Computer Modelling Reveals the Optimal Development for the Organisational Structure of Business Clusters

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Abstract:

Science and Technology Parks (STPs) foster innovation between firms inhabiting the cluster. Networking channels are considered as integral parts of the knowledge exchange process, and therefore the innovation process. We simulated three organizational topologies for STPs; firstly, in the star model all are connected to the cluster initiative (CI), secondly the strongly connected model, when all are connected to each other, and finally the randomly connected model, where the network follows no centralised topology.

Analyses used adjacency matrixes and Monte-Carlo simulation, trading transaction (networking) costs against knowledge benefit. Results show that star topology is the most efficient form from the cost perspective, and this is especially the case for start-up STPs. Later, when the cost of knowledge transformation is lowered, then the strongly connected model becomes the most efficient topology, but this transition to high transaction costs is very risky if direct ties do not quickly result in tangible benefits.

Keywords:
Cluster, innovation, network, tech-hub, simulation, modelling, Monte Carlo.

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1 Introduction

Science and Technology Parks (STPs) are defined as a cluster of interconnected firms often working in the same or similar industries and connected to a nearby institute of higher education (Porter, 2000). In technology entrepreneurship (Mellor, 2019) they have many designations, including: Technopolis, catapult, silicone-something-or-other, research/science/technology/park, STP, business cluster, tech-hub, etc (all with or without incubators). They are environments designed to support the creation of high technology economic development. Firms and the individuals inhabiting STPs acquire different benefits through enhancing knowledge spill-over, providing a pool of knowledgeable labour and they furthermore encourage innovation activities through networking and the sharing of ideas (Cojocaru and Ionescu, 2016). They are used as tools in initiatives involving regional development. Indeed, examples like Silicon Valley and Route 128 (Saxenian, 1994) have prompted national and local governments to build imitations, often consciously applying the 'triple helix principle' of connecting venture capital, educational institutions and public resources (Etzkowitz and Leydesdorff, 2000). This popularity amongst regional planners has led to a proliferation of STPs and the international association of science parks and areas of innovation (IASP) has reported a doubling in the numbers of its constituent members between 2007 and 2016 (IASP, 2016). Furthermore, Rowe (2014) reported that there are more than 365 STPs in Europe, employing around 750,000 people and with total investment of €12 billion.

Unfortunately, there is a high failure rate for STPs (Wadhwa, 2013). The World Bank (Kelly and Firestone, 2016), report success rates of around 20% and a rate of abject failure of around 20%, both figures globally, while in Wales 6 out of 10 failed recently (Pugh et al. 2018). A recent report by Ernst and Young (2017) states that for the £2.2bn UK Catapult programme, "*... it is unlikely that the impact of the network overall has been significant ...*"

STP conglomerations exhibit a range of developmental profiles, perhaps starting as an “adhocracy” or similar and subsequently enter an often-opportunistic scramble for development. Nobel Laureate Joseph Stiglitz (see e.g. Sah and Stiglitz, 1986, and more recently Will et al., 2019) have shown that ambidextrous organizational structure determines organizational performance. Aiming to increase STP performance we pose the research question: What is the optimal organisational structure of a new STP and how does that change as the STP develops and matures?

Case-based approaches clearly only investigate survivors, but we adopt an innovative econometric approach to answer this question because a modelling approach has the advantage of being completely case-independent.

Researchers have studied STPs from different dimensions; for example, Menzel and Fornahl (2009) and Sonderegger and Täube (2010) studied STP life cycle and tried to compare it to the product lifecycle. They proposed a methodology using data from on-cluster and off-cluster firms, alongside other parameters including the number of firms, to strive to identify the current developmental stage of any STP. Cojocaru and Ionescu (2016) identified the advantages and disadvantages of STPs, while other authors e.g. (Klofsten et al., 2015) studied the success of Cluster Initiatives (CIs) from the management perspective and identified five main factors; a well-defined idea, well networked and motivated management teams, well-organized networking activities, 'critical mass' of active firms as members of the cluster, and finally the degree of organization of the CI. Finally, Sternberg (2014) found little evidence for any impact arising from direct government support on the success of individual start-ups, especially spin-offs from universities, implying that they may be better helped in a nurturing STP-type environment instead.

High levels of innovation have been identified as one of the main success factors for business clusters in general and it is cited as one of the main reasons for creating STPs, which in turn has provoked different metrics and measures to evaluate innovation at STP level. These include methods based on R&D investments using quantile regression analysis e.g. (García-Manjón and Romero-Merino, 2012) and R&D volatility e.g. Mudambi and Swift, (2011). However, investigating R&D investments suffers the disadvantage that the effects of R&D investment occur in the longer term and over a longer period. The number of patents is a further metric that has been used (Delgado et al., 2014), but again cheap measures like trade secrets, or even applications for ‘blocking patents’ to thwart competitors, all tend to make results using this metric unclear. Nevertheless, innovation at STP level is believed to be enhanced by knowledge spill-over through firms networking and various studies such as Al-kfairy et al.,(2017); Al-kfairy et al., 2018; Bell, (2005); Squicciarini,(2008); and Dettwiler et al., (2006) all show that networking within STPs ('on-cluster' firms) is a significant factor in stimulating innovation in STPs to a level above that found in isolated firms ('off-cluster' firms) . For example, the formal and informal links that form the STP cluster network construct different topologies (structures) in STPs (Markusen, 1996), which in turn bring in different benefits and have various costs attached.

Two approaches typify building STPs: First, a 'top-down' approach, when STPs are established as a vision of regional or public authorities to further enhance regional innovation and financial development, and this has recently become the favoured approach world-wide (Skokan et al., 2012), mostly in form of science and technology parks e.g. Mjärdevi science park - MSP - in Sweden. Conversely, is the 'bottom-up' approach, where an STP is recognized as a 'critical mass' of similar and related industries in a specific area, which then comes to the notice of Multi-National Corporations (MNC), start-ups, and governments, who in turn try to develop it further (Skokan et al., 2012). A typical example of the bottom-up approach is Silicon Valley where MNCs had to open offices in order to not be left behind by new innovations.

In this paper, we use computer simulation techniques to evaluate the efficiency of innovation network forms by using the knowledge transformation costs and benefits occurring between firms in an STP. We aim to elucidate; which topology benefits a developing STP most, and how can this best change with age and development?

In order to build a comprehensive overview of the optimal topology, the next section (section 2) examines earlier and related work. Section 3 details the model design; section 4 shows the results while section 5 concludes by discussing the implications of the results in the light of current debates.

2 Previous work

2.1 Porter and the knowledge-based view

Networking and partnerships were identified as major determinants benefitting corporate innovation through knowledge sharing and transformation (Morosini, 2004; Pitelis, 2012; Mellor, 2014a, Mellor 2014b, Mellor, 2015). For example, empirical studies of STP success factors through the cluster life cycle have identified networking and trust as recurring success factors, which are very important in all stages of cluster evolution (Tavassoli and Tsagdis, 2014). Moreover, Ting Helena Chiu (2008) contributes towards understanding that the more central a firm is in the network, the more innovative it is. While, Saxenian (1994) argued that positive rivalry sprit was one success indicator, where competitors have no problem in contacting each other, using the power of informal networking to solve regular issues and exchange new ideas, seek finance and solve day-to-day issues. Indeed, Mellor (2015) showed that such 'just-in-time' knowledge is nearly as powerful as original homegrown innovations.

The 'Porters diamond' allows researchers to distinguish between e.g. firms and their suppliers, firms and customers, firms and higher education institute(s) and within firms themselves (Porter, 1998). Although Porters' diamond contributes to our understanding of how each component adds into the overall knowledge (knowledge stock) of a cluster, it does not distinguish between the different topologies in STPs and how that fits into different methods of establishing them (top-down or bottom-up). Moreover, Iammarino and McCann (2006) compared transaction costs and innovation within STPs exhibiting three different topologies. Their findings included:

- Personal relationship and social network: transaction costs are minimized by 'trust' between organizations, although building a trust relationship requires a long-term relationship.
- Complementarities effect: the relationship between firms and their suppliers, and other forms of partnership.
- Industrial topology of input-output: a long-term investment distinguished as having expensive 'entry and exit costs'.

Networking involves knowledge and innovation sharing through formal and informal channels. At the firm level, a 3D model was proposed to connect innovation with organizational performance to understand the effect of departmentalization on firms' performance (Mellor, 2011; Mellor, 2014a; Mellor, 2018). Between firms, formal channels include inter-firm relationships as well as informal channels like personal relationships. Moreover, Bell (2005) investigated the outcome of social and formal networking in a Canadian mutual fund cluster and argued that the more informal and socially networked the managerial team is, the more positive impact they had on firms' innovation albeit that the information source may limit the information they provide. However, that - in turn - did not have a large impact on the overall innovation output. On the other hand, it is also clear that large amounts of networking resources do not automatically imply good innovation (Guan and Chen, 2010), and networks with little and no learning capabilities can be quite ineffective (Gilbert et al., 2007).

Bathelt et al. (2004) distinguished between knowledge acquired by freely available knowledge inside a community ‘local buzz’ exhibiting close proximity, and investments named ‘pipelines’, which normally occur with the outside world (i.e. external to the cluster). Pipelines transfer codified knowledge, while local buzz is more tacit. However, these authors do not consider the acquisition of new knowledge or how this can benefit the cluster. Tacit knowledge sharing is one of the main factors that sustain business clusters (Bathelt et al., 2004; Breschi and Malerba, 2001; Maskell and Lorenzen, 2004). Informal and formal channel of networking enhance trust, which in turn decreases friction in the knowledge transfer process between firms, provided it is up to date and that firms can avoid any lock-in effects (Breschi and Malerba, 2001; Tallman et al., 2004). However, building trust requires time and investment especially through the informal channels (Iammarino and McCann, 2006). Some knowledge is proprietary i.e. private within the firm and is prevented from leaking. While ‘architectural knowledge’ can be shared, which addresses how firms organize, share, and adapt any knowledge obtained, and that is rarely immediately applicable and acquires further costs due to the need to be adapted to the new situation (Maskell, 2001). Moreover, there is evidence implying a relationship between explicit knowledge and process innovation, while tacit knowledge was found to be more related to product innovation (Casanueva et al., 2013).

Eisingerich et al. (2010) emphasized the role of social networks on sustaining the cluster performance. They defined ‘network strength' and 'network openness'. Network strength is the regularity and depth of the interaction, trust, and 'stability of the connections', while network openness is measured by the ease of acceptance of new members into the network, links to the outside world, and the 'diversity' of the members. There are two obvious proviso here, firstly in a freshly-founded cluster 'network strength/openness' cannot exist, and secondly in times of industry uncertainty, strong networks decrease the performance of a cluster. Network openness had a positive impact on cluster performance (Eisingerich *et al.*, 2010). Similarly, a 'small world' network structure between cluster organisations was discussed by (Kajikawa et al., 2010), where path length between organisations and a clustering coefficient were used to distinguish it from random-walk network structure. Shortest paths between firms can identify the small world network, and the availability of network shortcuts reduces path length. Overall, the findings from eight Japanese clusters suggested that network impact is positively related to the network size combined with 'small world' formation, meaning that the larger the network, the more benefits are expected to be gained by participating firms (Kajikawa et al., 2010). He and Fallah (2009) confirmed that networking has a positive relationship regarding innovation and cluster development in a mixed topology structure, where the degree of connectivity may be an indicator of cluster development stage. Breschi et al. (2001) added that the lack of university – industry network caused clusters to decline or fail. This again underlines the importance of continuous innovation, disseminated by an innovation network, in building a sustainable STP cluster.

2.2 Markusian business clusters

Knowledge transformation through networking links would normally shape the networking structure within the STP and indeed (Markusen, 1996) distinguished between four different types of general business clusters: First, the ‘Marshallian industrial districts’ when firms’ connections are built around suppliers that are off-cluster, plus small on-cluster firms and customers relations (off-cluster firms). In this case, the on-cluster firms shape a randomly connected network with a very high flexibility regarding labour movement within the constituent cluster firms. Because of the tendency towards specialization in the same industry sector, there is a parallel tendency to improve the knowledge stock inside the cluster as tacit knowledge is transferred through employees’ movements between firms, while codified knowledge moves through formal channels e.g. suppliers’ pipelines.

Second is the ‘hub-and-spoke’ district, where the cluster/STP is built around one or more dominant large firms in similar industries. This type occurs when there are one or few central organizations and all other firms are connected to the centre through ties that can consist of e.g. spin-offs or informal social connections. It implies a strong connection between on-cluster and off-cluster firms, but with less cooperation with competitors. In this form of cluster/STP, knowledge transfer is achieved through the ‘hub’ or central organisation, which is considered to be the main source of coordination.

The third type is ‘satellite industrial district’; which is a critical mass but can be quite difficult to consider as a cluster, because it does not conform well to most definitions of clusters. It consists of a critical mass of organisations in non-related industries where the business cluster is built around small organizations or branches of larger organizations, which are relatively isolated from each other and only connected to their headquarters or off-cluster customers. In this case, the main knowledge spill-over occurs vertically between branches of a firm and its headquarters, with less cooperation between co-located firms.

Finally, the ‘state-centred’ industrial districts, when STPs are built around one or more government-controlled research institutions or state-supported cluster-coordinating organizations that provide infrastructure, i.e. a more traditional science park type structure, where the central organisation (the cluster initiative or CI) is established. This may typically govern an incubator programme, and within time the incubated firms start to graduate and cluster around this central organisation as described in the ‘triple helix’ model connecting public, venture capitals (VCs), and higher education institutions (HEI) see e.g. (Klofsten et al., 1999; Etzkowitz and Leydesdorff, 2000; Kim et al., 2014). The proviso is; that the networking structure within STPs may change over time as the STP matures and the overall organizational topology evolves (Menzel and Fornahl, 2009).

As to topology, ‘Marshallian industrial districts’ would be expected to be an adhocracy, which moves to a more centralist aspect in the ‘hub-and-spoke’ district model. A ‘satellite industrial district’ would be expected to exhibit aspects of a non-controlled multi-level model, while ‘state-centred’ would (at least initially) conform to a star topology. Clearly, what is needed in all cases is a net increase in innovation capabilities that is large enough to produce more benefits than the investments spent to build and stimulate this network.

2.3 The transaction cost approach

Thus, the costs of networking can be considered to be a form of transaction cost, but all previous studies have neglected to consider the cost of obtaining knowledge in STPs, assuming it is close to zero. In this study, we argue that any transacted knowledge will not be available for free because it requires communication time, which has a cost attached to it. Moreover, the knowledge obtained will most often require adaptation and must be correctly interpreted by the receiving firm, thus incurring more costs. Previous work (Mellor, 2011; Mellor, 2014a) shows that the linkages represent potential benefit and while there is no guarantee that any specific link will have a quantifiable benefit, the number of links does represent a theoretical maximum gross benefit. The gross benefit, minus costs, result in net benefit, which in turn is assumed to be positive.

We have chosen to build directly on Markusen's (1996) work to measure the networking cost in three different network topologies: These are described in the next section.

3 Design Modelling and Simulation

In this study, we modelled three different scenarios of tech-hub network topology, which are:

A. Star model, where all enterprises are connected to one central organization, the *Cluster Initiative* (CI). The CI is defined as a central intermediary organization, which is trying to help STP members to grow (see Klofsten et al., 2015), by e.g. connecting firms inhabiting the STP with Venture Capital (VC) and public bodies. In this model, each constituent organization has exactly one tie connected to the central organisation, and all clusters' firms are connected through that organisation. In this case, CI represents the cluster ‘hub’, and all firms are connected to it, a topology sometimes also referred to as ‘state centred cluster’. Typically, this is the case for the development of science parks like Mjärdevi Science Park in Sweden (Hommen et al., 2006; Mjardevi Science Park, 2016). Moreover, it is a crucial part of the triple helix phenomena (Etzkowitz and Leydesdorff, 2000). Figure 1 illustrates this model (all connections are bi-directional with the same affect).

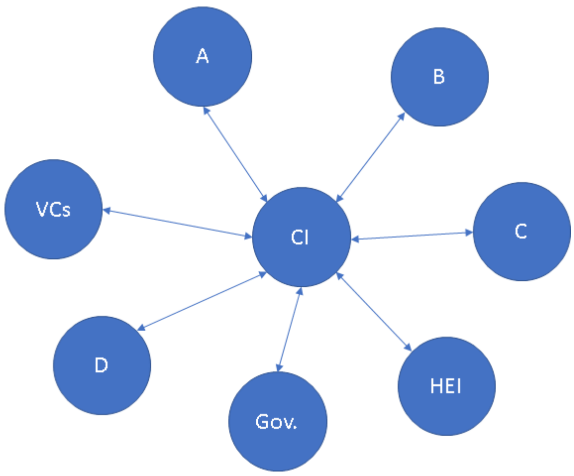

Figure 1. Illustrating the Star Mode, where CI=Cluster Initiative, VCs =Venture Capital and Gov =Government and HEI=Higher Education Institution

B. Strongly connected model. This model represents the case when all companies are centric and connected to each other. For example, if we have (*N*) companies, then each company is connected to (*N-1*) companies. In this case, all firms are centric to the network, and knowledge sharing takes place between all firms simultaneously. This represents a strong ‘spoke-and-hub’ topology (Figure 2).

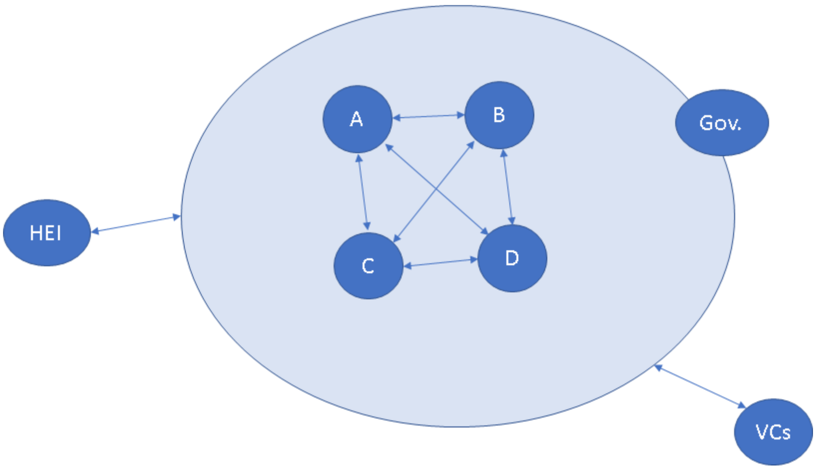

Figure 2. Illustrating the Strongly Connected Model, where Gov=Government, VCs =Venture Capital and HEI=Higher Education Institution.

C. Tree model (Multi-Level) of randomly connected firms. This represents randomly connected firms within the cluster; when firms are connected to a subset of firms in first level direct connection (L_1), another subset of level two (L_2), level three (L_3) and some firms are still isolated. Where L_1, L_2, L_3 and L_D represent number of firms connected in level one, two, three and *1,2,3* and *D* represent the *distance* between the firms. This cluster topology represents different structures (mainly Marshallian districts), where there are multiple ‘cluster hubs’ with accompanying firms surrounding them (Figure 3).

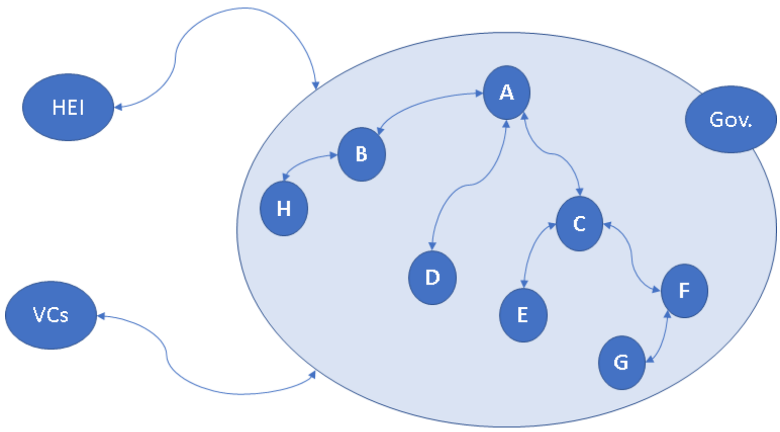

Figure 3. Illustrating the Multi-Level Model

In all three models, each connection is apportioned a networking cost that is attached to communication between information gatekeepers, as well as within the firm. This cost is a net sum of time spent building trust, adaptation, re-design or discussion time. This represents the cost (*C*) drawn randomly from a normal distribution with a random mean (μ, selected to be $0 \leq \mu \leq 100$ from normal distribution) where the cost was included for cases when the costs for communication tend to zero e.g. lunch time meetings or personal friendship events, and here σ^2 is equated to 1. In this scenario, each company will gain some benefits (*B*) from the knowledge obtained. Assuming that the value of the knowledge gained will always be positive, then the benefits were randomly obtained with ($1 \leq \mu \leq 100$) and σ^2 will be unity (1).

Because the International Association of Science Parks and Areas of Innovation (IASP) reported that the current STPs (Science and Technology Parks) contain between less than 50 firms and somewhat over 1000 firms, and where most STPs host between 100 and 400 firms, we initiated a computer model where the average number of firms was randomly obtained between 6 and 500 firms, i.e. well within the outliers.

Then the firms were put into a topological shortest path (*NxN)* matrix, generated from an adjacency matrix. Three *symmetric* (*NxN)* matrices were generated:

i. Networking Cost Matrix (*C*), which includes the costs of random ties between firms, because the connection is assumed to be bi-directional, meaning that we count only one symmetrical connection between two firms.

ii. Networking Benefit Matrix (*B*), this includes random ties gains (assuming that each networking tie will have financial gains, we call this networking gross benefits) and the same *C* and *B* were used for all three topologies examined to ensure case-by-case consistency.

iii. Distance Matrix (*D*), refers to the third topology and consists of the assumed distance between randomly connected firms.

Next, Monte Carlo simulations were performed with 1000 iterations, but with different numbers of firms, average costs and firms' matrices, according to the topology selected. The results were initially stored in Microsoft Excel files, and subsequently injected into SPSS for further analysis.

4 Results

4.1 Star topology

In the star model as presented in figure 1, each firm (N_i) is connected to a central node, called the CI (cluster initiative). The CI is responsible for co-ordination with one information gatekeeper per firm, who in turn shares and spreads the knowledge obtained openly within their firm. Eq

1 calculates the total benefits gained by networking, using the gross benefit minus the costs of each connection with the CI. If the CI is represented by firm at index (*1*), then the net benefit of networking for firm *j*, will be $B_{1,j} - C_{1,j}$, *where* $j \neq 1$. Put simply, we just go through the first row of the cost and benefit matrices.

$$\pi = \sum_{j=2}^{N} B_{1,j} - C_{1,j} \qquad \textit{Eq. 1}$$

From the adjacency matrix, a distance matrix was generated (table 1), where the distance between each firm and the central organization (*CI*) is 1, and between each firm and each other firm is exactly 2. Communication is always happening through the central organization, which obviates the need to incur the costs of walking the whole path between two different firms. Therefore, distance factor for this organisation structure is neglected because multiplying the D=1 with the cost *C*, will always result in *C*.

Table 1. Illustrating the adjacency matrix (Star Model)

Firms	A	B	C	D
A	0	1	1	1
B	1	0	2	2
C	1	2	0	2
D	1	2	2	0

Using the aforesaid configuration, Figure 4 shows that in the extreme worst case the total net benefit can be up to -31677. Conversely, the extreme best case would be +40668 with a mean of -390. The Pearson correlation between average networking (gross) benefits, average networking costs, and the average number of firms with net benefit show that the average number of firms has no effect on the total gross gain (R^2 = -0.063 and p-value = 0.045), while the average cost is the main determinant of benefit (R^2 = -0.613 and p-value less than 0.001), with less effect from average gain (R^2= 0.599 and p-value less than 0.001) albeit that the absolute difference between the gain and cost effect is not very large. These results imply that, even though this topology can minimize damage, it does not maximize benefit. In other words, this topology is beneficial under those conditions where the investment involved in networking is high, regardless of the cluster size.

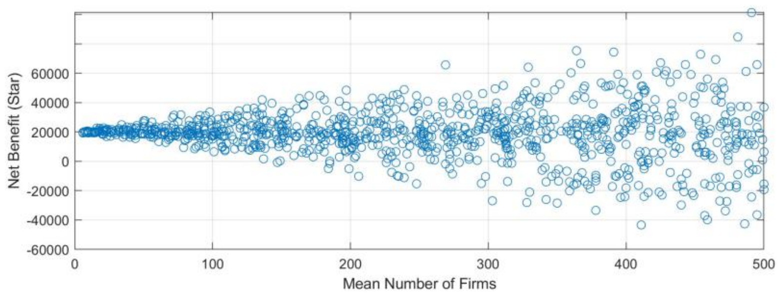

Figure 4. The mean number of firms VS net benefit (Star Model)

4.2 Strongly connected topology

In this model, all firms in the business cluster are in a centric position and cross-linked. The transaction costs incurred between firms are obtained from the matrix *C*, where each index represent the connection between firm (*i*) and firm (*j*), then the matrix entry $C_{i,j}$ and equivalent are the benefits from the connection $B_{i,j}$. However, the connection is bi-directional meaning it counts for (*i*) and (*j*) connection as well as *j* and *i*. Therefore, the connection *i*,*j* is only counted and the connection *j*, and *i* neglected, so that we go through half of each matrix (*C*, *and B*) instead of the whole matrix. This is also true for the third topology (randomly connected). Similar to star topology, the distance factor for this topology was ignored. To sum, the total net benefit can be obtained by applying eq. 2 (*connection benefit minus connection cost*):

$$\pi = \sum_{i=1, j=1}^{N} B_{i,j} - C_{i,j} \text{ , } where\ i \neq j, \qquad Eq.\ 2$$

Table 2. Adjacency matrix (strongly connected model)

Firms	A	B	C	D
A	0	1	1	1
B	1	0	1	1
C	1	1	0	1
D	1	1	1	0

Figure 5 and 6 presents two scatter plots regarding number of firms (N), net benefit (π) as well as mean cost, respectively. A sample of the simulation output is shown in table 3 and a larger sample is available in the appendix. Descriptive statistics regarding minimum, maximum, and average net benefit are shown in table 4. The analysis of the data shows that the strongly connected topology can be much more beneficial for the STP and the client firms involved, than the star topology is; however, in the worst case it can also be very harmful, for example in the case where only low benefits accrue accompanied by near-exponentially expanding co-operation costs, so if direct ties do not result in tangible benefits, then this scenario would be very expensive.

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Table 3. A sample table (Strongly Connected Model)

Mean Number of Firms	Mean Gross Benefit	Mean Cost	Strongly connected (Net Benefit)
17	33.9	26.3	1,014.37
34	76.96	2.91	41,501.31
225	23.74	3.72	504,552.00
283	7.03	3.34	146,831.40
306	13.24	2.84	485,089.50
339	6.55	45.05	-2,205,142.00
389	12.69	26.48	-1,041,321.00
409	12.79	57.54	-3,734,216.00
431	12.57	0.64	1,076,628.00
471	34.77	3.26	3,487,064.00
493	6.72	15.74	-1,093,278.00

The mean number of firms was denoted at random to from table 10 and are presented, re-ordered, to illustrate that cluster size does not impact the final benefit.

Table 4. Showing descriptive statistics for the Strongly Connected Model

	Minimum Net Benefit	Maximum Net Benefit	Mean Net Benefit	Standard deviation (Net benefit)
Strongly connected	-7,611,257.90	9,976,724.80	-86,316.50	1,620,837.90

This table shows that the strongly-connected model can be very beneficial, when costs are low and benefits are very high, and vice versa.

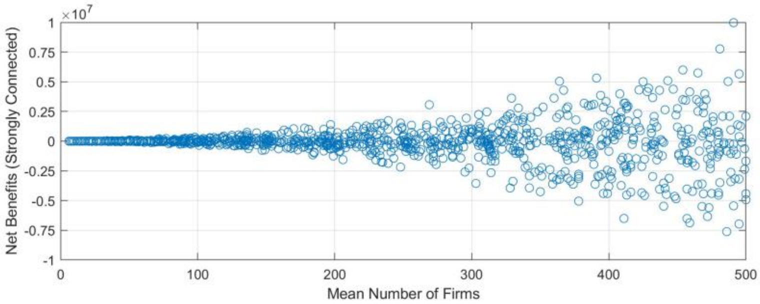

Figure 5 Strongly connect Number of Firms VS Net Benefits

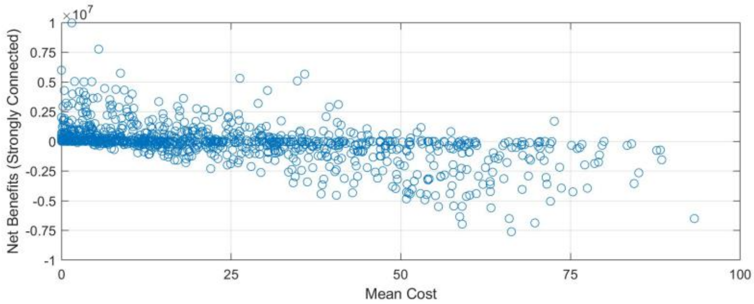

Figure 6 Strongly Connected Net benefit VS Mean Cost

Correlation analysis shows that cluster size (as number of firms) has no impact on the net benefit, which is the same conclusion as found for the star topology, meaning that it is not possible to predict the optimal number of firms in an STP using networking structure only, because both mean cost and mean gross benefit has almost-equivalent impact (one positive for mean benefit, and one negative for mean cost) with (R^2= 0.504 and -0.520, with p-value of less than 0.001 for both of them), or that in larger STPs networking costs increase but benefits also increase proportionally. One observation is that the impact of cost for strongly connected, is less than the star topology, while the impact of mean benefit is similar.

4.3 Multi-level (Tree) topology

In reality, clusters will not follow a specific networking topology especially when the agglomeration will tend to follow demand rather than a stricter state vision. Thus, firms will eventually become connected to firms that interest them in a mixed topology. For example, firm (*X*) could establish a partnership agreement with another firm (*Y*), a supplier for example, who would establish another partnership with another supplier (*Z*), this would create the pairs (*X*, *Y*) and (*Y*, *Z*) which indicates that firm (*X*) is connected to firm (*Z*) through firm (*Y*), and indeed this chain can be much longer, but for simplicity in this model we assume that it is maximum four levels. In this case, there will be firms which are more centric than other firms, and some firms which are more isolated and therefore need to build connection networks. Consequently, a distance factor must be added to the total cost. For simplicity, we assume that the distance will be multiplied by the cost, so if the distance becomes two, then the cost will be doubled, given that the first order distance is always one. Table 5 illustrates a sample distance matrix (*D*), in a symmetric matrix, where the same distance is assumed between firm (*i*) and (*j*) as well as between (*j*) *and* (*i*). Similarly, to the strongly connected model, the connection cost and benefit were only counted once (half of the matrix).

Table 5. An adjacency Matrix for the Multi-Level Mode

Firms	A	B	C	D
A	0	2	1	2
B	2	0	1	2
C	1	1	0	1

D	2	2	3	0

$$\pi = \sum_{i=1,\, j=1}^{N} B_{i,j} - C_{i,j} \times D_{i,j} \text{ , } where\ i \neq j \qquad Eq.\ 3$$

Figures 7 and 8 show mean cost and mean gross benefit plotted against net benefit and the analysis indicates that there no correlation between net benefit and distance, with correlation coefficient -0.02, p-value = 0.534 implying that distance does not significantly affect final benefit. On the other hand, and in contrast to previous topologies, the number of firms exhibited a moderate impact on net benefit of -0.432 with p-value less than 0.001. Moreover, the mean gross benefit had a low impact on the final net benefit, while mean cost has higher impact in this case than in the cases of the strongly connected and star models (-0.618 and p-value less than 0.001). This confirms that this topology can be helpful under conditions of low communication costs and high knowledge benefits e.g. in smaller highly-specialized STPs.

Table 6. Showing descriptive statistics pertaining to the Multi-Level Model

	Minimum Net Benefit	Maximum Net Benefit	Mean Net Benefit
Randomly connected	-19,323,860.80	9,692,557.80	-1,662,454.30

This table illustrates that multi-level model can be less efficient when costs are high, and benefits are low, and vice versa (compare table 4)

The picture overall (table 6) shows that, in the best-case, tree topology is beneficial for the cluster (maximum obtained net benefit), except where the knowledge obtained is expensive, or if it is not particularly beneficial. Under these conditions then it is better to avoid this type of structure (minimum net benefit).

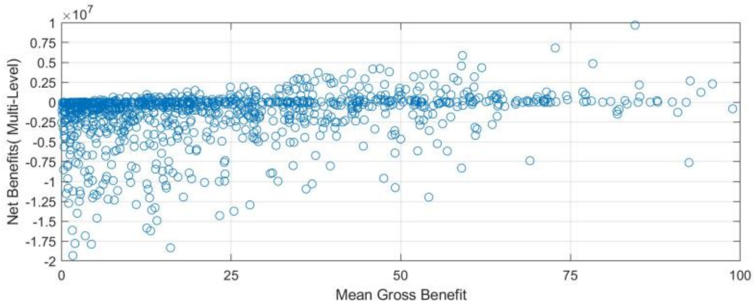

Figure 7 Mean Gross Benefit VS Net Benefit (Multi-Level Model)

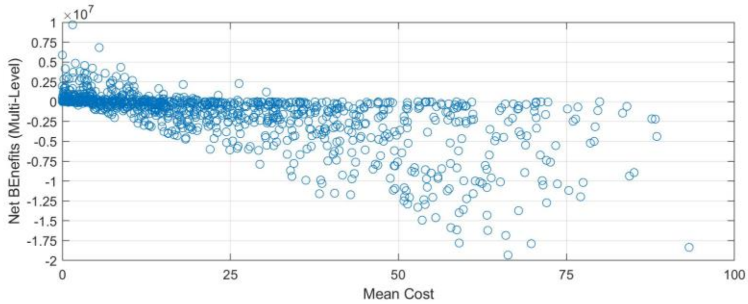

Figure 8 Mean Cost VS Net Benefit (Multi-Level Model)

4.4 Comparing topological structures

The previous sections presented the results obtained from simulating three different cluster topologies without *a priori* knowledge of which structure is better for an STP or why. In order to understand the effect of each structure on the development STPs, dummy variables were created, which are the size representing the STP size expressed as the number of firms and divide the STP into five groups (1 – 5), each group consist of 100 firms. Then divide the cost into four groups (1 - 4), resulting in 20 different categories, where the impact of the three different structures can be determined.

Tables 7 - 9 present the mean values of three different topologies with different sizes and cost categories. These tables confirm the findings presented in earlier sections that the main factor influencing the cluster net benefit from knowledge is the mean cost. These results, which focus on the mean values only (please note that other descriptive statistics are available in the appendix, see tables 11– table 15), show that the mean net gain upon implementing a strongly connected network structure (or even the randomly connected multi-level one) is better than the star model under conditions where the knowledge sharing cost is small, regardless of the cluster size. However, the star model becomes a better solution when the costs become more expensive.

We assume that during the early stages of an STP or when ideas/products are still young, the cost of sharing will be higher, especially if the firms network is not well-established. Moreover, in case of state-centred STPs, most firms will be start-ups, SMEs etc and that inter-personal connections will hardly be matured, which in turn implies a costly development and knowledge sharing, which indicates that when STPs are still new, a star topology is the most efficient cluster topology.

However, when knowledge sharing costs are low, then as shown in tables 11 -15 in the appendix, the strongly connected model will perform better. This means that as knowledge becomes more accessible and widespread (i.e. to be found in many firms) and the STP matures, then the cost of knowledge sharing, and implementation will decrease, and as consequence the star model will not be as helpful as other models. Because the strongly connected model is the best performing model among all the three investigated, this implies that – at the firms' level – the more centric the firm is in the network, the more it will benefit from knowledge sharing.

The randomly (multi-level) topology is about as valuable as the strongly connected model, albeit that these benefits diminish as the cluster grows. Overall, the randomly connected topology is as efficient as the strongly connected topology under circumstances where the cost of knowledge sharing and application is low, i.e. the STP is still small and the knowledge is mature. The drawback is that it is harder to transform this topology into a strongly connected topology if it becomes needed, and this may become a major hurdle in future of that STPs development.

In conclusion, simulation results show that the star topology is the best, when the networking costs are high, which in turn is associated with the earlier stages of cluster development. On the other hand, later in STP development, when connection costs are low, a trust network is established and knowledge benefits are high, then the strongly connected topology is most efficient. However, under these circumstances, the randomly connected model can also be as efficient as the strongly connected topology, albeit that this is affected by the STP size. In particular, tables 7, 8, and 9 shows that in multi-level only, when costs are smaller than benefits, does increased size tend to decrease the profit (net benefit). However, this is not the case for star and strongly connected models.

Table 7. Star Topology Net Benefits (Mean)

Size (Number of Firms) / Mean Cost	6-100 (Firms)	101-200 (Firms)	201-300 (Firms)	301-400 (Firms)	401-500 (Firms)
0– 10	1,319.15	3,759.62	3,669.34	6,143.43	9,644.34
11 – 25	607.54	565.56	2,038.85	1,151.28	1,211.52
26 – 50	-662.81	-1,644.55	-4,014.13	-1,792.38	-4,730.21
51 – 100	-1,792.16	-6,062.40	-8,817.38	-15,780.70	-17,935.70

Table 8. Strongly Connected Topology Net Benefits (Mean)

Size (Number of Firms) / Mean Cost	6-100 (Firms)	101-200 (Firms)	201-300 (Firms)	301-400 (Firms)	401-500 (Firms)
0 – 10	44,725.65	285,229.80	463,710.90	1,086,392.00	2,162,513.00
11 – 25	21,533.38	40,932.74	256,963.20	186,220.40	241,816.80
26 – 50	-22,742.90	-129,100.00	-505,972.00	-308,025.00	-1,084,207.00
51 – 100	-66,553.60	-470,822.00	-1,088,210.00	-2,830,166.00	-4,037,838.00

Table 9. Multi-Level Topology Net Benefits (Mean)

Size (Number of Firms) / Mean Cost	6-100 (Firms)	101-200 (Firms)	201-300 (Firms)	301-400 (Firms)	401-500 (Firms)
0 – 10	35,019.43	207,093.10	262,121.60	690,955.90	1,490,524.59
11 – 25	-27,268.70	-253,275.00	-525,406.00	-1,413,441.00	-2,351,561.54
26 – 50	-117,532.00	-813,158.00	-2,283,365.00	-3,711,968.00	-6,583,097.32
51 –100	-255,283.00	-1,562,314.00	-3,839,448.00	-8,891,550.00	-12,936,421.06

5 Discussion and Conclusion

Regardless of STP size, the main factor affecting the net benefit of knowledge sharing is the cost of knowledge acquisition. In this respect, the star model is the most efficient topology when the cost of obtaining and adapting knowledge (i.e. transforming knowledge into innovation) is high. The strongly connected model will perform better later on in STP development when costs are low, and the multi-level topology performs relatively poorly under all the conditions tested.

These findings support earlier work by (Lee *et al.*, 2010) who recommended starting with a central organization, which helps start-ups to innovate more and maintain a good networking structure with other firms in the industry and indeed the (Lee *et al.*, 2010) model is similar to the star model introduced in this study where the central organization can be a CI or it can be e.g. a tech-incubator. Here, the CI represents the state anchored model as presented by Markusen, (1996), while tech incubators can be simulated using the DI (diversity innovation) number attached to transaction costs, a concept introduced by Mellor, (2014 and Mellor, 2015).

The strongly connected model simulated the case when all companies are in centric positions (similar to the hub-and-spoke model, when all firms are dominant) which Chiu (2008) reported to be the best position for firms in innovation networks, and indeed the simulations reported here confirm the efficiency of this topology, but also show that it is only the most suitable when costs are low. Indeed, if firms want to innovate more, they must incur some costs in order to be more centric. This topology may be attractive for mature firms, which have either started to generate money or have attracted investors.

While the multi-level connection may be the one most often used by a firm, it is clearly advantageous to avoid this topology under conditions where knowledge sharing is expensive.

Clearly factors other than those discussed here may contribute to the capacity of a tech hub/cluster, for example the space available, availability of venture capitalists (VCs) and proximity of related industries. Moreover, as the regression analyses in previous sections indicate, it is not possible to predict the optimal STP size using only the firms networking structure, which in turn is influenced by many factors. However, marginal effects like marginal gains and marginal costs could be added to future models to see if there is such a concept of an optimal size for an STP.

Generally, the findings in this paper have both research and policy implications. First, they suggest that policy makers at regional level should start by implementing a central organisation (CI), if they are following the ‘top-down’ approach to STPs. Then, once the STP is well-established, they can let it move freely, possibly tending towards a strongly connected solution, however, a randomly connected model will be as beneficial as the strongly connected model, when the ‘trust’ network is well-built and has a cost close to zero. If this is not the case, then the model shows clearly that a CI “star” topology must remain in place to avoid excessive transaction costs without concomitant benefits, which is clearly a risky strategy.

Concepts such ambidexterity (Benner and Tushman, 2015) may also be relevant, where a STP, surrounded by innovations and innovative firms wanting entry, has to decide on which innovations to implement. This is essential because not inviting new talent means that incumbents may proceed along a developmental path where on-cluster firms slowly enter a technology lock-in stage featuring few innovations, thus even in “non-star” structures, some form of CI is needed to steer the cluster in fruitful directions. Presumably if this is successful, then eventually large firms and MNCs will arrive, “fishing” for new talent and new innovations.

The results presented here are based on a theoretical framework from which we have built a conceptual model for optimizing innovation networks, including that the development of an STP is not analogous to a product life cycle or a Y-shaped path starting with an adhocracy then choosing either star or hub-and-spoke, but indeed is more nuanced and may include devolving from star topology to other forms as the costs (to use the terminology of Mellor 2011, and Mellor 2014a, “per unit length of knowledge trails”) decrease. Indeed, historically one case study (MSP) began as a state-sponsored centre initiative with 6 companies in a star configuration (topology). Then, it moved into a hybrid (Klofsten et al., 1999; Mjardevi Science Park, 2016; Tavassoli and Tsagdis, 2014), and today it is so large that it is uncertain what topology it has now, except for that it is no longer ‘star’. Supporting evidence for this can be obtained by looking at other STPs including Umeå with ~100 micro-firms (named Uminnova), and Gothia Science Park with ~80 micro-firms and 2 large firms, one can also observe that they have both started in star topology (Gothia Science Park, 2013), and it will be interesting to see at what developmental stage the star topology starts to be superseded.

One other limitation of this work is its conceptual nature, as it is based around topology only and needs to add other factors that influence the development of the inhabitants of STPs e.g. financial factors, social factors, and size factors at firm level. To address this and to build a more comprehensive view of what the best method for building and enhancing the development of STPs is, we report in a companion paper (Al-kfairy et al., 2019) on differences between on-cluster firms and off-cluster firms.

Acknowlegements

We gratefully thank Dr Matthias G. Will, Martin-Luther-Universität Halle-Wittenberg, Germany, for innumerable enlightened comments and invaluable help during the course of this work.

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Appendix

Table 4 Sample Simulation Results (First 200 records)

Mean Number of Firms	Mean Gross Benefit	Mean Cost	Mean distance	Central (Net Benefit)	Strongly connected (Net Benefit)	Randomly connected (Multi-Level) (Net Benefit)	Firm Size	Cost Cat
409	12.79	57.54	1	-18,236.40	-3,734,216.00	-10,964,839.08	5	4

431	12.57	0.64	1	4,978.09	1,076,628.00	943,873.22	5	1
471	34.77	3.26	3	14,855.99	3,487,064.00	2,945,730.49	5	1
306	13.24	2.84	3	3,174.66	485,089.50	284,332.71	4	1
17	33.90	26.30	1	116.16	1,014.37	-4,540.68	1	3
389	12.69	26.48	2	-5,381.14	-1,041,321.00	-4,035,799.94	4	3
225	23.74	3.72	3	4,452.20	504,552.00	363,053.43	3	1
283	7.03	3.34	1	1,007.11	146,831.40	-53,557.30	3	1
493	6.72	15.74	4	-4,423.73	-1,093,278.00	-3,956,443.24	5	2
339	6.55	45.05	4	-13,017.90	-2,205,142.00	-6,068,879.07	4	3
34	76.96	2.91	1	2,445.85	41,501.31	39,052.00	1	1
273	7.04	9.08	3	-568.68	-75,670.80	-585,151.10	3	1
259	8.07	14.24	2	-1,648.99	-206,499.00	-923,976.14	3	2
149	40.12	22.64	2	2,559.09	192,675.60	-181,203.31	2	2
273	1.16	0.86	2	37.42	8,061.28	-51,337.52	3	1
120	25.80	5.62	3	2,421.89	144,243.00	84,591.58	2	1
134	47.08	4.33	3	5,676.96	380,985.00	323,257.27	2	1
399	4.57	35.36	4	-12,220.40	-2,444,164.00	-6,661,941.46	4	3
73	2.53	17.49	2	-1,066.06	-39,310.60	-106,349.44	1	2
458	31.21	21.54	1	4,407.19	1,012,410.00	-2,360,653.71	5	2
426	8.57	25.34	3	-7,157.46	-1,517,924.00	-4,956,021.36	5	3
202	5.79	15.46	2	-1,963.32	-196,250.00	-665,034.17	3	2
7	16.92	2.01	1	93.89	323.05	267.78	1	1
58	33.28	14.77	3	1,040.19	30,552.65	-6,579.61	1	2
348	19.86	7.48	2	4,258.73	747,884.80	69,899.20	4	1
500	2.79	38.25	1	-17,718.60	-4,422,938.00	-11,594,714.26	5	3
239	2.81	0.19	3	495.57	56,714.25	22,195.64	3	1
143	2.81	31.48	2	-4,061.87	-291,081.00	-761,705.20	2	3
70	48.82	65.89	1	-1,183.96	-41,220.60	-279,208.82	1	4
197	13.62	31.29	3	-3,444.22	-341,174.00	-1,244,819.82	2	3
394	53.37	3.52	2	19,630.91	3,860,316.00	3,453,029.15	4	1
460	6.55	7.51	2	-470.81	-101,367.00	-1,289,905.10	5	1
131	8.54	40.91	2	-4,203.97	-275,660.00	-804,557.09	2	3
469	43.90	17.09	2	12,574.30	2,941,891.00	134,540.75	5	2
188	53.48	30.59	2	4,302.19	402,176.20	-402,785.13	2	3
94	16.15	1.42	4	1,374.51	64,115.28	54,304.72	1	1
139	4.71	8.90	4	-557.12	-39,823.10	-168,456.90	2	1
50	60.61	22.58	3	1,865.10	46,572.72	4,327.78	1	2
161	19.16	30.09	3	-1,717.60	-140,516.00	-722,522.12	2	3
26	1.40	0.30	2	26.50	225.45	-190.60	1	1

400	0.92	48.79	4	-19,042.60	-3,805,003.00	-9,651,955.33	4	3
340	43.34	33.97	4	3,144.83	539,912.40	-2,376,120.99	4	3
475	4.35	15.11	3	-5,074.38	-1,211,140.00	-3,757,372.03	5	2
474	1.35	21.99	2	-9,721.28	-2,302,977.00	-5,994,976.94	5	2
32	57.18	35.33	1	663.75	10,840.58	-15,983.63	1	3
202	20.50	2.73	4	3,575.80	360,730.30	276,858.95	3	1
495	12.58	38.63	1	-12,832.60	-3,184,718.00	-10,299,365.56	5	3
283	17.19	11.67	4	1,536.12	220,433.90	-479,693.69	3	2
448	13.29	59.66	3	-20,725.50	-4,642,146.00	-13,581,172.08	5	4
77	87.75	11.42	2	5,835.25	223,335.20	173,412.40	1	2
494	52.48	41.18	2	5,597.10	1,375,503.00	-6,140,758.21	5	3
474	1.46	7.75	3	-2,945.90	-697,112.00	-2,001,978.05	5	1
63	35.69	12.12	4	1,482.92	45,933.49	10,507.98	1	2
400	8.28	18.88	1	-4,224.33	-845,446.00	-3,107,428.90	4	2
286	24.96	4.32	4	5,926.48	841,619.80	578,059.41	3	1
136	61.51	0.87	2	8,182.11	554,741.40	539,773.47	2	1
150	42.89	0.00	1	6,263.26	470,354.30	456,882.80	2	1
202	4.68	19.96	3	-3,083.27	-310,158.00	-919,787.25	3	2
300	51.77	35.07	1	5,007.25	749,086.70	-1,588,587.90	3	3
158	21.54	24.32	4	-399.03	-34,422.50	-484,086.80	2	2
85	23.25	0.02	1	1,883.98	80,097.93	75,701.47	1	1
454	7.65	11.38	3	-1,698.48	-382,630.00	-2,130,817.73	5	2
298	35.65	32.18	3	1,035.13	153,505.90	-1,973,650.54	3	3
281	42.79	20.76	1	6,147.57	866,189.10	-361,375.04	3	2
412	15.85	4.64	1	4,636.13	948,905.50	359,059.02	5	1
438	2.33	0.62	4	564.29	132,957.70	-3,219.56	5	1
65	37.27	38.60	3	-87.77	-2,672.87	-124,007.29	1	3
213	60.98	19.71	4	8,713.07	931,650.90	269,082.74	3	2
450	26.93	15.17	2	5,256.73	1,187,883.00	-1,116,911.33	5	2
148	17.72	6.13	3	1,708.16	126,335.10	27,522.50	2	1
465	61.92	8.69	1	24,678.35	5,743,020.00	4,338,101.61	5	1
124	0.38	12.58	4	-1,417.94	-89,234.80	-231,429.23	2	2
414	92.45	72.61	2	8,208.83	1,696,320.00	-7,613,359.62	5	4
451	10.69	22.57	3	-5,318.99	-1,204,493.00	-4,643,838.83	5	2
295	3.68	63.52	2	-17,551.40	-2,594,670.00	-6,720,320.02	3	4
431	56.84	49.39	4	3,169.65	689,517.10	-6,169,115.24	5	3
267	37.00	4.45	2	8,659.38	1,156,074.00	919,413.70	3	1
68	27.57	31.47	4	-272.78	-8,880.92	-114,656.12	1	3
281	0.13	5.76	2	-1,377.87	-194,922.00	-537,829.64	3	1

330	29.20	24.60	3	1,527.42	249,720.30	-1,745,932.71	4	2
480	5.76	1.23	2	2,076.20	508,322.10	278,750.45	5	1
248	4.32	2.16	3	561.31	65,519.53	-34,951.57	3	1
150	24.89	8.04	3	2,499.64	187,994.20	52,149.64	2	1
497	4.11	4.90	2	-417.42	-97,032.70	-1,004,269.21	5	1
378	1.05	72.05	4	-26,706.70	-5,047,679.00	-12,733,685.01	4	4
48	9.31	23.56	3	-672.07	-16,087.30	-57,516.04	1	2
314	9.26	43.23	1	-10,640.90	-1,669,270.00	-4,858,838.42	4	3
296	59.32	15.02	1	13,087.03	1,934,058.00	952,418.03	3	2
306	33.53	1.18	4	9,874.15	1,504,250.00	1,413,174.97	4	1
433	1.45	4.94	2	-1,434.22	-320,213.00	-1,013,324.14	5	1
190	25.37	15.22	2	1,943.09	182,013.40	-229,813.22	2	2
215	25.66	8.48	1	3,642.44	395,414.50	103,101.83	3	1
239	71.45	10.68	4	14,429.48	1,728,022.00	1,274,417.40	3	2
312	9.59	17.37	2	-2,424.46	-377,680.00	-1,643,570.22	4	2
81	5.40	0.25	2	364.89	14,746.76	10,540.91	1	1
249	43.86	9.00	2	8,627.68	1,076,347.00	657,773.01	3	1
115	42.70	65.32	3	-2,559.61	-148,390.00	-789,172.04	2	4
457	8.62	26.01	2	-7,996.92	-1,812,938.00	-5,881,137.64	5	3
414	35.16	0.22	2	14,191.48	2,935,975.00	2,831,120.23	5	1
125	71.48	7.54	4	7,941.64	495,409.60	407,718.55	2	1
447	51.91	8.01	1	19,553.95	4,376,637.00	3,181,236.12	5	1
82	1.53	14.60	2	-1,065.04	-43,321.70	-116,604.65	1	2
495	82.14	35.83	2	22,931.34	5,662,481.00	-901,993.70	5	3
420	13.60	30.38	2	-7,029.05	-1,476,909.00	-5,492,150.58	5	3
407	14.54	2.79	2	4,731.68	970,749.50	625,006.79	5	1
88	30.89	18.82	3	1,038.38	46,234.73	-60,911.36	1	2
361	37.18	29.40	3	2,803.20	505,207.70	-2,355,703.95	4	3
183	59.16	18.64	3	7,369.70	674,285.60	203,363.68	2	2
491	84.51	1.52	4	40,668.54	9,976,725.00	9,692,557.76	5	1
185	24.11	8.70	1	2,825.50	262,313.70	37,582.57	2	1
396	4.79	61.11	4	-22,261.80	-4,404,324.00	-11,590,320.93	4	4
338	49.15	48.35	4	234.54	45,535.16	-4,068,776.26	4	3
206	14.85	88.44	1	-15,083.80	-1,553,880.00	-4,379,644.36	3	4
226	8.44	15.41	3	-1,549.51	-177,481.00	-765,246.31	3	2
370	0.90	46.57	2	-16,787.80	-3,103,937.00	-7,871,833.30	4	3
368	28.80	39.03	4	-3,712.31	-691,149.00	-4,637,446.81	4	3
150	2.90	17.52	4	-2,205.74	-163,123.00	-459,587.89	2	2
138	7.05	47.79	2	-5,575.97	-385,425.00	-1,068,673.65	2	3

234	2.19	1.21	2	195.77	24,165.06	-30,130.19	3	1
10	53.07	23.23	1	276.66	1,359.67	-522.84	1	2
476	39.22	21.13	3	8,577.42	2,045,120.00	-1,542,190.65	5	2
89	8.24	21.95	2	-1,182.43	-53,755.40	-184,426.01	1	2
165	27.82	70.50	1	-6,981.40	-577,226.00	-2,015,115.14	2	4
294	14.89	3.74	4	3,294.10	480,160.20	239,717.67	3	1
471	14.85	7.17	1	3,577.53	849,697.40	-338,613.96	5	1
75	60.61	13.46	2	3,514.30	130,842.20	75,675.78	1	2
468	25.74	21.69	4	1,921.58	442,042.20	-3,115,442.26	5	2
60	5.02	23.86	1	-1,108.33	-33,348.80	-97,088.41	1	2
197	3.19	3.49	3	-47.27	-6,092.86	-108,558.16	2	1
70	22.19	3.83	4	1,280.93	44,340.76	30,685.38	1	1
422	19.45	6.55	3	5,472.37	1,144,911.00	271,127.47	5	1
488	35.07	17.36	3	8,636.90	2,104,099.00	-982,992.76	5	2
491	12.56	57.80	2	-22,138.40	-5,442,354.00	-15,864,502.31	5	4
83	11.32	12.70	1	-125.83	-4,577.10	-70,027.46	1	2
472	5.02	18.37	2	-6,277.44	-1,484,163.00	-4,556,106.61	5	2
20	15.36	54.96	2	-752.91	-7,539.20	-21,918.53	1	4
286	8.31	38.29	2	-8,477.80	-1,221,744.00	-3,559,313.40	3	3
199	5.97	9.67	2	-759.35	-73,080.20	-360,072.16	2	1
454	59.08	0.00	3	26,442.53	5,993,656.00	5,870,265.46	5	1
241	40.54	51.33	1	-2,619.45	-312,293.00	-2,533,623.37	3	4
99	6.67	20.19	3	-1,317.77	-65,613.10	-212,186.81	1	2
305	52.75	4.31	2	14,711.16	2,246,161.00	1,947,305.15	4	1
444	9.90	41.67	1	-14,087.00	-3,124,154.00	-9,253,851.48	5	3
409	32.09	8.84	1	9,495.49	1,940,595.00	837,226.41	5	1
312	23.83	32.71	2	-2,747.40	-430,565.00	-2,821,790.07	4	3
480	0.70	40.50	4	-18,897.00	-4,541,922.00	-11,522,365.71	5	3
50	80.93	3.05	2	3,805.95	95,397.06	89,721.47	1	1
85	34.31	40.82	1	-527.28	-23,329.60	-238,461.58	1	3
226	2.95	2.61	2	82.43	8,547.71	-91,484.20	3	1
246	48.09	19.42	2	7,029.81	863,589.90	-13,635.01	3	2
44	19.04	70.44	4	-2,209.09	-48,656.60	-146,654.50	1	4
395	8.28	12.00	4	-1,460.30	-290,107.00	-1,693,302.68	4	2
382	8.77	24.38	4	-5,924.47	-1,135,381.00	-3,797,141.24	4	2
91	0.92	23.14	3	-1,993.79	-90,292.30	-232,282.54	1	2
192	51.89	29.34	4	4,349.51	413,225.30	-395,803.39	2	3
219	13.94	0.20	4	2,858.35	313,715.60	284,463.89	3	1
342	4.09	2.50	3	549.20	92,786.55	-127,119.20	4	1

453	10.71	26.15	3	-6,983.19	-1,580,683.00	-5,592,467.91	5	3
101	5.23	5.89	4	-66.55	-3,422.73	-48,675.21	2	1
252	6.00	22.43	4	-4,131.99	-519,538.00	-1,575,012.19	3	2
145	15.38	14.63	1	98.75	7,625.02	-224,370.23	2	2
382	72.85	28.97	2	16,740.34	3,192,557.00	27,928.61	4	3
253	0.18	19.68	4	-4,765.51	-601,573.00	-1,539,572.67	3	2
250	24.48	13.14	4	2,806.67	353,028.90	-265,401.88	3	2
80	20.81	58.43	4	-2,961.54	-118,981.00	-394,988.90	1	4
248	2.16	73.39	1	-17,628.10	-2,181,310.00	-5,528,599.94	3	4
357	2.87	40.48	3	-13,363.80	-2,389,696.00	-6,256,398.40	4	3
335	3.67	22.04	4	-6,127.62	-1,028,155.00	-2,877,921.57	4	2
27	31.55	1.25	4	778.53	10,566.35	9,882.71	1	1
472	16.34	4.07	1	5,787.21	1,363,008.00	685,123.31	5	1
89	52.38	4.69	3	4,202.68	186,707.40	159,055.26	1	1
227	2.75	42.68	3	-9,060.73	-1,024,397.00	-2,675,289.41	3	3
263	40.61	20.86	2	5,181.85	680,579.00	-406,752.20	3	2
10	2.21	8.59	3	-55.68	-281.94	-861.13	1	1
449	2.62	50.82	1	-21,614.50	-4,847,107.00	-12,487,637.83	5	4
21	29.51	70.47	4	-814.11	-8,633.02	-30,211.88	1	4
290	2.17	14.56	2	-3,596.38	-518,533.00	-1,441,588.48	3	2
495	7.64	4.51	4	1,537.88	383,809.10	-442,873.15	5	1
154	49.84	33.18	4	2,550.08	196,221.00	-397,335.28	2	3
275	3.47	15.93	1	-3,436.96	-469,471.00	-1,362,884.47	3	2
412	39.03	0.68	2	15,641.03	3,222,033.00	3,098,169.07	5	1
82	14.49	5.45	2	719.20	30,037.95	2,363.10	1	1
127	20.78	70.22	1	-6,228.36	-395,373.00	-1,223,627.04	2	4
454	43.89	9.91	2	15,390.00	3,494,411.00	1,966,146.43	5	1
427	5.93	6.46	3	-239.91	-49,381.50	-934,108.15	5	1
229	1.97	31.88	4	-6,845.80	-780,353.00	-2,029,129.09	3	3
86	19.95	35.43	3	-1,305.40	-56,813.60	-253,337.98	1	3
486	9.28	16.30	4	-3,395.18	-827,555.00	-3,708,181.72	5	2
456	11.49	10.23	1	569.08	130,969.90	-1,465,260.68	5	2
466	9.26	16.89	4	-3,596.90	-827,102.00	-3,569,607.96	5	2
223	10.21	43.70	2	-7,456.22	-828,842.00	-2,460,356.82	3	3
450	34.44	7.30	3	12,220.47	2,742,799.00	1,637,972.71	5	1
453	44.47	39.40	4	2,298.32	519,123.00	-5,544,693.69	5	3
368	2.49	40.29	3	-13,880.50	-2,552,171.00	-6,626,697.27	4	3
372	3.36	6.22	3	-1,031.09	-197,275.00	-838,796.06	4	1
105	13.57	19.64	3	-646.80	-33,123.60	-195,677.21	2	2

488	9.10	10.64	1	-716.93	-183,419.00	-2,070,773.93	5	2
44	9.45	15.87	4	-279.11	-6,070.39	-29,598.91	1	2
241	0.52	32.00	3	-7,457.44	-899,327.00	-2,299,655.83	3	3

Table 11. Mean Cost (0-10), and Mean Size (6-100 Firms)

Mean Size (6-100 Firms) Mean Cost (0 - 10)	Mean distance	Star (Net Benefit)	Strongly connected (Net Benefit)	Multi-Level (Net Benefit)
Mean	2.51	1,319.15	44,725.65	35,019.43
Median	3.00	703.22	14,124.11	10,078.32
STD	1.06	1,640.24	69,799.81	66,016.85
Max	4.00	6,821.34	334,663.20	304,809.60
Min	1.00	-589.71	-27,528.00	-90,011.10

Table 12. Mean Size(101 - 200 Firms), and Mean Cost(0-10)

Mean Size (101-200 Firms) Mean Cost (0 - 10)	Mean distance	Star (Net Benefit)	Strongly connected (Net Benefit)	Multi-Level (Net Benefit)
Mean	2.72	3,759.62	285,229.80	207,093.10
Median	3.00	2,499.64	183,646.20	117,001.10
STD	1.10	3,836.75	327,638.30	336,393.60
Max	4.00	14,220.06	1,400,465.00	1,276,355.00
Min	1.00	-759.35	-73,080.20	-360,072.00

Table 13. Mean Size (201 - 300 Firms), and Mean Cost (0 - 10)

Mean Size (201-300 Firms) Mean Cost (0 - 10)	Mean distance	Star (Net Benefit)	Strongly connected (Net Benefit)	Multi-Level (Net Benefit)
Mean	2.69	3,669.34	463,710.90	262,121.60
Median	3.00	2,387.16	308,558.60	154,509.40
STD	1.06	4,631.38	602,630.50	628,960.40
Max	4.00	22,856.17	3,069,430.00	2,667,548.00
Min	1.00	-1,994.10	-284,596.00	-829,966.00

Table 14. Mean Size(301 - 400 Firms), and Cost(0 - 10)

Mean Size (301-400 Firms) Mean Cost (0 - 10)	Mean distance	Star (Net Benefit)	Strongly connected (Net Benefit)	Multi-Level (Net Benefit)
Mean	2.46	6,143.43	1,086,392.00	690,955.90
Median	3.00	4,258.73	733,939.40	466,942.60
STD	0.92	6,450.86	1,172,756.00	1,204,708.00
Max	4.00	27,679.30	5,042,497.00	4,847,798.00
Min	1.00	-1,890.43	-375,345.00	-1,156,562.00

Table 15. Mean Size(401 - 500 Firms), and Cost(0 - 10)

Mean Size (301-400 Firms) Mean Cost (0 - 10)	Mean distance	Star (Net Benefit)	Strongly connected (Net Benefit)	Multi-Level (Net Benefit)
Mean	2.22	9,644.34	2,162,513.00	1,490,525.00
Median	2.00	7,737.05	1,628,261.00	943,873.20
STD	1.01	9,572.77	2,213,581.00	2,290,458.00
Max	4.00	40,668.54	9,976,725.00	9,692,558.00
Min	1.00	-2,945.90	-697,112.00	-2,001,978.00