A Network Analysis of Investment Firms as Resource Routers in Chinese Innovation Ecosystem

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***Abstract*—This paper introduces the use of social network analysis for socially constructed data to study inter-organizational systems of innovation and their value-add supply chain. Through social network analysis, we explore the structure of relationships among Chinese technology-based companies, foreign technology-based companies with Chinese locations, Chinese investment firms, and foreign firms investing in Chinese companies – with particular attention to the business sectors related to e-commerce and internet security. We use an organizational sociology framework and socially constructed data in English to describe a Euro-American perspective on innovation ecosystems that link China globally. Our network analysis shows patterns of cultivation and harvest in investment networks.**

***Index Terms*—innovation, ecosystems, network analysis, finance, investment, China**

I. Introduction: Innovation Ecosystem

In response to large-scale social, technological, environmental and financial changes, businesses and policy-making groups seek to stimulate innovation. Innovation programs have been initiated at regional, national and international levels and are considered critically important to technology-based business development. The development of innovation networks has been recognized as an important strategy in developing technological capabilities of industrial clusters in China [24], as well as in other countries [25].

Innovation can be defined at the most general level as "a new idea, which may be a recombination of old ideas, a scheme that challenges the present order, a formula, or a unique approach which is perceived as new by the individuals involved" [5]. Innovations can include product innovations or process innovations, business model innovations, administrative innovations, and organizational innovations. Recently, they also include innovations in customer experiences [1]. There are a multitude of approaches, theories and frameworks to explain innovation; they come from many fields: economics, business, design, technology, sociology, and others.

With respect to its impact on businesses and their organizational infrastructures, innovation can be more purposely defined as "the ability to create and capture economic value from invention" [9]. In this context, innovation drives the economic prosperity of nations as well as the shareholder value of corporations. Therefore, innovations can be seen as vectors of economic significance, and as such, innovation is a primary driver of economic development. Economists, innovation policy makers, and business development practitioners are in agreement that participation in the global economy is essential for sustainable economic growth. The interdependence of industries and nations is recognized [25]. The dependence of innovation networks on knowledge flows is recognized [14].

We use the term "innovation ecosystems" to refer to the inter-organizational, political, economic, environmental, and technological systems of innovation through which a milieu conducive to business growth is catalyzed, sustained and supported. A vital innovation ecosystem is characterized by a continual realignment of synergistic relationships that promote harmonious growth of the system in agile responsiveness to changing internal and external forces.

In this study we apply the concept of innovation ecosystems to observe indicators of the broad system of innovation networks between China and the rest of the world in technology-based businesses. Indications of synergies in components of the innovation ecosystem are observed through network analysis of socially constructed data. Critical links in the flow of resources and drivers of convergence in innovation ecosystems are observed. Organizational systems and value chains are described, and implications for ecommerce and internet security are explored.

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II. Background

The past decade has seen both the emergence and the convergence of social and technological networks, powered by new systems, such as the World Wide Web. These are characterized by the interplay of the technology that supports it, its rich information content, and the millions of individuals and organizations who create and use that content. The ecosystem of business – at local, regional, national and international levels – is comprised of networks of technology-based businesses. Because they are constructed from relationships between people and the organizations or institutions in which people work, these networks are inherently social.

Social network analysis is a research field studying the structure of networks of social actors. The use of graphic images to represent social configurations is important because it allows investigators to gain new insights into the patterning of social connections, and it helps investigators to communicate their results to others [7]. Social network analysis has been used for several decades to study the sociological relationship of people and organizations. With the rise of consumer-generated content, social network analysis has been deployed to analyze communication structures, content and virality in social media [23]. In addition to examining networks visually, it is common to utilize variety of network measures to reveal the characteristics of underlying network. Key statistics of social networks include centrality (indicates relative importance of a node within the network), number of components in the networks (indicating how fragmented the network is) [22], [23].

Due in no small part to the democratization of knowledge and information accelerated by the Web 2.0 user-generated content phenomenon and the resulting crowd-sourcing mentality, significant attempts now exist to create and share data about technology-based companies and their investment firms – including the often missing data about start-ups. With the advent of user-generated content, socially constructed data has come into widespread practice. In fact, a study comparing the accuracy of Britannica to Wikipedia found that Wikipedia is more accurate than the longstanding authority [8]. Both resources are peer-reviewed; Wikipedia is essentially peer-reviewed by wide world wide web audience. Socially constructed data is openly available, and much of it is open to peer review by the entire user base of the World Wide Web.

In the on-demand world, timeliness is extremely important. Typically company data becomes available once the company is officially registered. Traditionally it may take years for the data to become publicly available. Waiting several years for this data is no longer acceptable. The technological capability of web crawlers allows active harvesting of online data, such as press releases, company reports, biographical background of company executives and board members, and investment events. Having the timely on demand data provides us with new opportunities for nearly real time analysis and utilization of the data.

Figure 1. Sector color-coding (used through out the paper).

The Innovation Ecosystems Dataset [17], built from web-crawling socially constructed data about technology-based companies and their investment firms, is a dataset of over 100,000 records, describing technology-based companies (over 34,000 records), their executives and board personnel (over 48,000 records), and investment organization (over 3,800) and their corresponding transactions totaling over US$ 193 billion. Companies from 16 sectors are included: advertising, biotech, cleantech, consulting, ecommerce, enterprise, games & video, hardware, mobile, network hosting, public relations, search, security, semiconductor, software, and finally web (Figure 1). The data use English language. Home office and satellite office locations are identified and reflect a global distribution of companies ranging in size from start-ups to multinationals.

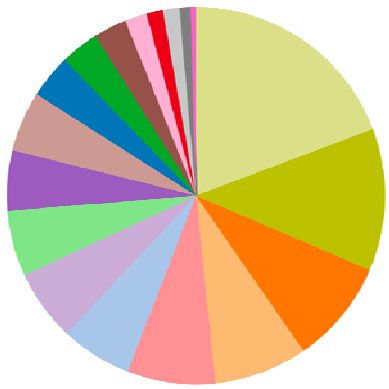

Figure 2. Sector classification of Chinese companies (ordered by the number of companies within the sector).

III. Method: Sample And Analysis

Data on 323 companies was assembled by sampling the Innovation Ecosystems Dataset for technology-based companies with one or more location in China; not including Honk Kong locations. These companies were segmented into two location-based categories -"Chinese

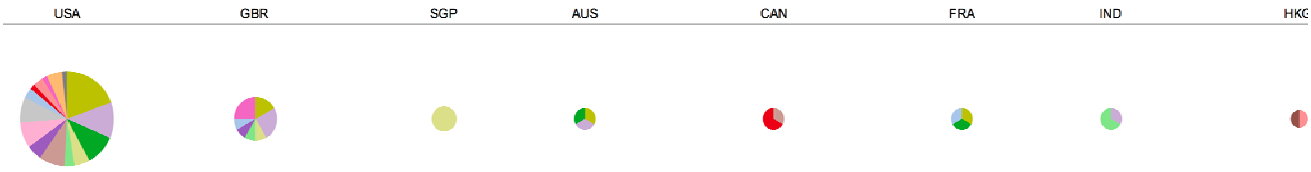

Figure 4. Sector proportion and home office location of 111 foreign companies with offices in China.

companies" (66%, 213), companies with their primary office in China, and "foreign companies" (33%, 110), companies with their primary office not in China. The company location information in the Innovation Ecosystems Dataset does not specify headquarters or branch office. To identify listing patterns, the first-listed location information in the IE Dataset of twenty (20) companies was cross-referenced with the company website. This verification identified that the first-listed location tended to be the company headquarters. Therefore, the first-listed location is taken to be the company headquarters.

Figure 2 shows the sector proportions of the Chinese companies in the sample; Chinese companies in this sample included all sectors in the Innovation Ecosystems Dataset. The foreign companies selected into this sample also included all sectors in the IE Dataset. Figure 3 shows the sector proportions of the foreign companies in the sample.

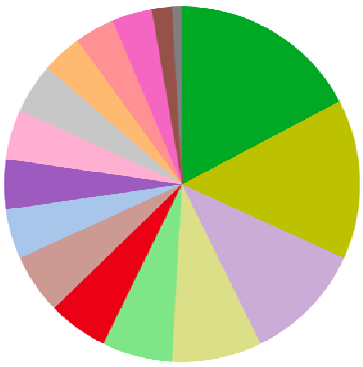

Figure 3. Sector classification of foreign companies with Chinese locations (ordered by the number of companies within the sector).

These companies were further segmented into two sector categories – "eCIS", business sectors in the innovation ecology of eCommerce and Internet Security (ecommerce, software, search, network hosting, mobile, games & video, and enterprise) and "other." Over half (53%, 113) of the Chinese companies are from eCIS business sectors; specifically, the sectors are represented as follows: web = 15.4%; software = 13%; search = 2.7%; network hosting = 2.5%; mobile = 7.7%; games & video = 6.2%; and ecommerce = 5.8%. Exactly half (50%, 55) of the foreign companies are from the eCIS business sectors; specifically, the sectors are represented as follows: web = 8.2%; software = 14.5%; search = 4.5%; network hosting = 1.8%; mobile = 10.9%; games & video = 3.6%; and ecommerce = 6.3%.

As shown in Figure 4, the major share of foreign companies have main offices in the US.

To this data was added, also from the Innovation Ecosystems Dataset, data about "Chinese investment firms" (home office in China) with US$3.1B investments in Chinese and foreign companies (Figure 5) and data about US$5.4B investments in the Chinese companies by Chinese and foreign (home office not in China) investment firms (Figure 6).

As shown in Figure 5, Chinese companies receive 76% of the funds invested by Chinese investment firms in this

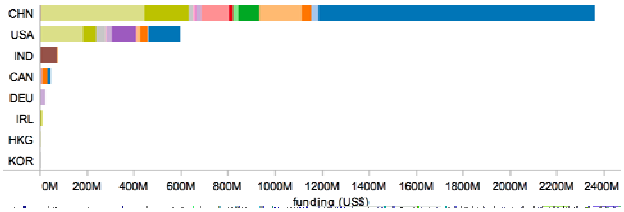

Figure 5. Sector and country proportions of investments (US$3.1B) by Chinese investment firms.

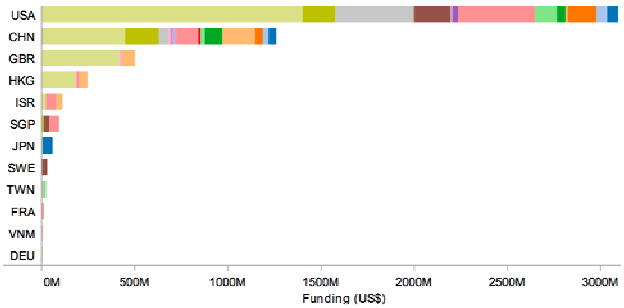

Figure 6. Sector and country proportions of investments by foreign investment firms (US$5.4B) into Chinese companies.

sample; foreign companies receiving investments from Chinese investment firms were dominated by the US, followed by India.

Two questions were explored through network analysis:

- What patterns in the existing relationships among Chinese companies and foreign companies, and among their Chinese and foreign investment firms, reveal insights about the flow of financial resources into and out of China for technology-based companies?
- What insights about existing patterns in the networks of financial resources can be leveraged for business development initiatives in the ecommerce and electronic security business sectors in China?

A network analysis was used to assess the relationships between businesses and investment firms in the sample of 323 technology-based companies and investment firms

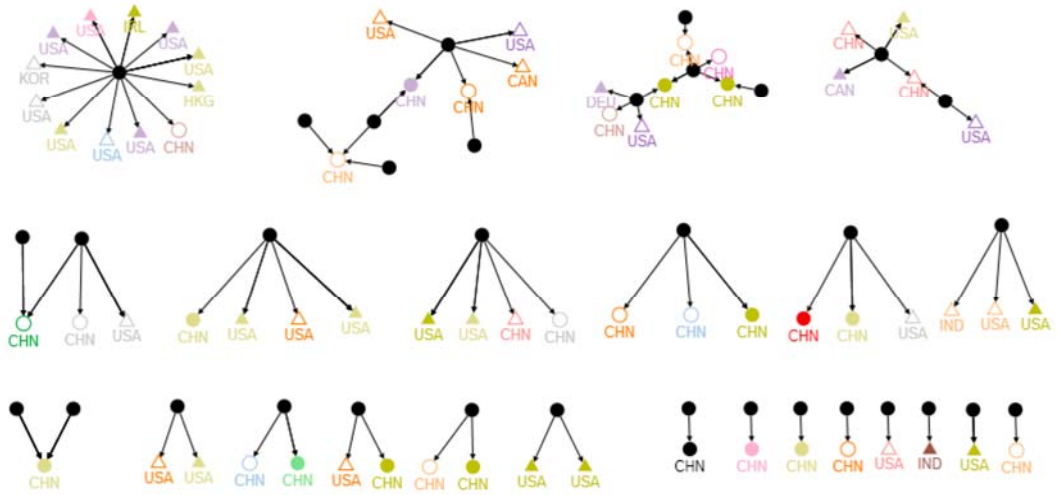

Figure 8. Home location of companies (eCIS-related sector = solid fill) receiving investments from Chinese investment firms (black).

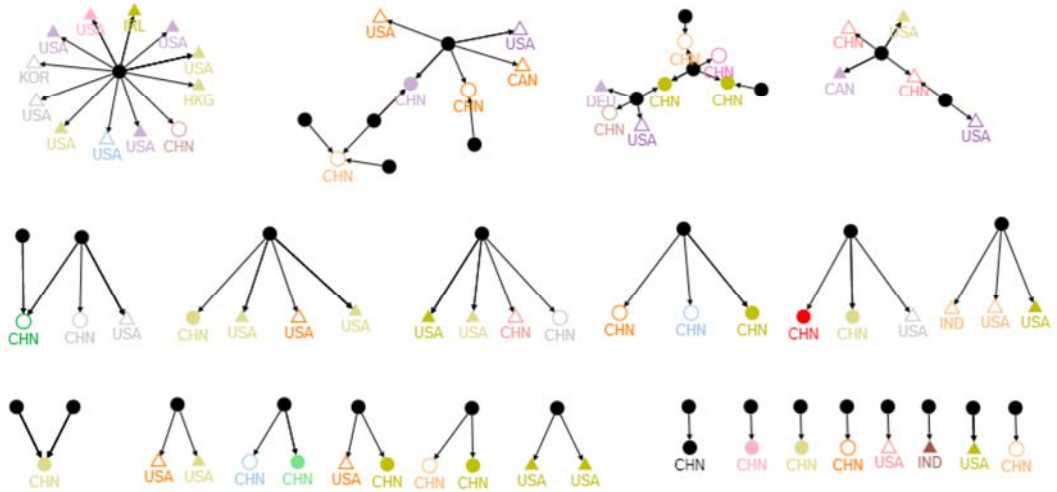

Figure 9. Home location of investment firms (black) making investments in Chinese companies (eCIS-related sector = solid fill).

(42 Chinese, and 77 foreign) in the sample (note that investment transactions may not be available for some companies and investment firms).

Figure 8 and 9 show the home country of these businesses (multi-colored) and investment firms (black).

With social networking analysis (the network analysis was conducted using the open-source NodeXL application; the code and application can be found at http://www.codeplex.com/nodexl), the unique edges (relationships) between companies and investment firms were calculated. The in-degree was computed for all companies; the out-degree was computed for all investment firms. Nodes in a graph were initially laid out by utilizing the force-directed Harel-Koren Fast Multiscale algorithm [10]. We then manually adjusted some of the layout components in attempt to better reveal the centrality and connectivity between and among companies and investment firms. Visual maps of the relationships between companies and investment firms were created to provide insights into the patterns of relationships among companies and investment firms.

Figure 7. Network Legend.

IV. Findings: Social Network Graphs, Cluster Identification

Network analyses revealed characteristically different investment patterns by Chinese and foreign investment firms (Figure 8 and Figure 9). Network legend is as

follows (Figure 7). A new black color-coding is added for financial investment firms. Origin of entity (company or financial firm) is represented through shape; Chinese entities are circles, foreign entities are triangles. Each entity is labeled with the country in which the home office is located; for some Chinese entities label is omitted to avoid clutter. Solid shapes indicate a company in the eCIS-related sectors. Arrows indicate directional flow of investment funds. The unique edges (relationships) are mapped to show directional links between investment firms and the companies in which they invest. The summary of graph metrics is provided in Table I.

Table I. Metrics for networks in Figure 8 (making) and Figure 9 (receiving).

Metric	*Investments*	
	making	*receiving*
Vertices	103	189
Unique Edges	**79**	**170**
Connected Components	24	26
Maximum Vertices in a Connected Component	**13**	**104**
Maximum Edges in a Connected Component	12	110
Maximum Geodesic Distance (Diameter)	**6**	**17**
Average Geodesic Distance	1	6
Maximum In-Degree	**3**	**8**
Average In-Degree	0.76699029	0.899470899
Maximum Out-Degree	**12**	**12**
Average Out-Degree	0.76699029	0.899470899
Maximum Betweenness Centrality	**132**	**5382.4**
Average Betweenness Centrality	6.40776699	349.2275132
Minimum Closeness Centrality	**0.026316**	**0.000814**
Average Closeness Centrality	0.29260078	0.203541772
Median Closeness Centrality	**0.142857**	**0.001828**
Maximum Eigenvector Centrality	0.076923	0.085388

A. Transactions of Chinese Investment Firms

Figure 8 shows the network of Chinese investment firms (black circles) and their transactions (investing in both Chinese and foreign companies). The out-degree of the investment firms ranged from 0 to 12; and the in-degree of companies ranged from 0 to 3.

With only four exceptions, a pattern of single relationships is evidenced across Chinese investment firms. Across sectors, investments by more than one Chinese investment firm into a foreign or Chinese company are the exception. Two nascent clusters show one Chinese company funded by two Chinese investment firms, at least one of which has made investments in a foreign company. The other two clusters, one with four Chinese investment firms and one with five Chinese investment firms show nascent cluster profiles, with at least one node having a betweenness centrality score of greater than 66. Overall this network is very fragmented (with 24 disjoint components), and is sparsely connected (average betweenness centrality of 6.4; even the most connected component has only 12 edges for 13 vertices).

B. Funding of Chinese Companies

In contrast, Figure 9 shows the network of Chinese companies receiving Chinese and foreign investments. The number of vertices and edges is roughly twice as big as in Figure 9. The number of disjoint component is 26, which is almost the same. Also very similar are the out-degree of the Chinese investment firms ranging from 0 to 4; and the out-degree of the foreign investment firms ranged from 0 to 12; and the in-degree of the Chinese companies ranged from 0 to 8.4

What makes this network very different, is a very large connected component (110 edges, 104 vertices), that dwarfs the largest component of Figure 9 with a number of vertices and edges smaller by approximately factor of 10. In the next section we will examine components in more details (a description of methods for network analysis and its concepts can be found in [7]).

C. Cluster Identification

Five interlinked clusters and two isolated clusters can be identified. An examination of the sectors of the companies and of home locations of the investment firms tells a story of virtual clusters and emerging globalization in innovation ecosystems. One large cluster, several small clusters, and many single relationships are revealed in this analysis, as shown in Figure 10.

Roughly half of the Chinese companies receiving investments from Chinese investment firms have investment from only one investment firm; and the other half receives investments from more than one investment firm. Among these Chinese companies with more than one investment source, the majority receives funds from an investment firm in a non-Chinese country.

The single edge relationships, shown by one company and one investment firm and located in the top right of Figure 9, may reflect a strongly utilitarian outsourcing relationship in a predictable business value chain. The single edge relationships may also reflect an experimental stance toward investments in a Chinese company by foreign investment firms – testing their capability in the relationship, learning the culture. Simple clusters in the lower right of Figure 9 suggest a receptivity to globalization strategies, as Chinese companies receive investments from multiple financial firms coming from multiple countries. Companies in the network hosting, software, web, and mobile sectors are well-represented among Chinese companies receiving foreign investment.

Two embryonic clusters are shown (Figure 10). In the cluster labeled “hardware and bio/cleantech”, one hardware, one biotech and one cleantech company are linked through two Chinese investment firms. In the cluster labeled “eCommerce, advertising, entertainment”, a Chinese eCommerce company and a Chinese software company are linked to foreign game and advertisement companies through a combination of foreign and Chinese investment firms.

A network of investment relationships is evidenced in five other interconnected clusters, showing foreign investment firms and Chinese investment firms investing in many of the same companies, and thereby offering potential for an ecosystem to develop. Several companies and several investment firms have high betweenness in the network, serving as the single link between groups of companies and investors.

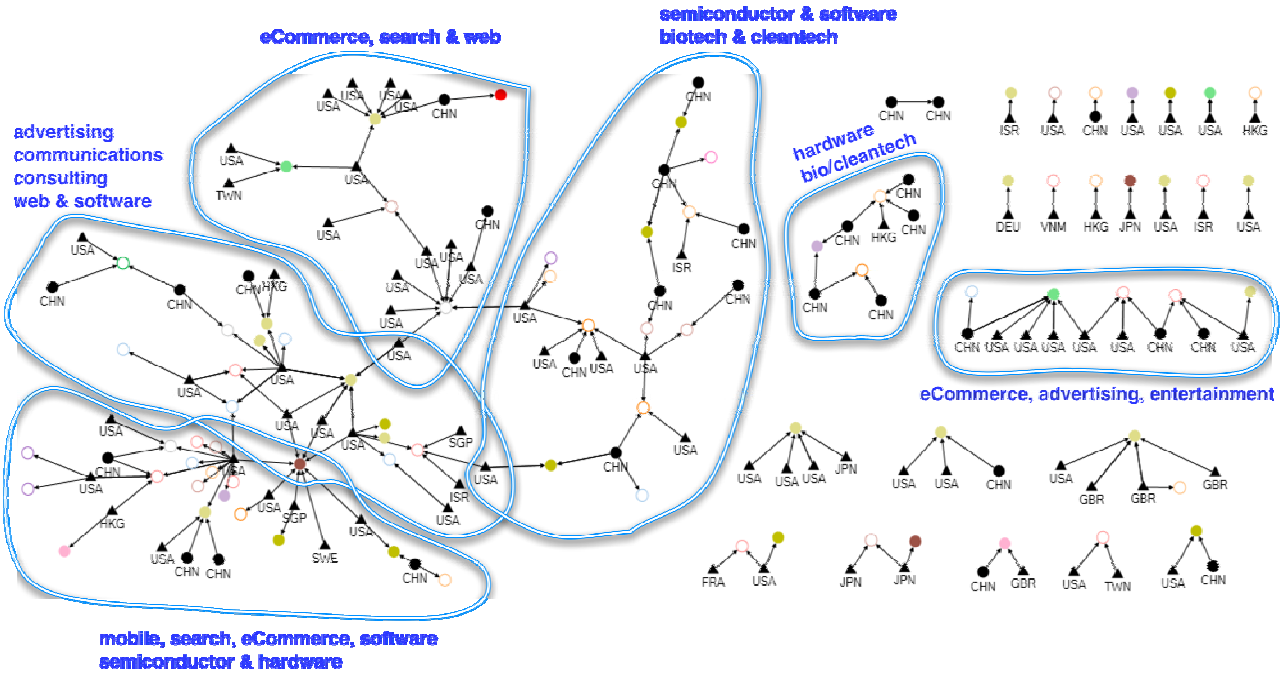

Figure 10. Emerging Chinese business clusters linked by investment firms as resource routers.

In the cluster labeled "semiconductor & software, biotech & cleantech" a single software firm is central as a link between a simple cluster of Chinese-funded semiconductor and cleantech companies and between several software and cleantech companies that are funded by both foreign and Chinese investment firms.

In the cluster labeled "eCommerce, search & web," Chinese companies focused on eCommerce, web and enterprise technology are linked to software and search companies through foreign investment firms.

Through a series of investment relationships made by foreign investment firms into Chinese companies the cluster labeled "eCommerce, search and web" includes a Chinese eCommerce company, a Chinese web company and a Chinese enterprise technology company. Through their investment relationships, the foreign investment firms may play a strategic role in knowledge and information flows across the companies linked in this cluster.

In a similar manner, foreign investment firms have relationships to several Chinese and foreign firms in the cluster labeled "advertising, communications, consulting, web & software." And in the cluster labeled "mobile, search, eCommerce, software, semiconductor & hardware" the centrality and the potential connectivity among a Chinese network hosting company, a Chinese software company and a foreign investment firm can be seen. The centrality of the brown circle (a network hosting company) at the interface of the "mobile, search, eCommerce, software, semiconductor & hardware" cluster and the "advertising, communications, consulting, web & software" cluster indicates a strategically important location in this innovation ecosystem.

The network patterns of investment into and out of China show another interesting difference. Chinese investments in companies elsewhere in the world show a strongly directed pattern. For the most part, these relationships are characterized by single connections, point-to-point. Some Chinese investments firms invest in more than one global company, but we see no global companies receiving investments from more than one Chinese investment firm or multiple Chinese investment companies making investments into the same global companies. On the other hand, global investments coming into Chinese companies show a variety of network patterns. There are some point-to-point connections, but there are also networks of 3 or more entities – some line networks, and - importantly - some mesh networks.

A caveat is warranted here. The data portrayed in these network analyses are drawn from a sample that is built from information openly available online and in English. Results are intended to be illustrative rather than descriptive or prescriptive.

V. Discussion: Resource Flows, Virtual Clusters, Open Innovation

Knowledge is regarded as the number one resource in today's knowledge-intensive economy [6]. Some scholars view the creation of knowledge as a linear process of data-information-knowledge [2] though most scholars and practitioners in the field of knowledge management consider that an over simplification of the complexities related to creating and managing knowledge. It is in the processes by which knowledge acquires meaning and context that value is accumulated [21]. The context of time and the processes of knowledge transfer contributed by investors offer both a catalyst and a filter for this – in addition to the financial resources they provide. As routers of resources, investment firms contribute to value co-creation and provide access to markets, knowledge and many other types of resources.

Economists have for decades supported the premise that national economic success depends, at least in part, on the development of concentrations of industrial specialization [12], [15]. Historically, these concentrations were envisioned as local concentrations. The advantage of the local/regional approach to global innovation has been heralded: ". . . paradoxically, regions offer an important source of competitive advantage even as production and markets become increasingly global" [20]. The concept of the virtual laboratory [18] introduced the possibility that with internet connectivity, co-location was not required for collaboration.

National policies play an important role in an innovation ecosystem by virtue of their diverse set of "key actors . . . in a system shaped by a set of distinct institutions which jointly and individually contribute to the development and diffusion of new technologies and which provide a framework within which governments form and implement policies to influence the innovation process [13] as well as significant financial commitment and policy support toward both direct and indirect interventions. These interventions, sometimes implemented through business clusters or science and technology parks, seek to create vibrant ecosystems through which local resources can be invested for participation in the global economy with the expectation of returns back to the area that provided the initial resources [19]. [24] have described the industrial cluster as a collection of internal, external and quasi-external innovation networks that are interdependent on what [26] refers to the "broad system": all parts and aspects of the economic structure and the institutional set-up affecting learning, as well as searching and exploring – the production system, the marketing system, and the system of finance. In these and other analyses, innovations are seen to be a result of the interaction among a number of mutually influencing actors and factors, which is why in this study the term "innovation ecosystem" is used to refer to systems of innovations : Central to these concepts is the flow of knowledge across the actors, where ever they are located.

Developed in the decades before the arrival of the information/knowledge age, these cluster concepts provide a historical basis on which new concepts of innovation ecosystems can be constructed. [4] introduced the concept of open innovation, in which he states "open innovation is the use of purposive inflows and outflows of knowledge to accelerate internal innovation, and expand the markets for external use of innovation, respectively" . A related concept, creation nets, represents a particularly powerful form of open innovation designed to harness the potential of distributed innovation activity pursued by hundreds or thousands of participants. These nets have been characterized as mechanisms with (a) goal-focused creation of new goods and services tailored to rapidly evolving market needs, (b) with multiple institutions and dispersed individuals, (c) for parallel innovation.

Much of China's economic success and the success of its innovation system have been attributed to multinational companies and their investments in China. In May 2010, China stated that its policy of actively attracting foreign investment will not change (China Daily May 8, 2010). At the same time, China wants to become more self-supporting. Two of the goals of China's medium to long-term S&T Strategic Plan 2006-2020 are (1) to build an innovation-based economy by fostering indigenous innovation, and (2) to foster an enterprise-centered technology innovation system [3].

According to a 2009 study, companies in China are more actively looking for sources of innovation knowledge outside of China (globally) than locally [11]. However, the number of patents in China is on the rise; statistics show that China approved 582,000 of 977,000 domestic patent applications in 2009, up 41.2% year-onyear. They also show that for the first time, Chinese companies and individuals made up over half of all domestically approved invention patents (China Daily April 30, 2010).

Foreign direct investment (FDI) to China was reported to have increased 7.7 percent year on year to $23.44 billion in the first quarter (China Daily, May 8, 2010). In 2008, the top sources of FDI in China in 2008 were: Honk Kong, the British Virgin Islands, Singapore, Japan, the Cayman Islands, South Korea, the United States, Western Samoa, and Taiwan . Interestingly, some of this FDI is Chinese in origin, however routed through other locations in order to get certain benefits (2009 Investment Climate Statement, US Bureau of Economic, Energy and Business Affairs).

Chinese outbound direct investment (ODI) has increased significantly since the PRC government introduced the "go abroad" policy. In March 2010, it was reported that Chinese companies overseas direct investment saw an annual increase of 60 percent . It has been said that China's investments are spread unevenly around the world, with Asia, and especially Honk Kong, receiving the largest share; and it has been speculated that total outbound direct investment (ODI) for 2009 would be similar to $52.2 billion in 2008 [16].

The concept of open innovation recognizes that innovation takes place among individuals, as well as within and among companies. The utility of those relationships for catalyzing innovation networks includes design, research, development, production, distribution and marketing. Although open innovation continues to be challenged and its definitions (both in theory and practice) are not consistent , its general concepts contribute to the framework for this study, in which we have analyzed networks of organizations as indicators of resource flows in innovation ecosystems. These networks enable the co-creation of new processes and the novel aggregation of resources.

The companies and the investment firms in the networks revealed in this analysis are global; their emerging networks are global. The edges that link the nodes in these networks reveal the potential flow of knowledge across the nodes in the network. Regarding innovation, these flows of knowledge are the life blood and the oxygen of a dynamic and thriving ecosystem.

The differing patterns of global investments and Chinese investments revealed in this study have important ramifications regarding the flows of knowledge in innovation ecosystems. The mesh network patterns of global investments into Chinese companies may indicate investment strategies that include uncertainty and ambiguity, a desire to tap potential opportunity and spread the risk for that across multiple investments – a cultivation approach. On the other hand, the direct and single links from Chinese investment firms to global companies suggests a strategy of unambiguous intentionality – a harvest approach.

Further analysis of the investment firms, companies and technologies in this data could provide additional insight and explanations for these different investment patterns and the flows of knowledge that they suggest. Investment portfolios and the knowledge flows they enable may be driven by many factors – size of investments, stage of investment, pre-existing portfolio holdings, national incentives for investments with particular characteristics. The data used in this study can support that inquiry.

The limitations of this study include the nascent social media culture of China, in which open information exchange is in its early stages, and the limitations of data collection from English language sources. The sample drawn from the Innovation Ecosystems Dataset is not considered representative of all Chinese technology-based companies nor of all Chinese investment firms. Rather the companies included in this sample reflect a segment of those, specifically, a segment that is sufficiently oriented to global relationships that they contributed information (in English) about their company to the openly available online data sources – press releases, company listings, and other sources captured by the Innovation Ecosystems Dataset. The authors acknowledge that there are many Chinese technology-based companies and investment firms that are not included in the IE Dataset and, therefore, excluded from this analysis.

The critical value of this study lies in its first demonstration of the use of socially constructed data as a data source for a network analysis of international business relationships. Further, it is the first use of network analysis to analyze flows of financial resources into and out of China, using socially constructed data about those investments. The role of investment firms as nodes through which information and financial resources flow across businesses, sectors and countries is illustrated with data-driven visualizations. Further, the visible impact of government, business and academic initiatives – in China and in other countries – requires time series analyses, and we encourage scholars and practitioners who study innovation ecosystems to repeat studies at regular intervals.

VI. Recommendations: Validate And Augment Data, Track Over Time

The authors encourage further exploration of business relationships in innovation ecosystems using socially constructed data, as well as using social network analysis. Recommendations for next steps in this include the important step of validating the data about Chinese companies and investment firms in the IE Dataset with data available from Chinese sources – both official registries, as well as new sources of socially constructed data. Additional opportunities to further pursue questions of business and organizational structures in the fields of eCommerce and Internet security include the augmentation or federation of Chinese data sources with the Innovation Ecosystems Dataset.

In summary, this study has introduced the use of social network analysis on socially constructed data describing Chinese and foreign technology-based companies and their Chinese and foreign investment firms. It has described patterns of isolated relationships, emerging clusters and innovation ecosystem in the network analysis of these firms. The implications of these patterns on the innovation ecosystem of the ecommerce and internet security sectors of China and its partners are explored in a preliminary manner. Recommendations for further study of innovation ecosystems using data-driven visualizations were provided.

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