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5. Facilitating Regional Industrial Symbiosis: Network Growth in the UK's National Industrial Symbiosis Programme

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INTRODUCTION

In the years since the discovery of Kalundborg's long-lived network of resource exchanges, industrial symbiosis, and its potential for reducing the environmental impact of industrial activity on a local or regional scale, has been the subject of intense interest. Industrial symbiosis is defined as the enlistment of geographically proximate facilities in the "physical exchange of materials, energy, water, and by-products" (Chertow, 2000: 314). While some industrial symbiosis occurs between firms that are closely co-located, such as those in the same industrial park (see Chapters 4 and 6), other efforts to develop industrial symbiosis are undertaken on regional geographic scales. This chapter considers regional-scale industrial symbiosis, and, in particular, the development of a network of industrial symbiosis facilitated by a single brokering organization

It is now well documented that instances of self-emerging industrial symbiosis, similar to Kalundborg but often more modest in scale, are infrequently observed (see Chapter 6).On the other hand, efforts to create viable industrial symbiosis through the establishment of eco-industrial parks and other activities, have largely failed (See Chapter 4). In this chapter, we explore a 'third way' of establishing industrial symbiosis, the facilitation of a regional-scale industrial symbiosis network. We track the development of industrial symbiosis in the West Midlands region of the UK, and its facilitation by the National Industrial Symbiosis Programme (NISP). NISP was established, in the words of its founder, to "work with the willing," engaging with companies who wanted to participate in potential resource exchanges. It also recognized the inherent limitations in working with established companies operating over a relatively large geographic region – thus, potential exchanges had to be logistically feasible and economically attractive to the companies involved. Through a variety of activities ranging from holding workshops to introduce the idea of industrial symbiosis, through making specific introductions between firms, to in-depth, joint innovation projects, NISP was able to facilitate a large number of resource exchanges over a relatively short period of time. From NISP's inception as a regional pilot program in 2001, industrial symbiosis activity in the West Midlands increased dramatically. By 2007, 243 participating members (companies and a few non-profit organizations) had engaged in 307 industrial symbiosis projects.

What led to this rapid growth in industrial symbiosis activity? What kind of network formed between firms engaged in industrial symbiosis, and how did that network grow? We consider these questions in this chapter by drawing on archival data on all initiated, attempted, and completed resource exchanges in the West Midlands between 2005 and 2007. Data from interviews with NISP staff and participating company members enhanced our understanding of observed changes in the network. While the emergence and growth of a network of organizations can be regarded as indicative of structural embeddedness – all firms in the network are in some (direct or indirect) way connected to all others, potentially altering how information flows and power is exercised – our analysis suggests that network itself must be understood in relation to other dimensions of embeddedness. For example, we find that the trajectory of network growth can best be understood by considering the political, economic and cultural embeddedness of key actors in the network. This finding accords with the observation made by network scholars that networks “are already embedded in their broader ‘network’ of economic and social relations” (Provan et al, 2007: 481). It also supports the approach taken by some industrial ecology scholars who have attended to the broad social conditions surrounding industrial symbiosis arrangements, drawing attention to the historical, cultural and political conditions in which they emerge (Tomescu, 2005; Cohen, 2006; Gibbs et al, 2002; Ashton, 2008; Howard-Grenville & Paquin, 2008), and enabling infrastructure and institutions (Burstrom & Korhonen, 2001; Korhonen & Snakin, 2001; Jacobsen & Anderberg, 2004). By probing specifically how a network of industrial symbiosis evolves over time, we also explicitly attend to the temporal embeddedness of such arrangements.

INDUSTRIAL SYMBIOSIS, NETWORK STRUCTURES, AND TEMPORAL DYNAMICS

Network approaches have become increasingly important in the social sciences as sociologists and others have sought to understand organizations and individuals in relationship to each other, rather than as distinct entities subject to a sea of external forces (Emirbayer, 1997). A network describes the web of relationships existing between a set of individual or organizational actors. More formally, “a network is a metaphor to characterize a form of economic organization in which organizations have…permeable boundaries, and numerous connections to other organizations” (Smith-Doerr and Powell 2005: 380). Social network theory and the analytic techniques of social network analysis (SNA) offer powerful ways of visualizing, analyzing, and comparing network structures and relationships. Network ‘ties’ are the formal or informal connections between ‘nodes’ (typically organizations or individuals, depending on the network being studied). Social network analysis offers ways of measuring not only the relative importance of ties between actors (nodes) in a network but also enables researchers to probe characteristics of the whole network, comprised of the aggregate of all ties. The whole network may be sparse or dense, centralized around one or a few focal actors, or more balanced. Each structural configuration of the network has implications for how information flows, how power is concentrated (or not) and how the network evolves (Kilduff & Tsai, 2003; Smith-Doerr & Powell, 2005).

The literature on the emergence and development of industrial symbiosis has tended to mirror findings from the literature on networks more generally. Social network analysis is starting to be used in studies of industrial symbiosis to probe these relationships more fully (Ashton, 2008; Jacobsen & Anderberg, 2004; Howard-Grenville & Paquin, 2008). On the one hand, a few instances of viable, self-emerging industrial symbiosis have been documented, or ‘uncovered’ (Chertow, 2007; Gertler & Ehrenfeld, 1996). Perhaps the best known and longest-lived example of this is Kalundborg, where, over a period of more than 35 years, 20 physical resource exchanges have developed between six key organizations, and a handful of peripheral ones, within the Kalundborg industrial park (Ehrenfeld & Chertow, 2002). While the exchanges have had to overcome some significant technical challenges, the success of this system is frequently attributed to the “short mental distance” between managers in the close-knit community (ibid.). Indeed, while each exchange was developed bilaterally as a business opportunity and had to meet economic and environmental criteria, managers of many of the early participating organizations knew each other through prior social interactions.

Kalundborg represents what network scholars have called a “serendipitous” network, or one that forms through random social processes and is not necessarily oriented around a particular goal nor administered by a governing body (Kilduff & Tsai, 2003). Trajectories of such networks tend to involve slow, decentralized growth, the development and flourishing of many sub-networks, and the inclusion of relatively heterogeneous actors. Serendipitous networks may be resilient and enduring because they build upon pre-existing social ties and trusting relationships (Gulati & Gargiulo, 1999; Uzzi, 1996). Indeed, many studies find that structural stability within these networks flows from the social embeddedness of actors (Kilduff, Tsai, & Hanke, 2006). The robust and long-lived nature of Kalundborg's industrial symbiosis certainly supports this general observation.

On the other hand, numerous efforts have been made to initiate or accelerate the development of industrial symbiosis. While some of these have been successful (e.g., in Australia and China; see Ehrenfeld & Gertler, 1997; Van Beers, Corder, Bossilkov, & Van Berkel, 2007; Zhu, Lowe, Wei, & Barnes, 2007), a great many have not. Challenges to the actual development of industrial symbiosis relationships are well documented in this volume (see Chapters 4 and 6) and elsewhere (Chertow, 2007; Gibbs, Deutz, & Proctor, 2005). These include technical and regulatory challenges (Ehrenfeld et al., 2002; Gertler & Ehrenfeld, 1996), the difficulty of establishing trusting relationships between firms previously unknown to each other (Burström & Korhonen, 2001), and the fact that the environmental and economic benefits – if immediately present at all – are typically unequally distributed among parties (Chertow & Lombardi, 2005).

These results echo the expected trajectories of "constructed" or "goal-driven" networks identified by network scholars (Kilduff et al., 2003). Goal-driven networks are characterized by the presence of an administrative member which "acts as a broker to plan and coordinate the activities of the network as a whole" (Kilduff & Tsai, 2003: 89). Members are assumed to share a common goal that they seek to attain through their participation in the network. As a result, a goal-directed network may have relatively clear boundaries, experience little sub-network formation, and may be comprised of relatively homogenous actors (Kilduff & Tsai, 2003). Furthermore, in such a network, the trajectory and robustness of the network is particularly sensitive to the activities and internal legitimacy of this administrative body (Human & Provan, 2000).

The 'third way' that we explore in this chapter, the development of industrial symbiosis networks through 'facilitated emergence,' relies on the presence of a brokering organization to bring firms together. Brokerage is defined as the process “by which intermediary actors facilitate transactions between other actors lacking access to or trust in one another” (Marsden, 1982: 202). In the case of facilitated industrial symbiosis, the broker engages individual firms interested in such collaborations but who otherwise lack some combination of experience, knowledge, or contacts with other interested firms. By making introductions, the brokering organization may ‘stand in’ as an alternative to pre-existing social ties and thus speed the development of a trusting relationship between previously unknown firms. Additionally, the active hand of the broker can strategically shape the development of a broader-based regional exchange network. Each of these slightly different activities relies on two different forms of legitimacy. The former (connecting individual firms to each other) depends on the legitimacy of the network as a form of interaction, the latter (establishing industrial symbiosis regionally) depends on the legitimacy of the network as an entity (Human & Provan, 2000).

This facilitated emergence approach also raises questions about the dynamics of an industrial symbiosis network as it forms and grows. Early network forms may ‘lock in’ certain structures and norms of interaction. Some research suggests that initial actors in emerging networks tend to remain dominant over time because they have a disproportionately large impact in shaping the early rules or norms of interaction (Baum, Shipilov, & Rowley, 2003). Our first research question probes these network dynamics: how does the initial configuration of the industrial symbiosis network shape its growth or evolution?

Our second research question looks specifically at the role of brokerage in facilitating network emergence and development. In organizational research, brokerage has largely been considered a ‘structural’ concern focused on the positioning of actors within a network. For example, Burt’s work argues that powerful brokers are those who fill ‘structural holes’ within the network (Burt, 1992). Others argue that “brokerage is inherently and inextricably tied to structural position in transaction networks”

(Gould & Fernandez, 1989: 94). More recent work, however, has begun to integrate action with structure, exploring not just the 'positioning' of brokers but how they engage in the brokering process, and its outcomes (Hargadon & Sutton, 1997; Hargadon & Douglas, 2001; Obstfeld, 2005). Industrial symbiosis research views brokers as possessing more than simply a valued structural position. Institutional "anchor tenants" (Burström et al., 2001) such as local authorities (von Malmborg, 2004), key manufacturing facilities (Chertow, 2000; Chertow & Lombardi, 2005), or professional associations (Baas & Boons, 2004), can be critical to the development of exchanges. Such entities are valuable to the extent that they are regarded as trustworthy and hence possibly enhance the legitimacy of the emerging network and the network as a form of interaction (von Malmborg, 2004). Our second research question explicitly probes the effect of a broker on the developing network of exchanges. We ask: how does the presence of a brokering organization shape the growth or evolution of the network? How do the actions and interests of the brokering organization shape the network evolution?

METHODS

Research Setting

The focus of this study is on the activities of the National Industrial Symbiosis Programme (NISP) in the West Midlands region of the United Kingdom. Formed in April 2005, NISP's goal is to "encourage government and industry of the benefit of industrial symbiosis (IS) as a key policy tool in helping the UK to achieve a sustainable economy, further supporting the integration of an industrial symbiosis approach into the nation's resource management strategy" (NISP, 2006). NISP operates on a regional level to facilitate industrial symbiosis projects and, while national in scope, operates semi-autonomously in each of the UK's 10 economic regions. Within each region one or more NISP employees or ‘practitioners’ work with companies to identify possible industrial symbiosis projects. They engage in a range of brokering activities – from hosting networking events and workshops for firms, to facilitating direct introductions between interested firms, and coordinating in-depth consulting projects with individual firms.

NISP grew out of a regional pilot project, WISP (West Midlands Industrial Symbiosis Programme) which began informally in 2001 and formally launched in 2003. The national program continues to be headquartered in the West Midlands region. Our analysis begins to track the network in 2005 because this was the time that the program was secure enough to move beyond its pilot phase, and when it formalized its own project tracking process to enable data collection. Both of these events were related to the receipt of national-level funding and a mandate to increase the scope of the program into other UK economic regions.

As of 2007, the great majority of NISP’s funding came from the UK government, originating indirectly through the collection of the UK landfill tax. Passed into law in 1996, the landfill tax set an escalating tax on industrial landfill which in 2008 was 32 GBP/tonne and expected to rise to 48 GBP/tonne by 2010. Part of these tax revenues were set aside specifically to competitively fund regional and national organizations, such as NISP, to assist UK firms in finding novel ways to remain economically competitive under increasingly stringent UK and EU environmental regulations. NISP’s funding is tied not to specific industrial symbiosis projects but to its ability to create aggregate reductions in landfill, carbon dioxide and other environmental metrics in economically beneficial ways. Due to its funding structure, NISP’s services are free to interested businesses.

NISP’s activities in the West Midlands offer a good setting in which to explore the trajectory of facilitated industrial symbiosis because this relatively mature region displays elements of both goal-directedness and serendipity. It involves an administrative body (NISP) that has explicit goals for (and whose success is measured against) reducing net environmental impact. On the other hand, industrial symbiosis remains a relatively new environmental activity for UK firms, unknown to the great majority of businesses in the region, and also unknown to others on whom the success of the program may depend (e.g., local environmental authorities, regional development agencies, etc.). As a result, efforts to build and gain legitimacy for the network were expected to involve building on prior relationships and connecting previously unconnected firms. The evolutionary paths of such networks are poorly understood, and the practical challenges to developing and maintaining them equally poorly understood.

Data

We collected quantitative and qualitative data to enable us to represent and analyze the network structure in the West Midlands, and to understand some of the processes behind its emergence and change.

Quantitative Data: Archival records of interfirm resource exchanges. We collected quantitative data on all initiated, attempted, in-progress, and completed industrial symbiosis projects facilitated by NISP in the West Midlands from 2005 (earliest period at which this data was formalized) to 2007. These data included facility name, location, industry, size, prior experience in the exchange network; and project information such as the material involved, the quantity and quality of material, which facility was the intended receiver of the material, when the project was initiated, when and if it ended (failed) and changes over time. Projects were tracked on a 1 to 5 scale with: 1 = introduction made between relevant firms; 2 = firms discussing project past introduction; 3 = firms negotiating details of projects (costs, logistics, etc.); 4 = firms beginning project; 5 = project is ongoing or complete. We used NISP's own internal tracking scale as our basis for capturing the progress of individual projects.

Qualitative Data: Interviews. Between December 2005 and November 2007, we conducted open ended and semi-structured interviews with 11 NISP staff directly or indirectly involved in NISP's work in the West Midlands. In these interviews, we probed individual histories and roles within NISP, how interviewees perceived NISP as an organization and a broker, and how they engaged with firms in their particular roles within NISP. We also held dozens of informal interviews and conversations with NISP staff during our visits to NISP offices and when attending other events. These gave us more insight into some of the nuances of NISP's operations. We also conducted 23 interviews with members of companies who participated in NISP in either the West Midlands or East Midlands region. Some of these companies had initiated or completed industrial symbiosis projects through NISP, others had not but had attended workshops and/or expressed interest in engaging in potential projects. The company interviews gave us a sense of how NISP's activities were viewed more broadly, and helped us understand different ways that companies engaged with NISP.

Analysis

We analyzed the archival resource exchange data using standard social network analysis software UCINET version 6 (Borgatti, Everett, & Freeman, 2002). This software allowed us to analyze characteristics of individual nodes within a network, as well as characteristics of the overall network. In our case, the network nodes were individual companies engaged in industrial symbiosis projects and the ties represented the actual projects. It is important to note that not all ties represented completed projects. As mentioned above, we used NISP's own scale (1 through 5) to capture the status of individual projects from '1' representing the fact that two firms had been introduced to each other around a specific project idea, to '5' representing a fully completed (or ongoing) symbiosis project. Thus, we consider the status of individual projects as a measure of tie strength between the firms involved.

We analyzed the emerging resource exchange network quarterly from 2005 to 2007 (nine periods total), with each quarter providing a 'snapshot' of the evolving network. Each successive quarterly ‘snapshot’ provided a cumulative view of all exchanges in the network up until that point in time. For our first time period (2005), a number of firms and projects are already active in the network. Of course, these firms did not all immediately jump into action during this time period, rather these projects were already under development but it was in this period that NISP first formally captured data on these projects. As discussed above, NISP’s precursor organization (WISP) began in the region in 2001, but formal project data was not tracked until 2005. Thus, the data listed as ‘2005’ is an aggregated baseline of the network roughly from its beginning through the end of 2005.

Once we had obtained numerical and graphical data of the industrial symbiosis network across these time periods, we assessed how the network changed over time. This was done by relying both on our social network analysis and by drawing on our interviews to add texture to the quantitative findings.

FINDINGS

The Growing Network

By several measures, the network of industrial symbiosis projects in the West Midlands, and hence the firms connected through such a network, grew considerably between 2005 and 2007. The number of industrial symbiosis projects grew from 175 in 2005 to 307 in 2007. The number of firms involved in these projects also grew substantially from 162 firms in 2005 to 243 in 2007. During this period, the number of new industrial symbiosis projects outpaced new firms engaging in the resource exchange network. Another way to view this is through the mean number of projects a firm was involved in during this time. This measure grew from 2.20 in 2005 to 2.53 in 2007[1]. This implies that the network grew by engaging new firms in industrial symbiosis and, importantly, by re-engaging firms already in the network in new projects. Table 1 provides a number of descriptive measures for the network for each quarter from 2005 to 2007 and includes the mean number of projects (exchanges) per firm.

[1] Because industrial symbiosis projects are interfirm collaborations, the project/firm ratio is not computed as #projects / #firms. Rather, since industrial symbiosis projects require at least two (and in our data, sometimes more) firms collaborating, the project/firm ratio equals the averaged sum of the number of projects each firm is engaged in.

The rate of network growth increased somewhat later in the time period studied. This is most easily seen by the change in the graphs shown in Figure 1, where a marked increase in slope occurs in early 2007. Figure 1 also discerns between the core component or ‘main’ network (meaning the larger group of firms who are cohesively connected to each other) and other unconnected components that are not connected to the main network. In social network analysis, the ‘network’ per se is often not a completely connected network, but rather a collection unconnected or sparsely connected subgroups of actors. For ease of discussion, we will refer to the largest subgroup or core component as the ‘main’ network; and the smaller unconnected subgroups collectively as ‘components’ (Scott, 2000). Figure 2 shows graphical portrayals of the overall network at three time periods (2005, 2006, and 2007) with the ‘main’ network and ‘components’ differentiated by shape and color. Each dot depicts a firm, and each line is an industrial symbiosis project initiated, underway, or completed between the connected firms.

INSERT TABLE 1 AND FIGURES 1 & 2 ABOUT HERE

By discerning the main and component portions of the network, another trend is clear in the overall network growth. Both the proportion and actual numbers of firms and projects unconnected to the main portion of the overall network decrease over time. In other words, industrial symbiosis activity becomes concentrated within the ‘main’ network, comprised of more fully interconnected firms. Two dynamics contribute to this. First, as can be seen in the network snapshots in Figure 2, firms in the components tend to develop new projects with firms in the main network, in effect, bringing all the firms from a given component into the main network. An example of this is seen in the circled set of firms in the lower part of these network diagrams. Second, and less obvious from the network diagrams, is that most new industrial symbiosis projects involve new firms (previously not in the network at all) engaging with existing firms in the main network; of the 81 firms who enter this network after 2005, the large majority engage with firms already in the main network (as opposed to firms in the components). Thus, network growth results primarily from increasing activity within the main network, and only secondarily from activity in the components.

Qualitatively, our interviews with NISP staff and company participants supported the findings of rapid network growth and offered reasons for it. One oft-cited reason for companies engaging with NISP was that it expanded their access to information and opened them up to potential new opportunities and contacts. For example, one interviewee remarked that NISP offered them "really an added opportunity to network and find out about [additional] opportunities." Another noted that "They [NISP] have the time and energy to get around and talk to a huge cross section of companies within the region that they are operating in. It's quite easy for them, from the outside looking in, to recognize that a company might have a waste product that another company could use." This interviewee went on to add, "the benefits to us of NISP, [are that] they are able to come up with ideas that we wouldn't have thought of, and then they introduce us to other companies that we might never have crossed swords with."

From NISP's point of view, generating contacts and engaging more firms was essential to growth and success, and took up a considerable amount of time and effort, especially in the early days. One NISP practitioner said "the challenge for us was to try and engage businesses, but why will they come if every other business group in the country is knocking on their door? So we tried to establish events and workshops around themes." As interest in the program grew, NISP staff could become more selective and 'hands on' in their work with firms because recruitment to the program required less time. One NISP regional coordinator put it this way:

> "When you start off the program you generate the membership. … After that level, [when] there are about 80 members within a region, you find that the companies are making referrals through their supply chain, saying 'this program is good we got such and such out of it, you might get involved with it as well.' We are finding that whereas in the first few months we were making all the phone calls to get people to come in now we are getting calls to the office from people who heard of us, now it's about 50-50 calls in to calls out."

As this change occurred, NISP staff were able to potentially add more value and engage existing firms in projects that might have required more innovation and facilitation. This may be one of the reasons that the number of projects per firm increases over time, as sheer recruitment is gradually replaced by more strategic development of industrial symbiosis projects. The latter type of activity is valued and sought after by both participating firms and NISP itself. For example, one company member noted that "what I need NISP to do is actively facilitate between people." Another observed that NISP would add value to their business by "analyz[ing] the information they have and go[ing] back to companies and say[ing] there is an option *here* for you."

While our data do not show it explicitly, there is a potential tension between the need to recruit firms and show rapid growth in the network – an early indicator of 'success' – and the need to develop complex, knowledge-intensive projects that may require significant investments of time, expertise, and technology. We turn next to analyzing in more detail where and how the growth in the network occurred, and to further probing the incentives of participating companies and NISP itself.

"Churn" in the Network

As discussed above (and shown in Table 1), both the number of firms and number of projects increases over time with new projects in the network out-pacing new firms engaging the network. On its own, this is fairly consistent with prior work on social networks which suggests that those already in the network (especially those central in the network) continue to reengage and profit from their position in the network over time (Baum et al, 2003). In other words, the 'rich get richer' (para, Provan, Fish, &

Sydow, 2007). As we look more closely at firm-level activity, however, this does not bear out exactly in the industrial symbiosis network.

In the 'rich get richer scenario,' network analyses would show an increasing stratification within the network between more central and less central actors. One measure of this is the network centralization index. This index provides a network-level measure of range of centralities of individual firms in the network, with centrality representing how connected each firm is to all others. A high centralization index indicates a network were a few key actors are highly connected to all others, and less central actors tend to be connected only to those central actors. In the 'rich get richer' scenario of network growth, we would expect to see the network centralization index increase over time, suggesting increased network stratification. As shown in Table 1, the West Midlands industrial symbiosis network does the opposite, with its network centralization index decreasing from 102.8% in 2005 to 95.3% in 2007. This decreasing stratification among firms in the network suggests that firms are not necessarily engaging in industrial symbiosis projects with the most centrally connected (and by implication, experienced) firms but with other, less connected, firms. This network growth path in itself might be regarded as a healthy, for it reduces the tendency for power and information to be concentrated among a few highly connected actors, and enables the potential infusion of new ideas and relationships throughout the network. We consider now possible explanations for this path.

First, an analysis of the connectedness of individual firms shows considerable 'churn' among the highly connected firms over time, elaborating on the trend in the network level centralization index. Table 2 shows this descriptively with a rank ordering of the 20 most central firms in 2005 against their centrality ranking in 2007; and vice versa with the 20 most central firms in 2007 – eight of which were not even in the network in 2005. Even when taking a comparable percentage of 'top' firms in 2007 as in 2005 (in this case the top 30 most central firms in 2007 to the top 20 in 2005), only two top firms in

2005 are in the top 30 firms in 2007 (these are shaded in gray). That so many firms who join the network 'late' become so central suggests something unusual in the network's growth. Understanding this requires a more in-depth exploration of NISP's activities and goals as a regional industrial symbiosis broker.

INSERT TABLE 3 ABOUT HERE

NISP's regional brokering activities. From our interviews, we learned that NISP engages in a number of distinct activities to facilitate industrial symbiosis projects. First, NISP sponsors regular workshops in each region for firms interested in learning more about or getting involved in industrial symbiosis projects. NISP staff and workshop attendees independently referred to these events colloquially as 'speed dating,' and formally as "Quick Wins" workshops. At such events, NISP staff introduced the idea and demonstrated, through examples, the value of industrial symbiosis. They then facilitated the sharing of waste and by-product information between firms. These networking sessions were valuable in several ways. First, they quickly gave attendees an idea of what types of projects their firms might get involved in. As one attendee noted, she was intrigued and surprised by the opportunities that came up during the workshop. She said, "I've been to one networking session where we all sat down and did a grid, [of] what [resources] we want and what we have; which I found absolutely fascinating. … [at the beginning] we were sitting there and thinking "God this is hard" and then at the end of it there were 132 synergies." Synergies is the term used by NISP to refer to potential or actual resource exchange or industrial symbiosis projects.

The workshops also provided NISP with each firms' contact information and details of its resource needs and capabilities which it may later use to facilitate introductions between firms with matching resource needs and capacities. NISP staff often followed up on the information gathered from networking events with visits to individual facilities to learn more about their environmental and waste management activities. These visits also enabled NISP staff to develop relationships with representatives from individual facilities - increasing NISP's perceived value in facilitating future industrial symbiosis projects between unconnected firms (Uzzi, 1997).

This information helped NISP staff gain an increasingly 'transparent' view of the potential industrial symbiosis field or network in the region (Dorado, 2005; Hargadon et al., 1997). In our interviews, we found that firms both (a) felt that their firms lacked this broader interfirm perspective and (b) looked to NISP (and other business support organizations) to help provide them with that more strategic perspective. One company participant noted that "more importantly you meet people on the cutting edge of technology - new systems, new methods - and you can start working with them. You say, ok, let's see what you've got. Let's see if it's applicable to our industry."

These activities, combined with NISP's internal decision to hire staff with greater industry-specific experience, increased NISP's aggregate level of expertise. This expertise was of value in both establishing the industrial symbiosis network as a legitimate form in the region, and in developing specific industrial symbiosis projects between interested firms. This change allowed NISP staff to move beyond simply making introductions to providing guidance and expertise around particular industrial symbiosis projects as needed. Lastly, NISP staff began engaging with individual facilities in more traditional consulting relationships – assisting with business and strategy development, funding, R&D support, etc - around new types of industrial symbiosis projects or expanding capacity for prominent resource streams in the region. For example, one NISP practitioner shared an experience of hearing from a farmer who wanted to use his farm waste to generate energy through anaerobic digestion, and sell the excess energy to a new industrial facility on an abutting site. The NISP practitioner liked the idea, but felt that the farmer was "thinking too small." Accordingly, working with the farmer, the industrial facility next door, and the local authority, he helped generate a plan to pull in additional waste streams and to build an energy facility five to ten times larger than that the farmer had originally had in mind. This kind of activity not only expanded the scope of potential projects, but was seen as generating regional capacity and a number of 'spillover' benefits.

INSERT FIGURE 3 ABOUT HERE

NISP's impact on the network. Our understanding of NISP's activities from the interview data is reflected in some quite significant changes in the actual resources exchanged over time. Figure 3 shows, by major resource type, the cumulative number of industrial symbiosis projects over time. Two types of exchanges are particularly worth noting for their increased prominence later in the time periods studied: i) expertise - when one firm or organization provides technical, production, or some other specialized expertise to help develop a new project; and ii) infrastructure - when one firm or organization engages in a consultative approach to help another develop or expand its capacity for engaging in industrial symbiosis. Given that one-third of industrial symbiosis projects in the network by 2007 are 'expertise' projects, we focus solely on those projects here.

NISP's engagement as an expert in projects – or rather in 'expertise' projects - increases from 9 to 27 projects or from 18.8% to 32.1% of the total number of expertise projects from 2005 to 2007. By 2007, 8.8% of the total projects in the network are due to NISP's role as expert in these 27 'expertise' projects. This suggests that NISP's influence on the network is more than merely a 'broker' passing information or making introductions (Marsden, 1982), rather it is an active player fundamentally shaping the network's path and the content of the exchanges, as suggested by some of the interview data.

To examine the influence of NISP activity on the network, we removed NISP's expertise projects from the overall network. We compared this second network to our original network as a way to evaluate the influence of NISP's expertise activities on the network over time. Table 3 provides some comparative descriptive data on these two networks at three points in time – 2005, 2006, and 2007. In Table 3, we see that for 2005, the networks look very similar by these measures, with a quite marked divergence in these measures by 2007.

INSERT TABLE 3 ABOUT HERE

Statistical comparison of the networks in 2005 and 2007 shows that removing NISP's expertise activities significantly changes the network structure and its pattern of evolution. Most importantly, when NISP's expertise activities are removed from the network, the 'churn' in the top firms observed earlier is less pronounced and no longer statistically significant. Thus, if NISP's expertise projects are ignored (but it's typical brokering activities remain), it seems that the 'rich may in fact be getting richer.' In other words, the most connected firms tend to gain proportionally more of the new industrial symbiosis partners and projects over time, when looking at non-expertise exchanges. Furthermore, this suggests that NISP's own activities are differentially influencing the network's growth path. The heavy increase in NISP's engagement in expertise activities in 2007 may reflect either the fact that opportunities to pick 'low hanging fruit' (achieve relatively simple industrial symbiosis exchanges) have decreased, or that a strategic decision was made to pursue these more innovative, potentially higher valued-added activities. Our interviews suggest that latter, but more research is needed to determine the contribution of each of these possible explanations.

Challenges to Growth of the Network. The growth of the industrial symbiosis network was not without some challenges. Among these were working out how NISP would work with companies and find a balance between advocating for particular projects and respecting the need for companies to make these decisions for themselves. One NISP practitioner observed, "every [company] meeting that we go to we try to make the decision as informed as possible, whether it be legislation or supply, etc. You can give advice there but it is really down to the companies concerned if they want to move forward." He added, "you can sit behind a company and act as a sounding board for them, [but] obviously we don't want to push it to far because we don't want to be interfering with the business process."

Some companies appeared to want more hands-on involvement from NISP. One interviewee noted that reviewing their waste streams on their own was "a bit resource intense from our point of view." He added that he would have liked NISP to be more proactive, reviewing his waste and that of others and saying "we see that you have this, well we have a match here with this other company, how about hooking it up?" Others, especially larger companies, felt that they had a good handle on many of their waste streams and, while they supported NISP's overall activities, had no need to engage in particular industrial symbiosis projects. One company member observed "unfortunately by the time NISP came along we had really sorted out all of our waste streams. Had it been ten years earlier I think we would have been more enthusiastic about using it. We are very supportive of it but we aren't actually using it."

For many other companies, NISP was of valuable assistance but it took time and effort to build trust and learn about opportunities. Part of this involved sorting out how NISP was distinguished from a number of other organizations who offered similar services. For example, one company interviewee noted:

> “There’s also another organization that’s also funded by the government that’s called WRAP - Waste Resources Action Programme. That’s been going since, must be 2001… To a certain extent, they’ve been doing what NISP is now set up to do. But, they’re [WRAP] now concentrating on finding the actual methodology of reuse, recycling in the end market. So they’re concentrating on end markets now, whereas NISP is doing more of the facilitation role.”

A NISP practitioner added that building relationships with companies was essential to aid their understanding of opportunities and willingness to pursue them. “We try to understand the business benefit that might be accruing from a particular opportunity, [but] it’s also a trust issue,” he noted. He went on to say that “if you rely on the database [NISP’s internal knowledge management database of potential waste exchanges], you lose the trust from the businesses; you become a passive waste exchange. So the networks and trust are the key here.” It is perhaps not surprising, given the importance of trust in developing other industrial symbiosis arrangements (Burström et al., 2001), that it is seen as so central even in a rapidly-growing, facilitated industrial symbiosis network.

DISCUSSION

Our analysis of the evolution of industrial symbiosis in the West Midlands demonstrates the effects of an active broker on the structure of the network itself as well as the level and nature of activity within it. Our findings show that the industrial symbiosis network grew significantly over a period of only three years, and that growth occurred primarily by new firms entering the network and becoming engaged in projects with firms already involved in other industrial symbiosis projects within the network. This in itself suggests that it may be possible to build a goal-directed network for industrial symbiosis. This path differs substantially from the self-emergence of Kalundborg’s industrial symbiosis in the absence of any facilitating body (until late in its existence). It also contrasts the planned approaches to setting up eco-industrial parks which have often failed to develop any significant industrial symbiosis activity at all (see Chapter 4 in this volume).

By exploring where and how growth occurred in the regional industrial symbiosis network, we revealed that the facilitating organization – NISP – had a disproportionately large impact on the network changes, particularly in the latter stages of our study. There are several possible explanations for this, all of which bear further study. First, NISP was acting not merely as a traditional broker occupying a position within the network that enabled it to make introductions between firms, but it was also acting as a network participant in its own right. In other words, it had its own agenda for seeding and developing certain types of industrial symbiosis projects and the increase in 'expertise' projects may have reflected this. Whether this was the result of regional staff gaining experience and expertise and becoming more inclined to work on more complex projects, or the result of the growth in staff and the addition of their individual networks and interests to the brokering activity, it suggests that brokering such a network needs to be understood not merely as a structural activity of making introductions. Indeed, which introductions are made and which projects are pursued aggressively is a reflection of individual interests and experience.

A second, and somewhat related explanation for the structural shifts in the network development, is found in understanding NISP's funding model and the metrics used to track its performance as an organization. As a primarily government-funded program, NISP's success is tracked by a number of specific environmental metrics, such as tonnes of material diverted from landfill, and reductions in carbon emissions, potable water use, etc.. As the 'low hanging fruit' associated with the diversion of some high tonnages (e.g. construction aggregate or glass recycling) is achieved in a region, other projects may require more sophisticated technological development, investment in capacity, and multi-party collaborations. The additional inclusion of economic metrics to track NISP's success (e.g. money saved, jobs created) as well as more detailed environmental metrics will inevitably further shape NISP's incentives for pursuing certain projects over others.

It is not possible with the data at hand to tease out these various influences, but the overall shift in the network development supports the general observation that structural network changes must always be understood in relation to the economic and other interests of the participants and brokers. In other words, structural embeddedness is in part a reflection of other forms of embeddedness, including temporal embeddedness which captures the trajectory of network growth. Indeed, networks are themselves embedded in broader relational contexts (Provan et al, 2007). In this case, the rapidly changing political, regulatory, and economic contexts surrounding resource provision, use, and disposal produce shifting incentives for brokers and other actors engaged in industrial symbiosis. This results in more pronounced network dynamics than those typically ascribed to social networks. Indeed, our finding that the network 'churns,' and becomes less stratified rather than more so, contradicts prior work on network development that suggest an increasingly centralization of key actors as the 'rich get richer' over time (Baum et al, 2003).

Our research suggests that the presence and nature of involvement of the brokering organization may be critical to the evolution of regional-scale industrial symbiosis, but also raises a number of questions for further study. These include a number of questions around brokerage itself: how does the value of a broker as perceived by other firms in the network change over time, how robust is the network under various degrees of intervention by a broker, and what characteristics must a broker possess to be effective in developing a network? The existing literature on industrial symbiosis provides some clues as to the importance of these questions. For example, issues of trust become even more pronounced when public entities – who might otherwise be in a regulatory role – begin to try to operate as collaborating partners (Burström et al., 2001).

Another critical set of questions to pursue address the nature of industrial symbiosis projects generated through a facilitated network model. Some have suggested that industrial symbiosis is more complex than simply a resource exchange between two firms, akin to traditional recycling. For example, Chertow has proposed a ‘three-two’ heuristic for what comprises industrial symbiosis: at least three firms must be involved in the exchange or sharing of at least two resource streams (Chertow, 2007). Using this heuristic, relatively few of the resource exchanges captured in the West Midlands network would qualify. However, several of the ‘expertise’ projects that targeted more complex schemes (e.g., the anaerobic digester that would pull in additional waste streams and operate as a larger facility) may well qualify. Perhaps the shift towards these types of projects, as observed earlier, marks the development of a more robust and longer-lived set of network ties than those that might be developed only around simple two-firm recycling or reuse arrangements. On the other hand, even ‘simple’ exchanges are likely critical to the establishment of relationships that lead to further and grander projects. The advantage of facilitating introductions in a network is it at least gets companies into contact with each other. Whether they go on to develop a specific project or not, their thinking about the issues may have changed, or their openness to pursuing a project when the time and partnership is right may have been primed. Indeed, in the absence of any communication between firms, one finds very little industrial symbiosis activity (see Chapter 6 of this volume), whether of a simple or more complex nature. As one company interviewee observed

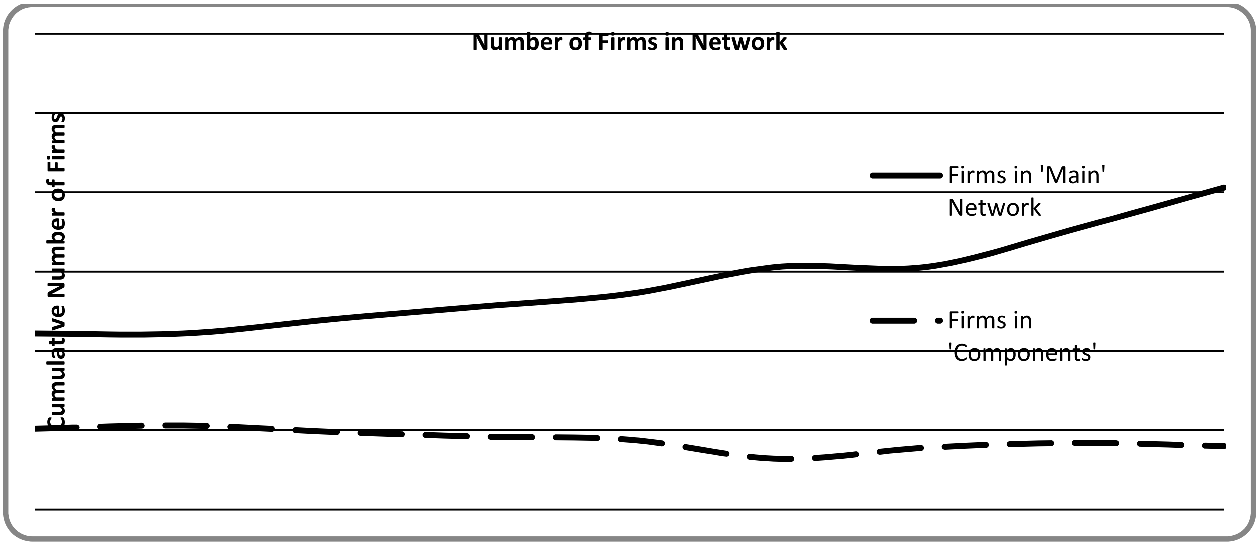
> “It could be that NISP would be just as valuable in putting us in contact with like-minded people rather than just the raw data and the waste materials, because I can learn just as much by talking to people. For instance, [I had] conversations with [a company] and they are coming in this afternoon. If it wasn’t for NISP perhaps we would never have heard about them.”

CONCLUSION

While the success of Kalundborg is indisputable, many observe that improvement of resource consumption on a regional scale cannot wait three decades to develop in other parts of the world. The evidence from this study that facilitated industrial symbiosis networks can grow significantly, achieve demonstrable net environmental gains, and do so in such a short period of time offers an alternative to the oft-debunked "constructed" approach of developing dedicated eco-industrial parks. Our findings, however, also suggest just how sensitive facilitated industrial symbiosis can be to the activities, goals, and incentives of a brokering organization, and the other firms involved. Whether a 'facilitated emergence' approach as shown here can offer a robust 'third way' model of facilitated interorganizational environmental collaboration depends to a great degree on the nature of the broker, the dynamics of the network and the robustness of the system that evolves as a result.

FIGURE 1.

Number of Firms and Industrial Symbiosis Projects in the Exchange Network over Time



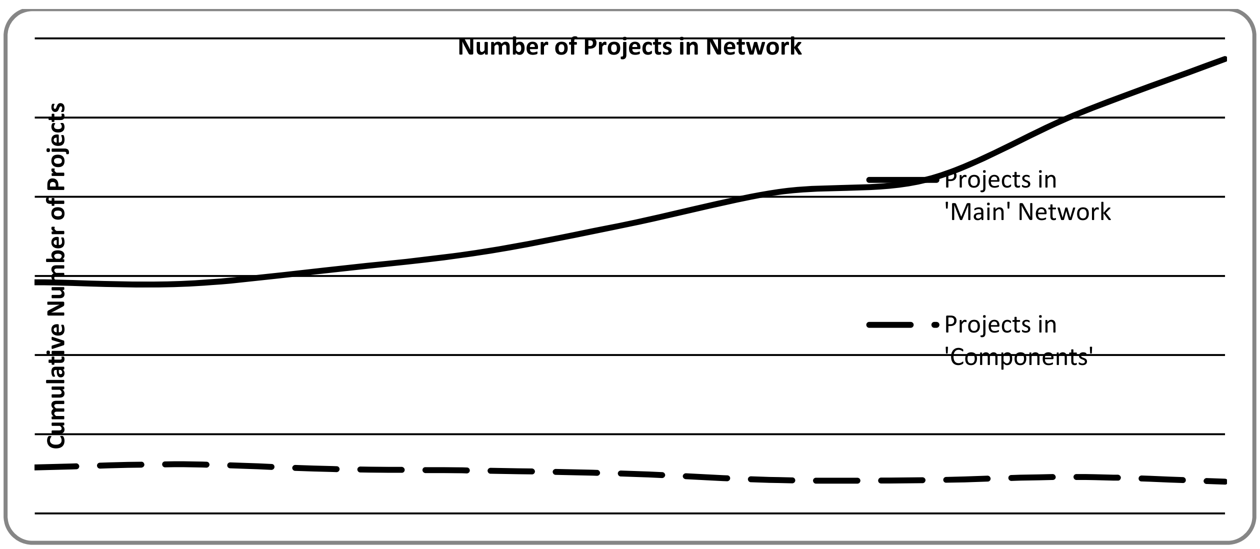
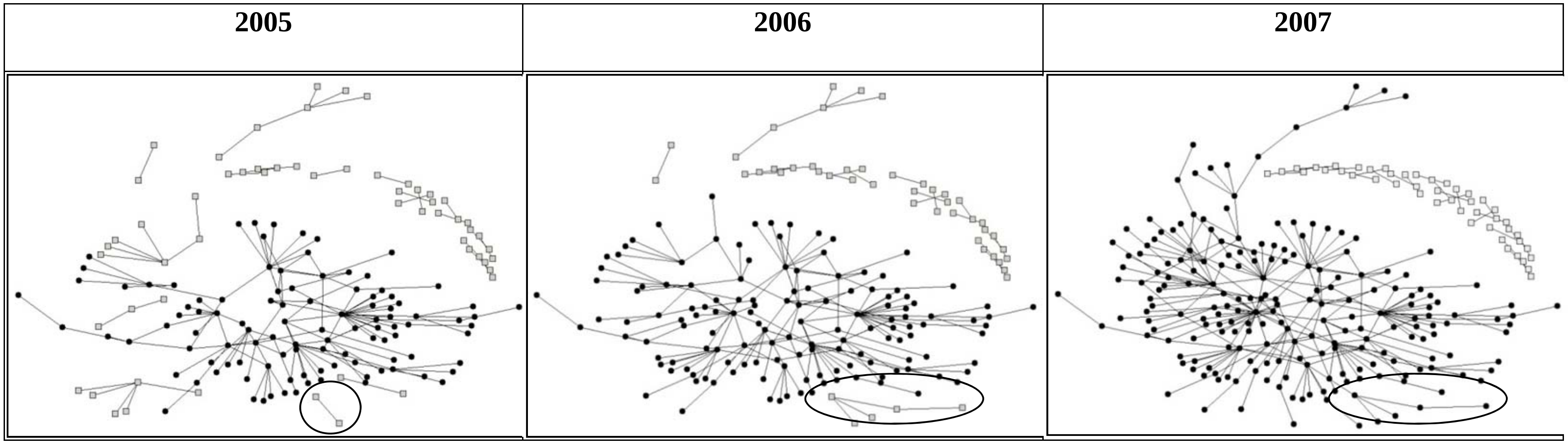


FIGURE 2

Snapshots of the Growing Exchange Network in 2005, 2006, and 2007



<u>Notes and Legend:</u>

- <u>Main network</u> == black circles
- <u>Unconnected components</u> == gray squares
- Each snapshot shows active firms (those engaged in industrial symbiosis projects) during that time period. As the network is cumulative, each time period has more firms and exchanges than the previous.
- The expanding oval shows the growth of one particular component in the network from 2005 to 2006, and its subsequent connection to the main network as a firm from the component and a firm from the main network engage in a new industrial symbiosis project during 2007.

FIGURE 3.

Types of Resources Exchanged in the Industrial Symbiosis Network over Time

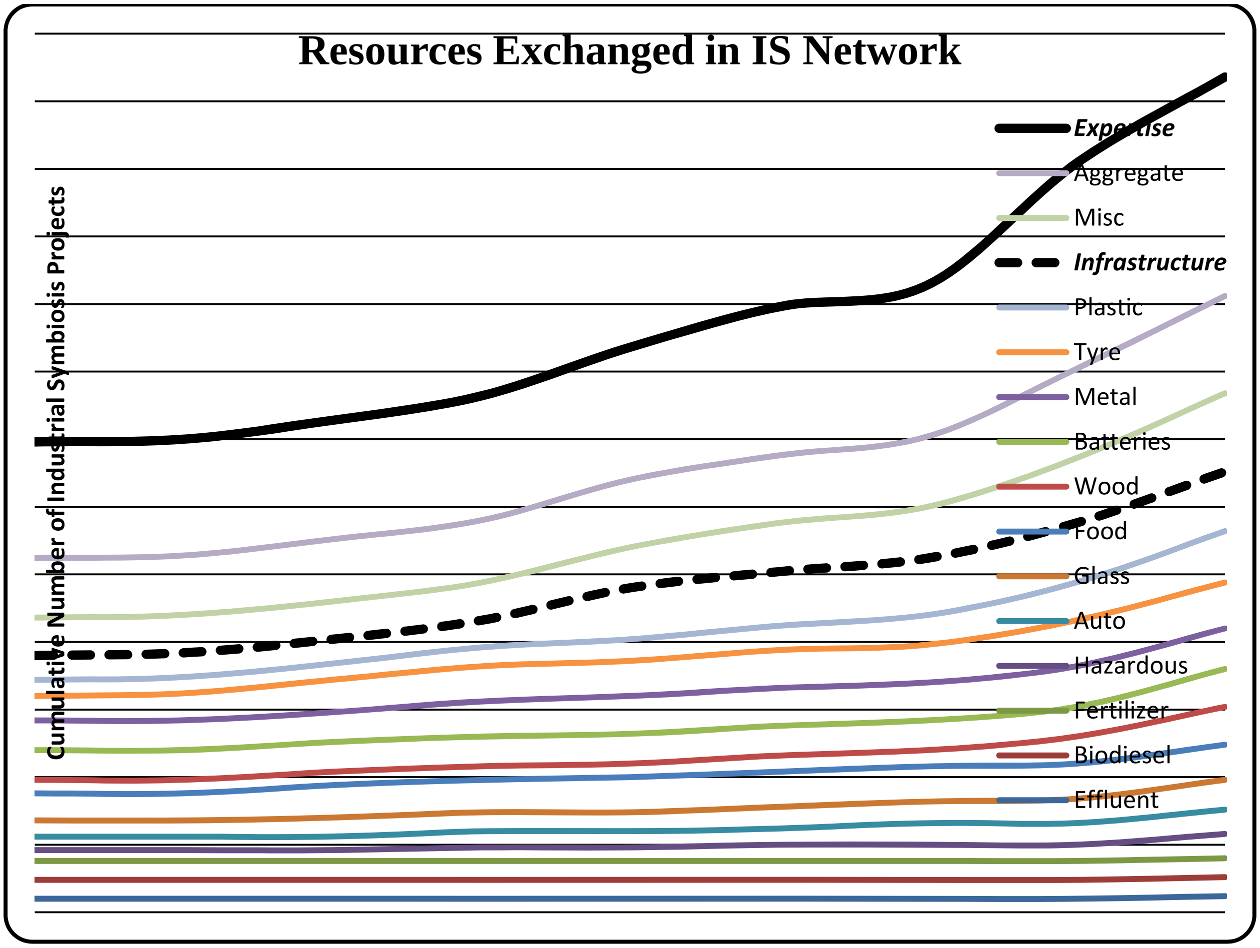


TABLE 1
Descriptive Measures of the Growing Industrial Symbiosis Network

Time periods	**T0** *2005*	T1	T2	T3	**T4** *2006*	T5	T6	T7	**T8** *2007*
Number of Firms in Network									
'Main' network	**111**	111	120	128	**136**	153	153	177	**203**
'Components'	**51**	53	49	46	**44**	32	39	42	**40**
Total	***162***	*164*	*169*	*174*	***180***	*185*	*192*	*219*	***243***
Number of Exchanges in Network									
'Main' network	**146**	145	154	165	**183**	203	211	252	**287**
'Components'	**29**	31	28	27	**25**	21	21	23	**20**
Total	***175***	*176*	*182*	*192*	***208***	*224*	*232*	*275*	***307***
Network Measures									
Mean Exchanges per Firm – *entire network*	**2.20**	2.17	2.19	2.26	**2.39**	2.47	2.45	2.52	**2.53**
Eigenvector Centrality (SD) – *main network only*	**4.66 (12.59)**	4.69 (12.58)	4.53 (12.09)	4.31 (11.73)	**3.76 (11.53)**	3.50 (11.17)	3.40 (10.92)	3.94 (9.87)	**4.66 (8.76)**
Network Centralization Index (%) - *main network only*	**102.8**	103.1	100.9	100.7	**94.9**	98.6	98.2	94.3	**91.5**

Note: 2005, 2006, and 2007 are bolded since they are used in comparison later in the chapter.

TABLE 2.

Rank Ordering of Firms by Centrality at 2005 and 2007

Top 20 Most Central Firms in 2005		
Firm	2005 Ranking	2007 Ranking
A	1	44
B	2	81
C	3	134
D	4	135
E	5	136
F	6	60
G	7	137
H	8	138
I	9	144
J	10	8
K	11	69
L	12	121
M	13	86
N	14	139
O	15	140
P	16	141
Q	17	50
R	18	113
S	19	131
T	20	20

Top 20 Most Central Firms in 2007, plus Firm A		
Firm	2005 Ranking	2007 Ranking
BX	76	1
DH	n/a	2
CD	82	3
CG	85	4
DI	n/a	5
DJ	n/a	6
AJ	36	7
J	10	8
AT	46	9
CE	83	10
DK	n/a	11
DL	n/a	12
AR	44	13
V	22	14
AH	34	15
DM	n/a	16
DN	n/a	17
DO	n/a	18
CA	79	19
T	20	20
…	…	…
A	*1*	*44*

Notes: Only firms J and T, ranked 10th and 20th respectively in 2005 were among the top 20 most central firms in 2007. Firm A, the most central firm in 2005, was ranked 44th in 2007.

TABLE 3.

Comparison at three points (2005, 2006, 2007) of Networks with and without NISP's expertise projects

	With NISP's expertise projects				**Without NISP's expertise projects**		
	2005	**2006**	**2007**		**2005**	**2006**	**2007**
# Firms - *Whole Network*	162	180	243		159	177	235
# Firms – *'Main' Network only*	111	136	203		106	133	194
# industrial symbiosis projects	175	208	307		167	200	281
Eigenvector Centrality (SD) – *'Main' network only*	4.66 (12.59)	3.76 (11.53)	4.66 (8.76)		4.88 (12.84)	3.51 (11.75)	2.82 (9.76)
Network Centralization Index – *'Main' network only*	102.8%	94.9%	91.5%		102.9%	90.0%	95.3%

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