Collaborative Innovation in Triple Helix Networks: Examining the Link between Informal Social Networks and Innovation

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Abstract. The importance of triple helix collaboration has been widely acknowledged; however, knowledge is increasingly specialized and trapped in discipline and sector silos. The current research explores collaborative interactions within an informal virtual hetarchical social network (VHSN) to determine the efficacy of social networks as distributed incubators for cross-sector, multi-disciplinary knowledge exchange able to facilitate knowledge spillover and accelerate innovation. Data was collected using customized network monitoring tools 1(CNMTs); self-report questionnaires and, interviews and analyzed using social network analysis (SNA) methods. Findings identify salient network activity and psycho-social characteristics of participants within the VHSNs related to knowledge exchange and the creation of a network of networks for accelerating cross-sector innovation. This article describes how distributed networks are able to serve as platforms for the incubation and sharing of ideas that are precursors to innovation. They constitute a low-cost investment capable of accelerating economic efficiency and growth..

Introduction

Innovation is a key determinant and driver of economic growth, and the anatomy of innovation must be fully explicated in order to manage and use it to foster economic growth. Innovations and related spillovers serve as major sources of economic growth (Verspagen, 2005; Romer, 1990; Schmookler, 1966; and Schumpeter, 1934). There is growing interest among scientists, policy makers, and throughout the private sector regarding the economic and social advances that are made possible through cross-cutting collaboration where diverse resources, people and knowledge sets can be blended to accelerate the pace of innovation. The respective skill sets of individual disciplines and sectors (government, academic, industry) fall short of addressing the complex and refractory nature of global problems and the multi-faceted requirements of many critical endeavors. Work across traditional boundaries through multi-disciplinary and triple helix collaboration is increasingly considered to be a scientific and social imperative (Klein, 2008; Kesssel, Rosenfield & Anderson, 2003; Nash, 2008; Rosenfield, 1992; Kahn & Prager, 1994; Polimeni, 2006; Higginbotham, Albrecht & Conner, 2001; Stokols, et al, 2008). Knowledge that spills over into novel spaces or that can be absorbed from novel points of view creates greater opportunity for serendipity and innovation. It is therefore efficacious to facilitate collaborations that straddle these ambiguous trilateral boundaries and internalize the flexibility and innovation inherent in each (Guston, 2000).

Innovation has traditionally been viewed as the application of an existing knowledge to develop a specific product. Increasingly, however, innovation is recognized as a complex event, responsive to contextual factors, organizational structures, and multiple dynamic processes. The formation of networks can bridge extant gaps between diverse knowledge sets (Granovetter, 1973). Virtual communities and social networks have significant potential for

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enhancing innovation processes (Powell and Grodal, 2005; Mizruchi and Stearns 2001; Ahuja, 2000; Baum et al. 2000; Godoe, 2000; Podolny and Baron, 1997; Burt, 1992; Coleman, 1988; and Freeman, 1977).

Social networks provide a bridge between organizations, geography, disciplines and sectors (Granovetter, 1973). Since every society is built around relationships, the behavior of individual actors cannot be fully understood unless it is put in context with the actions of others with whom the individuals are connected through various social ties (Granovetter, 1973). The advent of the Internet, social networking and collaborative technologies affords new opportunities for utilizing global social networks and distributed collaborative innovation.

Social networking sites were originally developed as entertainment and have been primarily used for social engagement. Social network sites are increasingly attracting the attention of academic, industry and government researchers who see the potential value of their affordances and reach (Boyd & Ellison, 2007; Hoover & Foley, 2009). Social networking sites offer a robust and versatile platform for cross-cutting knowledge exchange and new opportunities to expand co-located innovation systems into global, distributed systems for innovation.

According to Burt (2000), if network nodes (individuals) are able to strategically position themselves as bridges between structural holes, then they are perfectly positioned to receive and absorb new knowledge and perspectives that may trigger a flood of "eureka" moments that spark innovations. There is strong evidence concerning the role of "formal" Virtual Hetarchical Social Networks (VHSN) in facilitating knowledge spillovers, innovation and economic growth (Back et al., 2007; Fischer, 2006; Powel & Grodal, 2005; Lundkvist, 2004; Pyka & Kuppers, 2002; and Park, 2000;); however, there is scant research describing the effects of informal VHSNs on innovation.

The current research established an informal, virtual hetarchical social network or "colleague network" (www.3Helix.org), with the goal of collaborative engagement, rather than friending or social activities. The research explored the interactions between individuals from diverse settings, using self-report questionnaires, social network analysis (SNA) methods, and customized network monitoring tools (CNMTs). The study sought to explicate the role of informal factors in the innovation process. If VHSNs facilitate innovation, then they constitute a very low-cost investment that accelerates efficiency and economic growth and, moreover, can serve as incubators for sharing ideas that are precursors to innovation.

1. Method

The method and procedure for this research were conducted in four phases. Phase 1 consisted of building the VHSN; defining the tools and features able to promote collaborative innovation; and, recruitment into the network. Phase 2 initiated a series of cross-cutting knowledge clusters to facilitate activity within the network. In Phase 3, the VHSN was expanded to include University undergraduate and graduate students at a local state university. In Phase 4 several different networks were linked to catalyze a network of networks for collaborative innovation, christened the New Generation Social Network. Data was collected in all phases and analyzed to investigate interactions within the virtual hetarchical social network; the interplay of the nodes; the structural nature of the transactions that transpire in the VHSN; and, the social-psychological aspects related to participation and innovative activity.

Phase 1: Building the Virtual Hetarchical Social Network (VHSN)

A VHSN "colleague network" was developed to transpire communication through “strong tie” or “weak tie” relationships in broad (network-wide or large cluster) or thin (node-to-node or small cluster) forums. The following ICT tools were provided for use within the VHSN: (1) Network-wide collaborative tools (i.e., blog, listserve or forum); (2) E-mail messaging; (3) instant messaging; (4) teleconferences; (5) videoconferences; (6) profiles; and, (7) group spaces for open and private groups.

Phase 2: Knowledge Clusters

Communities of Practice (CoP) are *self-organizing* networks that arise spontaneously due to commonalities of CoP members. Knowledge Clusters were conceived as *intentionally* established networks of scientists, innovators, funders, and industry specialists brought together in around commonalities with expertly facilitated sessions to bridge formal boundaries, exchange explicit & tacit information, catalyze knowledge exchange, promote swift trust and foster serendipity (Jerome, 2009; Snyder, & Briggs, 2003). A series of six cross-cutting Knowledge Clusters were developed and initiated, with over 135 cluster participants distributed across time zones, nation states, and sectors spanning government, industry and academia. Each cluster came together for six to eight sessions over a two-month period to blend knowledge and form a thick network for collaboration on common cross-sector topics and projects. The six distributed Knowledge Clusters met online in weekly sessions on a WebEx conferencing platform and interacted within the 3Helix.org VHSN.

Phases 3: University Participation

The intent of the research was to examine cross-sector knowledge exchange through the VHSN network and to engage participants from a diverse constituency. Access to the university population provided a way to collect data from a broad and diverse spectrum and increased the size of the sampling. The University participation also added value to the study in their diversity, with participants ranging from ages 18-66, enrolled in 60 different majors, from a varied work and educational experience. These participants, younger on average than other participants in the study, from their lifelong experience with the internet and computer technology, approached openly the use of the VHSN. As university students, the acquisition of knowledge and use of collaborative exchange posed opportunities for them. In addition, the project was able to use incentives to encourage participation that validated some of the results.

Phase 4: New Generation Social Network (NGSN)

Social networks represent an ideal platform for blending knowledge across sectors and disciplines; however, social networking remains largely uncultivated for our scientific community. The final phase of the project aimed to create a network of networks where trilateral partners could blend knowledge sets and take advantage of multiple site activity and resources. Several networks were brought together for interaction with the 3Helix community to form a thick network of scientists and innovators , identified as the New Generation Social Network (NGSN). The idea was to provide accessibility into multiple, cross-cutting networks and thereby create opportunity for social network

cross-over, novel participation and interactivity. By linking together several networks, visibility and access were simplified for cross-platform participation; boundary-spanning; and, transformative collaboration.

1. 1 Materials and Measures

Customized Network Monitoring Tools (CNMTs) were used to calculate a variety of measures using VHSN system data: e.g., determine the extent to which network nodes employ available communication/collaborative tools during their network transactions; to assist in the calculation of Status Indexes; and to measure the frequency and direction (e.g. low-to-high status) of those transactions. CNMT were used throughout the life-span of the research to collect data in all phases of the project . Each participant was given a unique logins to the network that allowed them to create a profile and search or browse profiles of other participants. A time-stamped log was kept of each participant's searches, visited pages, and communications with other participants is coded by participant ID only. The number and type of communications was subsequently counted for each participant. Contacts between different nodes were counted and coded by the characteristics of the participants involved. Social network analysis (SNA) (Carrington et al., 2005; Barakat and Pratt, 2004; Freeman, 2004; and John 2000) provided the tools for measuring and analyzing the interplay of the nodes and the structural nature of the transactions that transpire in the VHSN. Three self-report questionnaires (Entry, Periodic, Final) were used to collect self-report data for investigating factors related to structure, social-psychological facets, and strategic economic dimensions. Various inferential metrics were also used to develop an ethnographic description of the knowledge clusters including the interaction and collaboration that resulted.

2. Results

The purpose of the proposed research is to test a series of hypotheses, which address the structural, social-psychological and economic factors that impinge on prospects for innovation through the VHSN. Space precludes an exhaustive presentation of these results, but several key findings are provided.

Five of the six Knowledge Clusters evidenced greater than one tangible opportunities for cross-sector collaborative innovation including novel partnerships for grant and article writing (new publication); the generation of novel ideas; planning for a new training program; dissemination of an emergent technology for trial in new geographical regions; and, spinoff clusters and the creation of new VHSN asynchronous groups. Further, when cluster participation required the exchange of elite knowledge, the commonality of specialization promoted swift trust and engagement, accelerating a rich transfer of discreet knowledge for specialized blending and new partnering/development potential. A robust platform with strong, stable and enabling collaboration tools fosters interaction between members. However, a mediating factor appears to be members' comfort with and willingness to use collaboration tools and virtual environments. Although there was strong consensus by VHSN members regarding the value of a virtual network for cross-cutting innovation and collaboration, the potential for knowledge spillover was not incentive enough to motivate continued activity, in the absence of facilitated sessions. This is an especially interesting finding because the level of trust demonstrated within every Knowledge Clusters was greater and developed more quickly than anticipated.

Several specific hypotheses were addressed:

H1: (Structural): The characteristics of the VHSN facilitated increased communication, which in turn, is correlated with innovation.

The characteristics of the VHSN were significant and positively correlated with the number of participant innovations. Therefore, the characteristics of the VHSN promoted innovation for the participants.

		Innovations	Q29	Q30	Q31	Q32	Overall Structure
Innovations	Pearson Correlation	1	.211**	.193**	.177**	.004	.244**
	Sig. (2-tailed)		.001	.002	.004	.946	.000
	N	262	262	261	260	261	258

Table 1. Correlations between innovation and VHSN structure

H2: (Structural): "Dunbar's Number" (Dunbar, 1992), which states that the maximum size of a real-world social network is 150 nodes does not apply to a VHSN of global innovators.

A single participant exceeded 150 nodes. This suggests that Dunbar's number may not apply to a VHSN of global innovators; however, this hypothesis cannot be confirmed by this research.

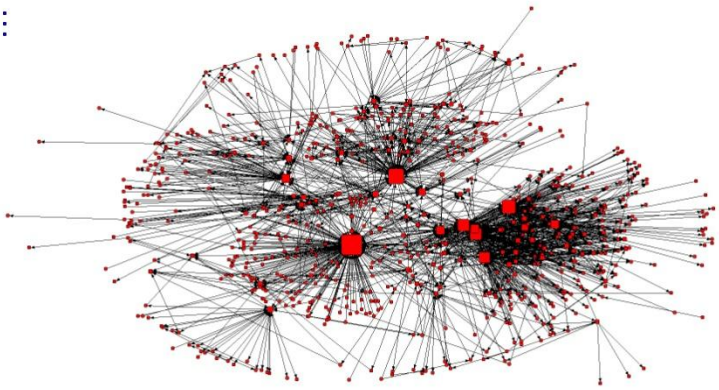

Figure 1. Network graph.

The study of communications in social networks is rooted in sociology and psychology and concerns the social interactions of humans and all of the related customs, formalities, and psychological issues (Freeman, 1992; and Granovetter, 1973). Generally, these issues can adversely affect interactions within social networks and can, thereby, reduce prospects for innovation. When social networks are informal and evolve in a virtual context, are human interactions different? We investigated trust and other aspects of human interactions within the VHSN by posing the following refined hypotheses. The first seeks to determine the level of trust in the network, which affects the level of interaction and the quality of information that is shared. The second assesses the extent to which the partial anonymity of the VHSN diminishes the tendency to adhere to customs and creates a level playing field where nodes seek information wherever it is likely to be found. Both questions impact prospects for innovation.

H3: (Social-Psychological) An increase in the number of nodal contacts within the VHSN is associated with self-reported trust of others in the network.

Trust is a complicated issue to interpret since there were many differences in the relationship between trust and nodal contacts for the different respective VHSN groups. Overall, nodal contacts had a linear relationship with trust, where a stronger correlation (red) between trust (frequent communication) and nodal contacts existed and a lower correlation between trust (few communication) and nodal contacts existed.

			Trust		
		Nodal Contacts	Frequent communication	Trust Moderate Communication	Trust Few Communication
Nodal Contacts	Pearson Correlation	1	.165**	.098	-.016
	Sig. (2-tailed)		.008	.115	.791
	N	262	259	262	261

Table 2. Correlation between nodal contacts and perceived trust.

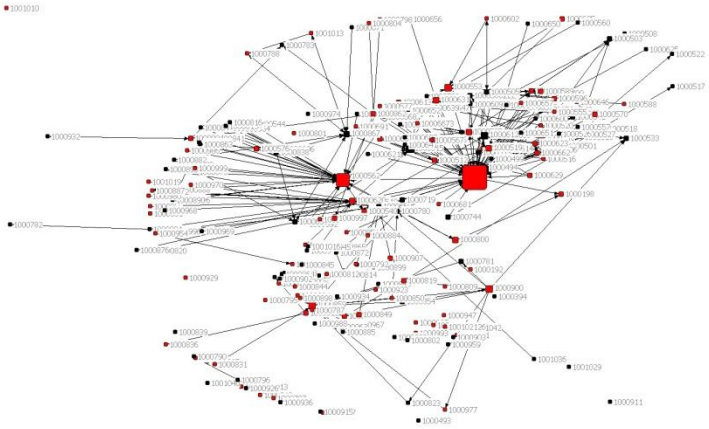

Figure 2. Trust based on nodal transactions.

H3 (Wiki): (Social-Psychological) An increase in the number of nodal contacts within the VHSN is associated with self-reported trust of others in the network.

The correlations between trust and nodal contacts with the wiki tool were similar to the correlations between trust and nodal contacts with other participants. Therefore, it appears that the issue of trust between levels of communication and the use of technology were consistent.

		Wiki Nodal Contact	Trust Frequent communication	Trust Moderate communication	Trust Few communication
Wiki Nodal Contact	Pearson Correlation	1	.149*	.087	-.037
	Sig. (2-tailed)		.017	.162	.552
	N	262	259	262	261

Table 3.Correlation between nodal contacts with wikis and perceived trust.

H4: (Social Psychological): VHSN participants (nodes) will initiate more inter-nodal contact with nodes of similar status as defined by a "Status Index" than nodes of a different status.

Research confirms this hypothesis. [Definitions: Artifact: contacts that leave a visible trace, such as a discussion posting, which is available for the other nodes to view. No artifact contacts, such as viewing a discussion posting, do not leave a visible trace.] Specifically, VHSN participants will initiate more inter-nodal contact with nodes of similar status; VHSN clusters reflect disproportionate numbers of intra- as opposed to inter-cultural/ethnic/national origin ties; and, the majority of dissimilar status index ranked nodal interactions were initiated on a low to high-rank basis. Nodal contacts were divided into two categories, artifact and No artifact contacts. The hypothesis was supported, since VHSN participants initiated more inter-nodal contact with nodes of similar status for both artifact and No artifact nodal transactions.

	Artifact	No artifact	Total
Similar	161	1891	2052
Dissimilar	16	735	751

Table 4. Overall artifact and no artifact transactions for similar and dissimilar participants

VHSN clusters reflect disproportionate numbers of intra- as opposed to inter- cultural/ethnic/national origin ties.

The research confirms this hypothesis, since nodal contacts were most common amongst participants with similar gender, language, and ethnicity. However, when the data were analyzed by artifact and No artifact types of nodal transactions, differences emerged. More intra-nodal contacts were based on gender and language. Further, more nodal contacts were between those of different ethnicities, as opposed to similar ethnicity for artifact nodal transactions. Ethnicity impacted the participants' artifact nodal transactions.

MM	FF	MF	FM	LangSim	LangDif	EthSim	EthDif
19	87	53	18	160	17	71	106
Gender		Gender					
Same	106	Different	71				

Table 5. Artifact transactions for similar and dissimilar participants.

MM	FF	MF	FM	LangSim	LangDif	EthSim	EthDiff
869	770	489	498	2182	444	1467	1159
Gender		Gender					
Same	1639	Different	987				

Table 6. No artifact transactions for similar and dissimilar participants.

MM	FF	MF	FM	LangSim	LangDif	EthSim	EthDif
888	857	542	516	2342	461	1538	1265
Gender		Gender					
Same	1745	Different	1058				

Table 7. Total transactions for similar and dissimilar participants.

The majority of dissimilar Status Index ranked nodal interactions will be initiated on a low to high-rank basis.

A majority of nodal transactions were initiated on a low to high-rank basis. A difference was found between artifact and No artifact nodal transactions. When the data were analyzed by artifact and No artifact nodal transactions, a majority of No artifact nodal interactions were initiated on a low to high-rank basis. Artifact nodal transactions occurred more frequently on a high to low-rank basis, which promoted the sharing of information from those of higher status to those of lower status more frequently.

	Artifact	No artifact	Total
Low-High	5	547	552
High-Low	11	188	199

Table 8. Artifact and no artifact transactions between low and high ranked participants.

Economists immediately translate the interaction of nodes in the VHSN into a game theoretic framework (Zagare, 1984; and Von Neumann and Morgenstern, 1944), and characterize the nodes as strategists who seek to optimize the amount of high-quality information that can be obtained given time and resource constraints. Those constraints, in turn, cause the nodes to constrain their participation in the game according to following condition: The cost of participation (time spent) must be equal to or greater than the expected benefits of playing the game. In other words, nodes must first develop an expected value or payoff for the game, and then decide how much time to allocate to play. Nodes may find it necessary to modify their expectations about the value of the payoff as the game progresses. Rational economic agents will abide by the aforementioned condition; if they do not, it signals that they are not rational and efficient economic agents. A preponderance of irrational agents in the network may imply that special factors are associated with the VHSN, which renders it an inefficient mechanism for producing innovation. We use the following hypothesis to test this idea:

H5 (Economic) There is a positive correlation between the perceived valuation of the VHSN and the amount of time spend on performing VHSN activities.

The perceived time spent performing VHSN activities was significantly correlated with overall value.

		Nodal Contacts	Perceived Time Spent	Overall Value
Nodal Contacts	Pearson Correlation	1	.006	.109
	Sig. (2-tailed)		.924	.085
	N	262	259	253
Perceived Time Spent	Pearson Correlation	.006	1	.148*
	Sig. (2-tailed)	.924		.019

Table 9. Correlation between nodal contacts, perceived time spent, and overall value of the VHSN.

The majority of nodal transactions within the VHSN will involve individual or small-group contacts, not large-group or network wide contacts.

The research confirmed that a majority of nodal transactions within the VHSN involved individual or small-group nodal contacts, as opposed to large-group or network wide contacts.

Communication Type	Transactions
Small Group	177
Wiki	44
Network Wide	0

Table 10. Communication transactions for small group, wiki, and network wide communication.

3. Discussion/Conclusion

When U.S. and world economies grow, that economic growth facilitates improvements in individual and community quality of life. Innovation is a key determinant and driver of economic growth. (Schumpeter, 1934; Schmookler, 1966, Romer, 1990; Verspagen, 2005). Innovation results when a confluence of complex, contextual, structural and dynamic process factors produce new social benefits, greater economic efficiency, and enhanced sustainability. Knowledge spillovers are the lynchpin for innovation. Innovation events increase when there is a rich flow of knowledge from sources such as the labor market; the fluctuation of employees between different employers; cooperative relationships; trade; publication; and, purchased goods and services (Fritsch, 2002).

Knowledge-generating activities do not occur in isolation, but depend on access to new ideas. We have long known that co-location and geographic concentrations of innovative activity facilitates knowledge spillovers by providing opportunities for both planned and serendipitous interaction potential. This, in turn, promotes networks and activities that accelerate innovation potential. It is also known that innovation is enhanced by collaboration, including informal interactions amongst scientists and innovators. What remains to be understood is the nature of those informal interactions and how they contribute to the process of innovation.

Brass et al (2004) define a network in a very general way as "a set of nodes and the set of ties representing some relationship, or lack of relationship, between the nodes." Real-world social networks grow from individual human relationships. Online social network platforms permit the development of virtual environments resembling real-world networks and their nodal relationships. When networks are characterized as business or organizational networks, they may be discussed as partnerships, strategic alliances, inter-organizational relationships, coalitions, cooperative arrangements or collaborative agreements. Regardless of context, networks have common themes including social interaction, relationships, connectedness, collaboration, collective action, trust, and cooperation (Provan, Fish, Sydow, 2007). The current research explored virtual hetarchical social networks (VHSN) as incubators for sharing ideas that may be precursors to innovation. The findings yield support for social networks as an able platform for knowledge incubation, exchange and spillover. Several ideas, beyond the specific findings for

each hypothesis, were revealed through this research bringing new insights regarding innovation in VHSN related to value chains, knowledge spillovers, incentives, absorptive capacity, structure, and trust.

Value chains and knowledge spillover in VHSN

Value chains are increasing distributed, complex and interdependent. Value chains are inclusive of the nodes and their connections and interactions that represent both tangible and intangible deliverables. The most fundamental resource in value chains is knowledge. The way knowledge flows, overlaps and is absorbed is the key to innovation. The importance of collaboration is widely accepted; however, knowledge has become increasing specialized and trapped in discipline and sector silos. As a global community we are plagued by intractable problems including disease, terrorism, poverty and illiteracy. Our conventional public and private bureaucracies are designed to solve stable problems for established constituencies through centrally managed programs and policies. These structures are not sufficient to address the messy problems we are facing today. The development of innovative solutions to complex problems requires cross-cutting knowledge exchanges where experts share their frames of reference and knowledge sets with other specialists, outside of their respective fields.

Effective alliances between government, academia, and industry, or triple helix partnerships, show great promise for creating new value chains poised to move science-based knowledge more efficiently from discovery to commercialization. Social networking sites offer a robust and versatile platform for cross-cutting knowledge exchange with collaborative technology capabilities including messaging, wikis, blogs, profiles and continuous updates. By blending knowledge from multiple individuals and sectors and linking small networks and vertical silos, integrated solutions may be generated that span diverse constituencies. Social networking platforms represent new opportunities to expand co-located innovation systems into global, distributed opportunities for innovation. Improving the knowledge base of developed and developing countries and making cross-sector linkages to apply new knowledge can stimulate innovation, contribute to greater intellectual capital, market creation, economic growth, job creation, wealth and a higher standard of living.

The current research built a virtual hetarchical social network VHSN specifically dedicated to promoting knowledge exchange and collaborative innovation amongst a diverse constituency of scientists and innovators. Consistent with previous findings, the VHSN platform offered demonstrable utility for cross-cutting collaborative engagement and knowledge incubation. The VHSN brought together novel groups of multi-disciplinary and cross-sectoral teams into a technology-rich forum where they had the opportunity to efficiently share knowledge, exchange ideas, deliberate problems, brainstorm innovative solutions and consider new partnering opportunities.

Innovation events increase when there is a rich flow of knowledge from diverse sources where a collision of ideas and spillovers are likely (Harmaakorpi, 2004). The current research provides evidence that of distributed cross-cutting networks are able to produce meaningful knowledge spillovers; and further, that the new platforms produce significant opportunities for novel innovation events.

An important finding of the research was that the knowledge spillover within VHSN is not sufficient to foment the enduring relationships necessary for the emergence new value chains. While the potential for knowledge spillovers and innovation in VHSN is significant, there are considerable challenges in creating an environment able to sustain activity amongst participants once the intentional event being produced to stimulate the knowledge exchange has ended. Individual nodes tend to come into the VHSN to exchange specific knowledge or accomplish a particular task and then retreat back into their respective egocentric networks, to continue development along their familiar trajectories. While VHSN represent efficient platforms with significant potential for accelerating collaborative potential and global, distributed partnering, people remain vested in their own co-located agglomerations and appear more likely to absorb new information for the enhancement of their local innovation system. This is consistent with research concerning proximity and co-location as catalyzing factors in innovation capabilities (DeBruijn, 2004; Deloreux & Parto, 2004).

Incentives in VHSN

This research contributes to a growing evidence base that validates the value of VHSN for knowledge exchange, cross boundary collaboration and networking (Amin & Roberts, 2008; Russel et al, 2004). What has not been previously explored is the methodology for generating and sustaining activity within a VHSN sufficient to create ongoing collaborative engagement for knowledge spillovers and innovation.

Social network sites are typically organized around people, rather than around specific topics or interests. Early public online communities such as Usenet and public discussion forums were structured by topics or according to topical hierarchies, but social network sites are structured as personal (or "egocentric") networks, with the individual at the center of their own community (Boyd & Ellison, 2007). Social networks are thus used primarily to maintain personal networks with people they already know (Pew Internet and American Life Project, 2008).

The VHSN developed in this research sought to engage participants in networks with a goal of cross-cutting knowledge exchange amongst a diverse constituency. This goal is a very different focus than friending and social exchange. This challenge led to an important finding. While the VHSN platform offers great potential for collaborative innovation, social network sites are not designed for or approached by participants as platforms for knowledge exchange and spillover. New features, strategies and methodologies must be developed that prompt participants with weak ties to interact, find replenishing value and reason to sustain new relationships. The issues of motivation and incentive are structurally fundamental to the development of distributed cross-cutting networks that will promote and accelerate innovation.

Social network platforms as they currently exist motivate participant activity through social incentives where individuals find implicit reward by connecting being active within their community and concomitant status from participation and community contributions. Social networks dependent on existing relationships do not have sufficient incentives to motivate the continuous exchange of knowledge and resources when participants have weak social ties. In this research trust formed swiftly between VHSN participants in Knowledge Clusters and communication was rich with new knowledge and boundary spanning. However, only under conditions where

Knowledge Clusters were fully produced and facilitated did members continuously engage. The level of activity and spontaneous engagement was not maintained with the cessation of the clusters. This finding was further documented in the University participants' data. The importance of incentives in attracting and retaining participants, stimulating communication and collaboration emerged as an issue with far-reaching impact for future research. Participants require continuous motivation to use a network. So, even with the creation of an exemplary VHSN for collaborative innovation, the network's value is strengthened or reduced relative to the effectiveness of the incentive. In the current research, increased activity within the VHSN spiked under several conditions: 1) When an event of significant interest occurred (e.g. knowledge cluster session); 2) When a new affiliate network was brought into the community; 3) When notifications and stories about events were emailed to participants; 4) when there was a desirable tangible reward for participation (e.g. extra credit). The literature offers some suggestions for infusing a VHSN with non-social based incentives but the availability of specific design and motivational catalysts are sparse. Suggestions include: 1) Include features that make participant contribution require zero effort, occurring as a side effect of something else they are doing; 2) Reward and promote contributors with community rankings; features about top contributors; and, direct comments to the community about contributions; 3) Create content that will be of sufficient value to engage the community.

Structure of VHSN

Another finding from the current research is germane to the discussion of incentives. The data indicates that the structure of the VHSN was positively linked to increased communication. This is consistent with the literature that reports that virtual communities are successful in that they satisfy key standards in the following dimensions: Structure, navigation, behavior, user control, and presentation Garzotto and Matera (1997).

Perceived ease of use of the VHSN was correlated with increased activity, communication and number of innovation events. As more features were added to the VHSN that improved navigation, visibility of profiles, information dissemination and notifications, activity significantly increased. This is a critical factor when introducing a new technology or new use for an existing technology, such as using VHSN for collaborative engagement. User acceptance is enhanced by familiarity and ease of use. As user acceptance of VHSN for collaboration an increases, VHSN are more likely to become valuable platforms for knowledge exchange and innovation.

Absorptive capacity in VHSN

The research findings are relevant to the topic of the absorptive capacity of participants within the VHSN. A community's absorptive capacity is their ability to sense their information environment, recognize new technological opportunities and capture new information for synthesis into their current routines and processes (Lane Salk & Lyles, 2001). The VHSN evidenced steady increases in membership throughout the lifespan of the project; however, activity was episodic and closely related to discrete events in the VHSN network. Even when evidence of significant spillovers were noted, as occurred in the Knowledge Clusters, these spillovers were narrowly absorbed. Knowledge exchanged during Knowledge Clusters tended to return to the silos and sectors of the

participants, to be integrated in traditional discipline and sector trajectories. Cross-cutting knowledge exchange within the distributed colleague network, therefore, did not realize the innovation potential the platform offers.

The literature outlines numerous barriers to cross-cutting collaborations in all the sectors, such as costs, incompatible objectives, risk averse attitudes, competition, insularity and fear. All of these factors are impediment to absorptive capacity and innovative potential. Research enumerates the following as key elements for absorption: valuation, assimilation, boundary spanning, power relationships, social integration mechanisms and regulative practices (Lerch, Wagner, Mueller-Seits, 2010). Improved structure and incentives of VHSN will aid in user acceptance, engagement and communication; however, traditional outlets such as conferences and peer review journal publication are the dominant form of knowledge exchange amongst scholars and researchers. They represent currency, prestige and tenure within the professional community. In order for the potential of VHSN to be realized as platforms for collaborative innovation, this systemic reward structure will need to be addressed.

Weak Ties, Trust and Innovation in VHSN

Trust has been shown to be essential to the communications/collaborations process when innovation occurs (Oswald et al., 2001; Tsai and Ghoshal, 1998; and Uzzi, 1997). It is interesting that the formation of strong and thick ties was not required for generous knowledge exchange to take place within the VHSN. The researchers hypothesized that trust would form at the same rate as the overall valuation of the VHSN; and, that increased trust would mark the quickening of VHSN engagement when activity would become self-sustaining. Nodes were expected to be very cautious in their initial exchange of information in the network. Instead, trust formed rapidly and there appeared to be a mutual regard for a range of node reputations and credentials. In the Knowledge Clusters specifically, knowledge was exchanged readily and did not require the anticipated period for a reduction of uncertainties. The knowledge cluster orientation, facilitated sessions and VHSN profiles provided sufficient information to promote swift trust and to facilitate the exchange of highly-valued information. The creation of trusted weak ties is extremely valuable for extending the network and access to tacit knowledge, advice and resources are necessarily exchanged between strong ties (Levin and Cross, 2004). This was further illuminated in self-report data collected from University participants. Trust is a complex issue. Differences were noted in the VHSN relationships between trust and nodal contacts for the different VHSN groups. The data from the overall participants suggests that where the participants were situated within the group produced different levels of trust.

Nodal transactions occurred most frequently between nodes of similar status. Age is a variable that must be considered. Older cohorts are less comfortable with and less active in social networks and the generation of collaborative user-generated content (Wunsch-Vincent, S. & Vickery, G. 2007). Another relevant factor is the kind of information being shared. Nodes tended to engage in the VHSN to exchange specific knowledge and/or accomplish a particular task, therefore nodes of similar status tended to engage in the network for similar reason and to accomplish a similar purpose. Promoting nodal transactions between different status nodes could increase levels of cross -fertilization. Cross-fertilization between entry level scientists and experienced scientists could generate innovations that could never have occurred between those of similar status.

While benefit would derive from a greater diversity in nodal exchange, all participant activities in the VHSN, whether low threshold or high engagement activities co-exist within a community to create a form of collective intelligence (Golan, 2008). This is of particular interest when aligned with the understanding that both strong ties mediate the exchange of valuable knowledge and weak ties mediate the exchange of non-redundant information (Levin & Cross, 2004).

In conclusion, the current research enabled study into the structure and impact of knowledge exchange in an informal virtual hetarchical social network. The results provide new insights to inform the formation of future informal social networks to incubate, enrich, and accelerate innovation. Current innovation policy has long been biased toward enhancing the supplies of inputs to innovation (basic research, invention, and basic skills) and away from encouraging demand and building absorptive capacity for the new (Kahin & Hill, 2010). This research brings into better focus the importance of considering complex value chains, information flows, incentives, and the formation of swift trust. What this research has begun to demonstrate is that distributed cross-sector networks are able to produce knowledge spillovers; and further, that the development of new platforms and models for cross-sector partnering produce new opportunities for innovation events. VHSNs have been shown as able platforms for the incubation and sharing of ideas that are precursors to innovation. They constitute a low-cost investment capable of accelerating economic efficiency and growth. From further research into knowledge exchange, spillovers and collaboration in VHSN, a network of networks can be built to stretch beyond where co-location is possible and to create profound innovation potential.

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