betweenness is medial-volume. Borgatti & Everett point out that radial measures of centrality are unlikely to be appropriate unless the network is “one group” or essentially has a “core-periphery” structure. When the network is composed of two principal groups, betweenness is likely to identify as central those actors who “bridge” the gap between the groups. While this is another important aspect of group structure, it is not usually a good measure of centrality. In a later section we discuss techniques used for identifying subgroups, but for now we choose one such technique and analyse centrality within the resulting grouping.

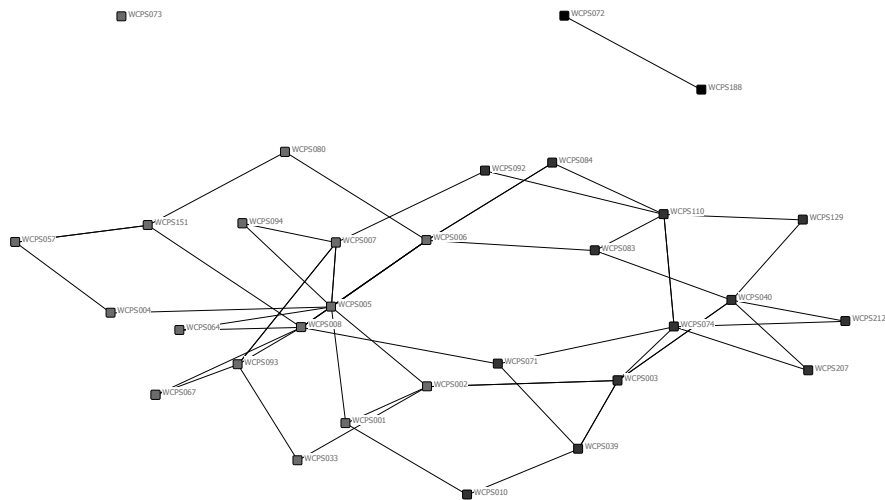


Figure 5. Digital - Newman-Girvan Subgroups (N=4)

Using Newman and Girvan's algorithm for identifying subgroups in the Digital network (Newman & Girvan 2004) we find two groups - on the left and the right of the main component, as presented in Figure 4. As we discuss later, these two subgroups are strongly geographic in composition, more or less east and west in the region studied. We then extract the two main subgroups and analyse centrality for them separately.

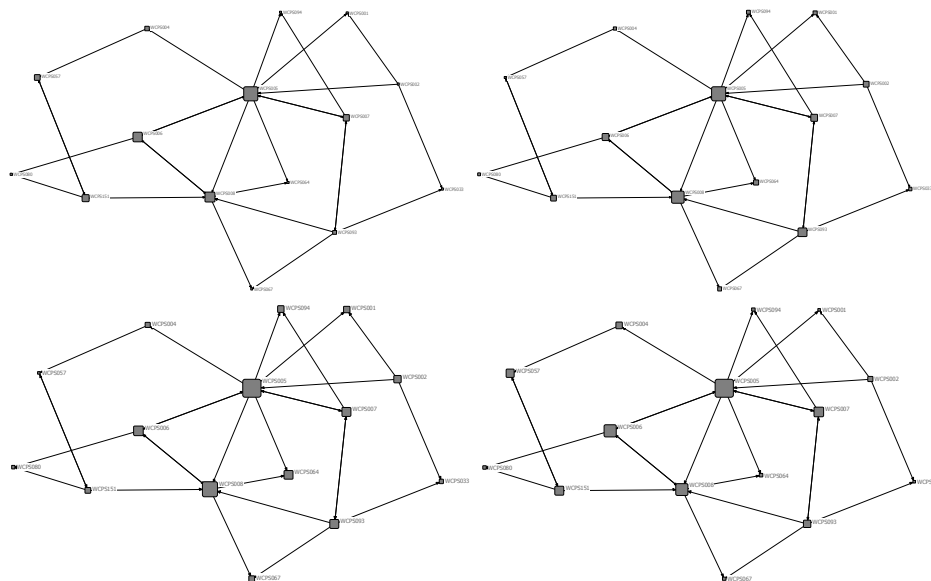


Figure 6. Digital - Four Measures of Centrality

Figure 5 shows four graphs of centrality for the first subgroup, one from each of Borgatti and Everett's four categories. The top-left is Freeman's (Node) Betweenness (medial-volume category); top-right is Information (Stephenson & Zelen 1989) which is a form of closeness that takes account of all paths, not just the geodesics and is a radial-length measure; bottom-left is Eigenvector (radial-volume) and bottom-right is Borgatti's Distance-Weighted Fragmentation (DF) (Borgatti 2006) which is in the medial-length category.

While there are differences in the centrality scores and in the ranking of the more peripheral actors, there are always two who are clearly "most central". These are a

supplier of wireless broadband and a company which is rapidly growing and which was identified by "expert" authorities in the development agencies as prominent. So, as in the Food network, network analysis identifies a "role model" firm as central.

The second sub-group is more problematic for centrality analysis, with identification of central actors not being stable with respect to choice of measures and no clear distinction between central and non-central actors. It is possibly the case that is not really a cohesive group but rather is a residual or complement of the first group. In support of that claim we may note that the first subgroup comprises 15 actors, of whom 11 were surveyed, while the second group comprises 13 actors, but only 6 were interviewed and it contains 2 non-respondents and 5 "partners". On the other hand, the qualitative data does suggest that broadband supply was less often named as important in the second group; the local wireless supplier offers speeds that are not significantly higher than fixed (DSL) broadband, DSL is more widely available in this area; and also there is a fibre trunk available in a local technology park there (where actors from one of the minor components are located). So this group may indeed have a different network structure, given that broadband infrastructure supply conditions are markedly different.

Network Cohesion & Cohesive Subgroups

While centrality measures are concerned with identifying "key" actors within a network, another viewpoint in SNA focuses in a more "macro" way on the structural composition of the network itself and on "the structures within which individual actors are embedded." (Hanneman & Riddle 2005, p.95). In the context of our research design we chose the two economic sectors – Food and Digital – purposively in order to express dimensions relating to embeddedness, materiality of products, and codification of knowledge inputs. Based on theory we made a number of initial hypotheses, including an expectation that the Food network would have more connections (and more local ones) – a feature that has often been associated with conceptions of "social capital". A simple network-metric for this is density, and a related one is reciprocity – the extent to which ties are reciprocated or two-way (in a directed network). Within our networks however there is no significant difference in density (6%) and reciprocity is actually higher for the Digital network (21% versus 15%, although this is not significant in a network context).

We may look more closely at the question of network structure by seeking to identify local sub-structures, or what are called "cohesive subgroups" (Wasserman & Katherine Faust 1994, p.249). There are (again) many ways of understanding and defining such groups. We will follow Hanneman and Riddle's (2005, pp.148-149) categorization of the methods as "bottom-up" – starting from the dyad or triad and seeking to extend it outwards to larger groupings – or "top-down" – starting from the whole network and seeking to sub-divide it into more locally-dense parts. We illustrate and interpret our results using one method from each of these categories.

In our earlier study of the Food network (Sloane & O'Reilly 2010) we used the technique of p-Clique (NEGOPY) (Richards 1975) as an example of a "bottom-up" method[‡]. We related the presence of a pair of outliers from otherwise strongly cohesive groups to the nature of those two firms' business relations and to social embeddedness. The p-clique doesn't give any useful information in the case of the digital network, as there are no such outliers. Instead we will consider an analysis using 2-Cliques (i.e. an N-Clique, with N=2). These are a slightly relaxed definition of clique (a maximal complete sub-graph) in which each member is connected to every other member by a path of length less than or equal to 2 (i.e. "a friend of a friend" or connected through at most one intermediary). In Figure 7 below we required that the minimum clique size be 7, coloured the nodes by clique and set the layout to group the members of the clique close together. A pair of 2-cliques is clearly shown – in blue and in black. The higher density of ties within each clique relative to ties outside is also readily apparent.

[‡] P-Clique analysis was done with Pajek (Batagelj & Mrvar n.d.; de Nooy et al. 2005)

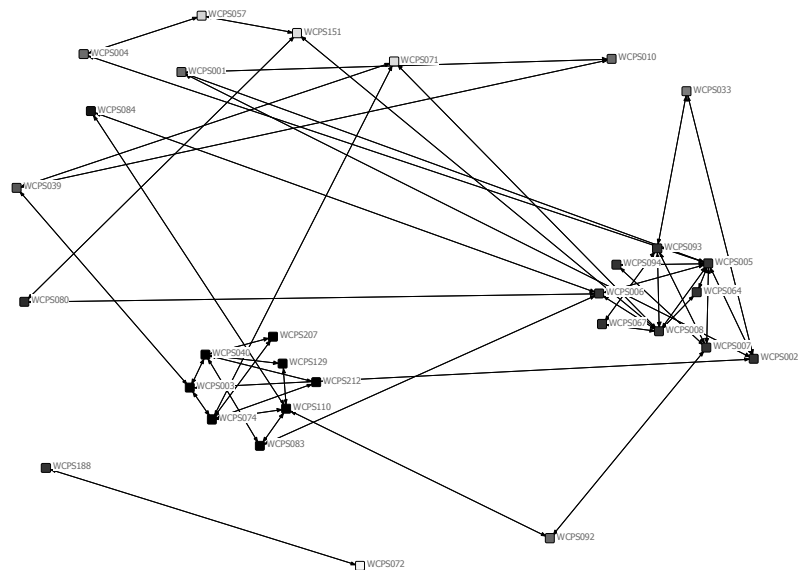
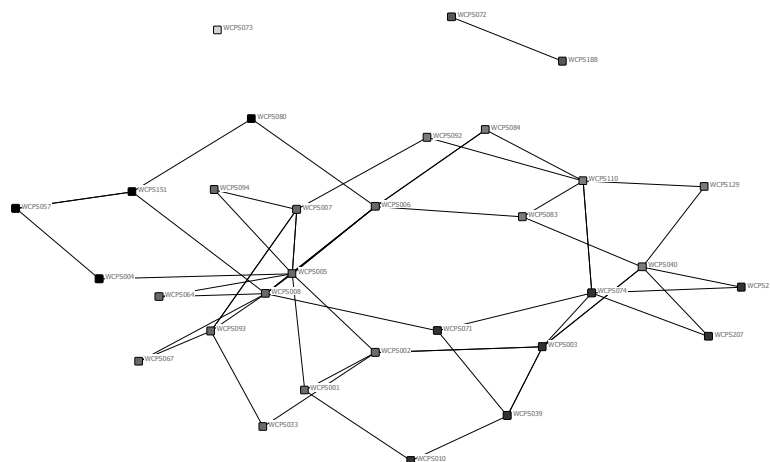


Figure 7. Digital - N-Cliques

These two subgroups are strongly correlated with geographic location – of the 8 members of the leftmost group, 7 are located at the eastern extreme of the region (out of 11 in total in that sub-region), and of the 9 members of the rightmost group, 6 are located in the western part (out of 9 in total in that sub-region).

As an example of a “top-down” method for identifying subgroups we have used Newman & Girvan’s “community-detection” algorithm (Newman & Girvan 2004). This algorithm works by iteratively removing the edge with the highest betweenness score, and thus identifying subgroups by finding the bridges that connect them. In the case of the Digital network we earlier showed the results of Newman-Girvan for $N=4$, and explained it in terms of geography. Going again to a finer level of sub-grouping, with $N=7$, results in Figure 8. In this case both of the earlier sub-groups have sub-divided. One of the new sub-groups comprises those members of the “eastern” group who had been earlier placed within the “western” group. Another is a “far-west” sub-group, also previously contained in the “western” group. So these remain consistent with a “geographical” explanation. The final new sub-grouping comprises a number of interconnected businesses which are involved in producing print media as well as electronic media such as web-sites. This suggests that specialism plays a role, as it did in the Food network, but is subsidiary in this network to geographic proximity.



Discussion:

In our exploration of the contrasting structure of these two networks we have found differences in the type of actors who are central, in the patterning of subgroups, and in the nature of linkages across subgroups. Turning to the qualitative data we collected we can seek explanation for these differences.

Food production evidences commonality in production methods, at least within subsectors, and so actors report sharing of inputs and equipment. Thus the use of common ingredients and packaging creates links through shared suppliers. Sometimes those linkages strengthen and are formalised into joint purchasing alliances. In other cases the linkages remain informal, for example sharing or borrowing equipment when technical problems arise; sharing packaging materials in times of shortage or sudden demand; sharing knowledge when purchasing, maintaining or operating specialised equipment. Such arrangements are advantageous to the individual firm, especially considering the large capital investment and sunk costs that specialised production machinery represents for small firms. Such sharing also allows firms to respond to demand-side delivery commitments in a flexible way. These linkages – formal or informal – provide an explanation for why we see subgroups in the Food network being aligned along business-subsector divisions.

By contrast the Digital network has no real sub-sectors. Within this local area and the local network such businesses are relatively “thin on the ground”, and actors feel more in common with one another than divergence along lines of technical specialism. Examining network graphs for the components of vertical relations or of competitors clearly illustrates this. Inputs (suppliers) and outputs (customers) are usually located outside the geographic area and rarely are common to pairs of actors. We do however observe some degree of local competition in locally-oriented services (e.g. website design), which is a likely explanation for the subdivision seen in the “eastern” sub-group. All of these businesses are “knowledge-based” but each occupies a very different niche. Thus sharing of knowledge – which is widespread and reported as very important to the actors – is primarily of general “business knowledge” and is often tacit. Codified knowledge inputs for these firms are widely divergent and generally accessed via internet resources. Without the “global pipeline” (Bathelt et al. 2004) provided by broadband ICT, these businesses report that they would not be able to operate in the region.

While sharing of tacit knowledge is primarily informal, “face-to-face”, and spatially proximate within this network, the digital businesses do seek other geographically-dispersed sources of tacit knowledge through travel – what Torre has labelled “TGP” or “temporary geographical proximity” (Torre 2011, p.218) – telephone, and “Skyping”. That last word was encountered frequently as a vernacular term for video-conferencing, not just among the digital businesses but even with otherwise very “traditional” farm businesses. As technological advances in ICT continue it seems likely that higher-bandwidth and more communication-rich technologies such as telepresence systems will further modify the boundaries of tacit-codified and spatially-relationally-proximate communication.

Consequently linkages between the actors in the digital network are not created by “supply-chain” links (suppliers or customers) but through alliances and service providers. Among service-providers, wireless broadband is particularly important to “digital” businesses, and so appears as central in our measured networks. For a variety of reasons the wireless broadband providers are geographically disjoint. The technology is sensitive to, and in large degree governed by, topographical factors. In other words, there is necessarily a “physical” network of transmitters, receivers and repeaters, and the placement of these is related to the topography, for example on high ground and within line-of-sight, and is constrained by transmission power and physical distance. A further reason for physical disjointness is business competition: in these relatively sparsely

populated areas it is generally only feasible for one provider to operate. Regulatory licensing requirements also decrease the likelihood of multiple providers. The observed "network" consequence of all these factors is that we see sub-groups, centred on a wireless broadband provider, and correlated with geographic location. Sharing a provider - often the search for one by new entrants to the area - in turn creates linkages among the digital businesses, and so increases the density of local ties. Such inter-linkage between multiplex networks, contingent on physical or geographic, social and institutional factors was apparent throughout the study.

Conclusion:

A network-theoretic point of view has much to offer in researching the "new economy" – for example, "dualistic" structures (Glasmeier & Howland 1993) might be theorized as arising from processes of cluster formation and co-evolution. Our research leads us to develop a conceptual framework, close in spirit to Storper's "trinity" of "technologies-organizations-territories" (Storper 1997), that comprises: (i) spatial processes of agglomeration and dispersal; (ii) social processes of culture, trust and embeddedness; (iii) Knowledge – both codified and tacit – and processes of its communication and formation; together with (iv) the economic "imperative" that seeks innovation and competitive advantage (Storper & Walker 1989; Porter 2003)

This last component has the effect of putting the whole assemblage into motion, as it were, bringing in processes of evolution over time and, in particular, of economic growth and success or, conversely, of stagnation and decline. Our framework is organized around "networks" – the social ones (friendship, trust, kinship etc.) and the economic ones (communication, cooperation, competition, exchange etc.) along with the physical infrastructure of the broadband network. It is within spatial areas that we most clearly see the effects of the degree to which these multiple networks are or are not coterminous. Thus actors may be spatial "neighbours", or even "social neighbours", but may not have any coincidence in their economic networks – in this regard it is interesting to find that social embeddedness was important to 'high tech entrepreneurs' in terms of 'a place to live' and of less importance to the success of their enterprise.

We find the mixed methods research design useful in that it combines and integrates both strands of analysis and thus deepens understanding of how networks affect business strategy and conversely how participants, through their pursuit of opportunity and efficiency, create and modify networks.

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