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Measuring social capital through network analysis and its influence on individual performance

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A B S T R A C T

Studies of social networks highlight the importance of network structure or structural properties of a given network and its impact on performance outcome. One of the important properties of this network structure is referred to as social capital, which is the network of contacts and the associated values attached to these networks of contacts. This study provides empirical evidence of the influence of social capital and performance within the context of academic collaboration (coauthorship) and suggests that the collaborative process involves social capital embedded within relationships and network structures among direct coauthors. Association between scholars' social capital and their citation-based performance measures is examined. To overcome the limitations of traditional social network metrics for measuring the influence of scholars' social capital within coauthorship networks, the traditional social network metrics is extended by proposing two new measures, of which one is non-weighted (the power–diversity index) and the other (power–tie–diversity index) is weighted by the number of collaboration instances. The Spearman's correlation rank test is used to examine the association between scholars' social capital measures and their citation-based performance. Results suggest that research performance of authors is positively correlated with their social capital measures. The power–diversity index and power–tie–diversity index serve as indicators of power and influence of an individual's ability to control communication and information.

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1. Introduction

Notable sociologists such as Burt (1992), Coleman (1988), and Granovetter (1973) claim that individuals' personal characteristics are not their only success factors; rather it is the extent of social capital accrued in their respective personal networks that is more influential (Oh, Choi, & Kim, 2006). The core idea of social capital is that a person's, or a group of people's, associates (e.g., family members, friends, colleagues) form an important asset that can be used to gain optimal performance (Woolcock & Narayan, 2000). Social capital produces benefits or outcomes for individuals and collective actors which drive from their social structure (Burt, 1992).

The concept of social capital provides a useful and comprehensive conceptual perspective (Sawyer, Crowston, & Wigand, 1999; Tsai & Ghoshal, 1998) for understanding the benefits and outcomes of individual and collective action, as well as value creation within a networking context. Accordingly, social capital has been defined as "the set of social resources embedded in relationships" (Tsai & Ghoshal, 1998, p. 464).

Social capital has three components: structural, relational, and cognitive (Tsai & Ghoshal, 1998; Wellman, 1988). The structural dimension involves social interaction that the actor uses to gain access, information, or resources. The relational dimension encompasses aspects that arise from interactions, including trust and loyalty. The cognitive dimension includes attributes such as shared norms, codes of action, and convergence of views. In this line of research, studies have anticipated "the creation of value" owing to the existence of social relationships (Arregle, Hitt, Sirmon, & Very, 2007).

Research suggests that conceptualizing social capital in terms of network structures, as articulated by the strength of weak ties theory (Granovetter, 1973, 1983), provides valuable insight into scholars' coauthorship activities. In most large organizations performance of individuals and teams is measured through a set of metrics that pertain to task and contextual performance. Similarly, in academia, scholars and scientists are evaluated on their academic performance (e.g., research productivity, teaching evaluations, governance capabilities, funded research grants). Such evaluation of scholars is necessary, not only for faculty recruitment and promotion schemes, but also for industry and government funding allocation, as well as for achieving a high reputation within the research community (Abbasi & Jaafari, 2013).

Collaboration is essential in the enhancement of knowledge and experience of graduate students and post-doctoral researchers (Bozeman & Corley, 2004) and also leads to improved productivity of scholars (Melin, 2000). On a global level, with respect to governmental funding (i.e., the allocation of funding for a specific project to a scientific research group) and university strategy, it is important to identify key scholars,

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collaboration areas, and research strengths within universities, with the aim of maximizing research output, cost optimization, and resource utilization.

A researcher's time, abilities, skills, and resources are understood to be restricted. Therefore, to conduct most large research projects, collaboration is required and, in turn, often leads to large-scale scientific collaboration. Bringing together scholars with different skills, expertise, and knowledge as human capital, in group work is, thus, essential (McFadyen, Semadeni, & Cannella, 2009). Diversity of actors involved in group work then facilitates the integration of expertise, contributes to successful projects' implementation, and accelerates cycle time for new product development (Cummings, 2004; Eisenhardt & Tabrizi, 1995; Griffin & Hauser, 1992; Pinto, Pinto, & Prescott, 1993). However, in such group work, a basic and shared understanding of each participant's knowledge and expertise is crucial to the overall understanding of the project, or research, as a whole.

A coauthorship network represents a form of collaboration among scholars that includes scientific interactions and collective action to conduct research, producing results in the form of a publication. Therefore, social norms and trust build among scholars, over time, through collaborations and constitute a form of social capital for academia. In other words, when researchers collaborate on projects they share substantial amounts of knowledge. This flow of knowledge becomes a stock of knowledge that mutually benefits the researchers (Dierickx & Cool, 1989). Therefore, social capital resulting in collaboration networks can be used to explain the concept of knowledge capital (Oh et al., 2006).

The motivating questions for this study were as follows: (a) How does one measure the concept of social capital of scholars? (b) Do scholars' social capital metrics associate with their performance?

2. Problem statement

The number of collaborations is the simplest proxy for quantifying the collaborative activities of scholars. Other studies have used concepts such as proximity (e.g., Frenken, Hardeman, & Hoekman, 2009; Havemann, Heinz, & Kretschmer, 2006; Ponds, van Oort, & Frenken, 2007) and diversity (e.g., Abbasi & Jaafari, 2013) to conceptualize the frequency of relationships among authors and institutions. By considering only the direct partners, such approaches reflect only the local position of the scholars in their respective collaboration network. In order to overcome this simplicity, i.e., considering only the number of partners, the RC-index (Abbasi, Altmann, & Hwang, 2010) is proposed as a bibliometric measure of scholars' collaborative activity that takes into account the performance of collaborators in combination with their frequency.

To quantify and highlight the importance of global position and role of the scholars in their collaboration network, studies (e.g., Abbasi, Chung, & Hossain, 2012; Yan & Ding, 2009; Zhuge & Zhang, 2010) have used traditional centrality measures and also proposed new hybrid centrality measures (Abbasi, 2013). These studies have shown the applicability of social network measures for coauthorship networks to indicate how centrality measures (as a proxy for scholars' collaboration activity) are useful for reflecting scholars' performance based on their position and influence within their collaboration network. But most of those studies are lacking a proper theoretical justification for the network measures used to evaluate scholars' collaborative activity. To fill that gap, the current study considers the social capital theory to conceptualize scholars' collaborative activity, emphasizing the importance of coauthors' roles and positions in their collaboration network, and proposes new collaborative measures.

3. Literature review

3.1. Social capital and network theories

The concept of social capital has become increasingly popular in a wide range of social science disciplines (e.g., political science, economics, and organization science). Social capital has been used by social scientists as an important factor in explaining success in a number of areas (e.g., educational performance, career success, product innovation, inter-firm learning, and real-estate sales). Hanifan's (1916) work on evaluating effects of community participation in enhancing school performance can be considered the first study on social capital. But Bourdieu's (1986, 1992) and Coleman's (1987, 1988, 1990) work on education, as well as Putnam's (1993, 1995, 2001) work on civic engagement and institutional performance, are the main studies inspiring most of the current research in social capital (Woolcock & Narayan, 2000).

Bourdieu (1986) identified several forms of capital: *economic capital*, "which is immediately and directly convertible into money and may be institutionalized in the forms of property rights" (p. 47); *cultural capital*, which could be embodied (in persons), objectified (e.g., in art), or institutionalized (e.g., university degrees); *social capital*, or resources grounded in durable exchange-based networks of persons; and *symbolic capital*, or the manifestation of each of the other forms of capital when they are naturalized on their own terms. Bourdieu and Wacquant (1992) defined social capital in detail as "the sum of the resources, actual or virtual, that accrue to an individual or group by virtue of possessing a durable network of more or less institutionalized relationships of mutual acquaintance and recognition" (p. 119).

Coleman (1988), who was interested in the role of social capital in human capital creation and educational outcome (Narayan & Cassidy, 2001), defined social capital as a function of social structure producing advantage:

> It is not a single entity but a variety of different entities, with two elements in common: they all consist of some aspect of social structures, and they facilitate certain actions of actors—whether persons or corporate actors—within the structure. (p. S98)

Putnam (1993) defined social capital as "those features of social organization, such as trust, norms and networks that can improve the efficiency of society by facilitating coordinated actions" (p. 167) or as "features of social life—networks, norms and trust—that enable participants to act together more effectively to pursue shared objectives" (Putnam, 1995, pp. 664–665).

Coleman's (1988) definition regards social capital as one of the potential resources that an actor can use besides other resources such as human or cultural capital (their own skills and expertise), physical capital (tools), or economic capital (money) (Gauntlett, 2011). He also highlighted the importance of social capital as effecting the creation of human capital. But social capital differs fundamentally from other types of capital, as it resides not in the objects themselves (i.e., people) but in their relations with other objects. For instance, human capital represents individual attributes and characteristics (e.g., attractiveness, intelligence, and skills). These assets are possessed by individuals, yet social capital is additionally embedded in the relationships among individuals (Shen, 2010).

Emphasizing social capital's function in different contexts, Portes (1998) defined social capital as "the ability of actors to secure benefits by virtue of memberships in social networks or other social structures" (p. 3). Adler and Kwon (2002) focused on social capital as a resource that exists essentially (permanently) in the social network binding a central actor to other actors: "the resources available to actors as a function of their location in the structure of their social relations" (p. 18).

In another approach, Lin's (1982) social resource theory named power, status, and wealth as determinants of *valued resources* in most societies. Accessing and using social resources can lead to better socioeconomic status and is determined by structural positions and use of ties. Some researchers defined social capital by considering capital (attributes) individuals possess in a network. For instance, Boxman, De Graaf, and Flap (1991) described social capital as "the number of people who can be expected to provide support and the resources

those people have at their disposal" (p. 52) while Burt (1992) defined this concept as "friends, colleagues, and more general contacts through whom you receive opportunities to use your financial and human capital" (p. 9) and also "the advantage created by a person's location in a structure of relationships" (p. 5). Therefore, from this point of view, social capital can be evaluated by the amount or variety of such characteristics of other actors to whom an actor has ties directly or indirectly (Lin, 1999). The core idea is that the actions of individuals (and groups) can be greatly facilitated by their direct and indirect links to other actors in their respective social networks (Adler & Kwon, 2002).

In the above definitions, the focus is on the sources (e.g., networks, norms, and trust) rather than the consequences of social capital. Some consider different dimensions for social capital, namely bonding and bridging (Woolcock & Narayan, 2000), taking into account valued social resources. In the bonding views of social capital, the focus is on collective actors' internal characteristics and ties structure (Adler & Kwon, 2002). Therefore, the bonding view of social capital undergirds reciprocity and solidarity, builds trust within the group, and provides substantive and emotional support (Shen, 2010). Bonding social capital is viewed as a property of a network, or group of individuals, which, however, is not the focus of this study.

3.2. Individual's social capital-related theories of network

3.2.1. Tie strength theories

Granovetter's (1973) theory of the 'strength of weak ties' argues that an individual obtains new and novel information from weak ties rather than from strong ties within that individual's group structure. Examining people looking for a job, Granovetter (1973) found, contrary to popular belief, that the most successful job seekers were not those with the strongest ties, as weak ties with acquaintances provided a broader set of information and opportunities than strong ties with family and friends.

The strength of a link (or an interpersonal tie)between actors in a network could be indicated and measured by the amount of time the link has been established, the degree of emotional intensity, the degree of intimacy, and reciprocal services (Granovetter, 1973). The interaction among the individuals creates opportunity for knowledge sharing and information exchange and is considered crucial in the building of trust among individuals.

On the other hand, Krackhardt (1992) showed that strong ties are important in the generation of trust. He introduced the theory of strength of strong ties in contrast to Granovetter's (1973) theory. Levin and Cross (2004) found that strong ties, more so than weak ties, lead to the receipt of useful knowledge for improving performance in knowledge-intensive work areas. However, controlled for the dimension of trust, the structural benefit of weak ties emerged in their research model. It suggests that weak ties provide access to non-redundant information and, thus, if the project is simple, facilitate faster project completion times. It enables faster search for useful knowledge among other organizational subunits. Strong ties foster complex knowledge transfer if knowledge is highly complex (Hansen, 1999; Reagans & Zuckerman, 2001).

3.2.2. Structural holes theory

Burt (1992) argued that the structural configuration of an individual's social network, which provides optimized "bridging" or "brokerage" position, is what dictates structural advantages such as information novelty and control. The basis for this argument rests on the statement that maximizing the number of ties (ego-network size), regardless of being weak or strong, in an individual's network does not necessarily provide benefits. Furthermore, as an individual's personal network grows over time, the extent of information coming from closely-knit clusters tends to become redundant.

This is consistent with Freeman's (1979) approach to betweenness which is built around the concept of "local dependency". It could be said that Burt's (1992) notion of structural holes built upon the assumption of betweenness centrality that advocated the idea of a brokerage position as providing information and control benefits.

Burt (1992) claimed that increasing the number of direct contacts (ego-network size) without considering the diversity reached by the contacts makes the network inefficient in many ways. Therefore, the number of non-redundant contacts is important to the extent that redundant contacts would lead to the same people and, hence, provide the same information and control benefits. He defined ego-network effectiveness as the number of clusters to which the ego is connected and can obtain novel information and benefits (Burt, 1992).

A structural hole (or hole in the network structure) is defined as lack of tie between any pair of actors in the network. Network brokerage refers to the social structure where an actor builds connections across structural holes (Burt, 2005), linking otherwise disconnected actors. Brokerage brings novel information and opportunities, but the connections are too weak to provide emotional and substantive support. For instance, in economic networks, producers brokering more structural holes were found to make better profits from negotiating more favorable transactions with suppliers and customers (Burt, 1992). Within organizations, individuals' mobility is enhanced by having an informational network rich in structural holes (Podolny & Baron, 1997).

Thus, Burt (1992) capitalized on his theory of structural holes by focusing on the importance of structural position (e.g., brokerage) rather than structural properties (e.g., ego's network size). This view of social capital as bridging can help explain the differential success of actors (e.g., individuals and firms). Bridging social capital leads to a broad worldview, diversity in opinions and resources, and information diffusion (Shen, 2010) which focuses on a property of individuals (ego-network) and not whole-network.

These views highlight social network engagement as a prerequisite for social capital. Walker, Kogut, and Shan (1997) suggested that "a social network structure is a vehicle for inducing cooperation through the development of social capital" (p. 110). Therefore, in brief, social capital could be regarded as the value of social networks, bonding similar people and bridging between diverse people, with norms of reciprocity (Uslaner, 2001).

3.3. Measuring individuals' social capital

Measuring social capital is required in order to use it as a development tool. Although multi-dimensionality (i.e., different levels and units of study) and dynamicity of social capital (due to changes of social interaction) over time make obtaining a single, true measure almost impossible (Woolcock & Narayan, 2000), several researchers have proposed different metrics.

Bourdieu's (1986) tool to quantify social capital is network size:

> The volume of the social capital possessed by a given agent thus depends on the size of the network of connections he/she can effectively mobilize and on the volume of the capital (economic, cultural or symbolic) possessed in his/her own right by each of those to whom he/she is connected. (p. 249)

It should be said that although greater network size is desirable, the quality of the individuals, in terms of power or performance, is crucial for social capital.

As previously noted, social capital's root in social networks and social relations could interfere in its measurement; thus it must be also measured relative to each of those (Lin, 1999). Therefore, network science and social network analysis metrics could be used for measuring social capital. In this regard, several researchers asserted the location of actors in a network, such as tie strengths (Granovetter, 1973; Portes, 1998) and structural holes and constraints (Burt, 1992), as the key elements of identifying social capital.

As social network's engagement is the principal for social capital, social network analysis metrics are also used (supporting the dimensions

discussed in the literature review) to measure social capital of scholars in their coauthorship network. Social network analysis is the mapping and measuring of relationships and flows between nodes of a social network. It provides both a visual and a mathematical analysis of human-influenced relationships. The social environment can be expressed as patterns or regularities in relationships among interacting units (Wasserman & Faust, 1994) (Table 1).

To measure social capital, several indicators are used. Diversity of contacts (ego's network size) (Bourdieu, 1986), representing the available resources for an individual, has been considered in the literature as one of the important factors on information diffusion and novelty. Another important factor emphasized in the literature is tie strengths (Granovetter, 1973; Krackhardt, 1992). In addition, ego-betweenness centrality (Freeman, 1979) and effectiveness (Burt, 1992) are used in order to measure, respectively, the structural position and brokerage characteristics of an individual in the network.

In order to synthesize the two different approaches of social capital, i.e., diversity, and power, as determinants of valued resources (Lin, 1982), an actor's social capital can be defined as the frequency and diversity of the powerful partners directly connected to him or her. Having the power (or value) of actors in a social network helps to measure their social capital. A new measure, the power–diversity index (PDI), is proposed here to take into consideration the added value of direct contacts in addition to their quantity. Furthermore, proposing another measure, the power–tie–diversity index (PTDI), adds the tie strength factor to the PDI. These measures are explained in detail below. These two new proposed measures reflect the thinking that connecting to more powerful individuals will, in turn, give individuals also more power. Accordingly then, this reflects individuals' power and influence on transmitting and controlling information as well as the popularity of an individual based on popularity of direct contacts.

4. Data and measures

4.1. Data

Scopus is one of the main sources presenting bibliometric data. To construct a database for this study, publications were extracted using the phrase "information science" in their titles, keywords, or abstracts and restricting the search to publications in English published between 2001 and 2010. Indeed, the publications extracted cannot be considered as representing the world production in the information science field, but the dataset illustrates a good portion of publications in this field not limited to only a specific sub-field, conference, journal, institutes, or country.

After extracting the publication metadata from Scopus, an application program (described in Abbasi & Altmann, 2011) was used for extracting relationships (e.g., coauthorships) between and among researchers, and the data were stored in tables in a local relational database. Four types of information were extracted from each publication's metadata: (a) publication information (i.e., title, publication date, journal name, etc.); (b) authors' names; (c) affiliations of authors (including country, institute, and department name, etc.); and (d) keywords.

Exploring the original extracted data, affiliation information was found to be inconsistent, as for some publications there were several fields missing and there were variations of written names for countries of origin and institutions. Manual checks were undertaken to fill the missing fields using other existing fields (e.g., institute names were used to identify countries). Also, universities and departments with variant names (e.g., misspellings or abbreviations) in the original extractions were manually merged. Finally, after the cleansing of the publication data, the resulting database contained 4579 publications published in 1392 journals and conference proceedings reflecting the contributions of 10,255 authors from 99 countries.

Table 1
Social capital dimensions and relevant proposed metrics as assets in networks.

Indicators	Focus	Authors
Ego network size	Diversity of contacts	Bourdieu, 1986 and Boxman et al., 1991
Ego average tie strengths	Tie strengths	Granovetter, 1973 and Krackhardt, 1992
Ego betweenness centrality	Structural position	Burt, 1992
Ego effectiveness	Brokerage and diversity	Burt, 1992
Contact status (power)	Embeddedness resources	Lin, 1982 and Burt, 2005

4.2. Measures

4.2.1. Measuring scholars' performance

To assess the performance of scholars, many studies suggest quantifying scholars' publication activities as a useful measure for their performance. But many researchers also point to the limits and bias of such quantification focusing on publication, mainly on the most visible articles from international databases. Further research shows that the number of citations a publication receives qualifies the quantity of publications (Lehmann, Jackson, & Lautrup, 2006). New citation-based metrics are being proposed, following Hirsch's (2005) *h*-index as the core metric for measuring the combination of quantity and quality of researchers and academic communities. Although there is considerable debate on the reliability of the *h*-index (e.g., Haque & Ginsparg, 2009), the *h*-index is still widely used worldwide among academicians. While the reliability of the measure is not the subject of this paper per se, it does provide at least an empirical and very widely used metric so as to gauge a researcher's prolificacy. Thus, the *h*-index is considered and operationalized as a citation-based surrogate measure and as a proxy for the performance of scholars.

4.2.2. Measuring scholars' social capital

To answer the first research question: "how does one measure the social capital of scholars?", the following metrics are proposed to measure individuals' social capital. Although some have been used previously, the two new measures (PDI and PTDI) combine two and three different properties of individuals in their respective social network in order to quantify their social capital.

4.2.2.1. Existing measures

4.2.2.1.1. Individual network size (degree centrality). In order to measure diversity of contacts representing the available resources for an individual, as one of the important factors of information diffusion and innovation, individual degree centrality, which is defined as the number of direct contacts, is used. In a coauthorship network, network size of an author is the number of that individual's coauthors. The degree centrality of a node i (i.e., p_i) is represented by:

$$D(p_i) = \sum_{j=1}^{n} l\left(p_i, p_j\right)$$

where n is the number of nodes in the network and $l(p_i, p_j)$ is a distance function: $l(p_i, p_j) = 1$, if and only if node p_i and node p_j are connected, $l(p_i, p_j) = 0$ otherwise.

4.2.2.1.2. Individual tie strengths (average tie strengths and weighted degree centrality). To evaluate an individual's tie strengths, the sum of tie strengths and also average tie strengths are used as proxy for social capital in order to represent the average strength of each tie of an actor. The sum of tie strengths of an author is the total number of collaborations he or she has (including redundant collaborations with any coauthor). The sum of tie strength (weighted degree centrality) of node i (i.e., p_i) is given by:

$$WD(p_i) = \sum_{j=1}^{n} wl\left(p_i, p_j\right)$$

where n is the number of nodes in the network and $wl(p_i, p_j)$ shows the frequency of connections (in our analysis coauthorships).

Average tie strengths are simply the average of the weights of collaborations. This means dividing the sum of tie strengths (i.e., the number of collaborations) by the network size of the author (i.e., the number of different coauthors). Thus, simply the equation is as follows:

$$ATS(p_i) = \frac{WD(p_i)}{D(p_i)}$$

4.2.2.1.3. Individual effectiveness. In order to optimize an individual's network by capitalizing on structural holes, Burt (1992) claimed that increasing the number of direct contacts (network size) without considering the diversity reached by the contacts makes the network inefficient in many ways. Therefore, the number of non-redundant contacts is important to the extent that redundant contacts would lead to the same people and hence provide the same information benefits. The term *effectiveness* is used to denote the average number of people reached per primary contact in networks. Burt (1992) used *effective size* as a term to denote the same.

In conclusion, effectiveness of an individual is defined as the number of non-redundant (not connected) contacts. Precisely, it is the number of contacts that an individual has, minus the average number of ties that each contact has to other contacts of individuals. Assume that node A has links to three other nodes, and all of them are linked to each other. The links are "redundant" because node A can reach all three neighbors by reaching any one of them. So, the effectiveness of node A is 1:3 (the number of contacts) − 2 (the average degree of the neighbors).

4.2.2.1.4. Ego-betweenness centrality. Considering bridging dimension, actors' ego-betweenness centrality is used to measure social capital. Betweenness centrality is an indicator of an individual's potential control of communication within the network and highlights bridging (brokerage) behavior of an actor (Freeman, 1979). Ego-betweenness centrality is defined as the sum of an individual's proportion of times the individual lies on the shortest path between each part of alters (direct contacts to ego) (Hanneman & Riddle, 2005). For alters connected to each other, the contribution to the ego-betweenness of that pair is 0; for contacts connected to each other only through ego (individual), the contribution is 1; and for alters connected through ego and one or more other alters, the contribution is $1/k$, where k is the number of nodes that connect that pair of alters.

4.2.2.2. Proposed measures

4.2.2.2.1. PDI. In order to synthesize the two different approaches of social capital, diversity and power, the individual PDI is defined to measure social capital based on both the frequency of connections and also considering the power of contacts (directly connected individuals). Having captured the power (value) of individuals in a social network, an individual's sum or average of the power of direct contacts could be simply calculated to synthesize quantity (frequency of contacts) and quality (their value) of embedded resources (contacts) of an individual as a proxy for his or her social capital. But in order to have a more advanced and accurate metric (rather than merely the sum or average), the h-index (Hirsch, 2005) base formula is used to quantify the quality of contacts of an individual by counting top h powerful (valued) contacts whose power value is at least h.

The PDI of an individual is the largest number such that an individual's top h coauthors have each at least a power value (e.g., h-index, citation count) of h. In other words, PDI is the "h-index of coauthors' h-indices" or "h-index of coauthors' citation count". Here, the h-index of authors is considered as the ongoing indicator of their power or value and is still widely used worldwide among academicians despite the debate on its reliability (Haque & Ginsparg, 2009). But, as shown, other power measures (e.g., citation count) can be substituted. For instance, looking at Table 2 the author has 17 coauthors who have h-indices of 6, 3, 2, …, 1, …, 0. The PDI is 2 as only two of her coauthors have an h-index of equal to or higher than 2 and one cannot find three coauthors who have an h-index of equal to or higher than 3.

4.2.2.2.2. PTDI. In another effort, individuals' tie strengths are taken into consideration as another important property of individuals' social capital. This measure can be applied in weighted networks. It is similar to the individual PDI but taking the weight (strength) of ties into account. To define this new measure for an individual (in a weighted network), the first one defines coauthors' *power–strength,* which is the h-index of each coauthor multiplied by the strength of the tie between that coauthor and the author. Thus, the individual PTDI is the largest number such that his or her top h coauthors have each at least the *power–strength* of h.

To calculate the individual PTDI in a coauthorship weighted network, one first needs to calculate the power–strength (co-ps) of each of an individual's coauthors as that person's h-index times the number of collaborations (tie strength) he or she has had. Then, PTDI of an individual is the largest number such that the top h coauthors have each at least co-ps of h. For instance, Table 2 shows the coauthors' power–strength of an author, which are 9, 8, 6, 4, 4, … in descending order. Thus, the author's PTDI is 4 as for 4 of the coauthors' co-ps are equal to or higher than 4.

The PDTI value is always higher or equal to PDI since in the calculation of PTDI the tie strengths value (which is at least 1) times coauthors' power is used.

5. Analysis and results

5.1. Scholars performance and social capital measures

Every pair of authors who were listed as authors of a publication was retrieved. Repeated coauthorships were merged by increasing weight (tie strength) to their link (tie) for each relation. Thus, the coauthorship network of scholars was formed, as well as a weighted network. These relational data (i.e., who is connected to whom with which frequency) were the basis for social network analysis. These data were imported to UCINET (Borgatti, Everett, & Freeman, 2002) to calculate the social network measures. In addition, using (Abbasi & Altmann, 2011) application, the number of publications and their respective citations count for each scholar were extracted. This enabled the calculation of the citation-based performance measures (e.g., h-index and citation count) of all scholars in the information science collaboration dataset.

The second research question, "Do scholars' social capital metrics associate with their performance?", was explored by calculating both the citation-based performance measures (i.e., h-index and citation

Table 2
An individual's (M. Thelwall) coauthors and their h-index and frequency of collaborations.

	Coauthors	h-index	Frequency of collaborations	Power–Strength (co-ps)
1	CA1	3	3	9
2	CA2	2	4	8
3	CA3	6	1	6
4	CA4	2	2	4
5	CA5	2	2	4
6	CA6	2	2	4
7	CA7	2	2	4
8	CA8	2	1	2
9	CA9	1	1	1
10	CA10	1	1	1
11	CA11	1	1	1
12	CA12	1	1	1
13	CA13	1	1	1
14	CA14	1	1	1
15	CA15	1	1	1
16	CA16	0	1	0
17	CA17	0	1	0

count) and the social capital measures (i.e., network size, weighted size, average tie strength, effectiveness, ego-betweenness, PDI, and PTDI) of each scholar. To illustrate, the results for the top 10 productive scholars are shown in Table 3.

The Spearman correlation rank test was applied between the social capital measures and scholars' performance measures, and indicated high significant correlation coefficients between the two (Table 4). Results suggest that individuals' PDI has the highest coefficient with their respective performance, either considering citation count or *h*-index. This highlights the importance of the power and role of coauthors to generate social capital for an author in his or her coauthorship network, which may also lead to enhancement of performance.

It is noteworthy that while these correlations are formally statistically significant, most of these coefficients (10 out of 14) are rather low (between 0.1 and 0.3) but the PDI's and PTDI's coefficient values are approximately two times higher than the second highest measure (i.e., ego-betweenness centrality for the *h*-index and weighted degree centrality for citation count). This could be explained in that PDI and PTDI may not be independent from the two performance measures (i.e., citation count and the *h*-index). One possibility is that an *h*-index of an individual is highly correlated to *h*-indices of that person's collaborators (if they belong to a highly dense cluster having very similar coauthors which is based on similar publications) simply because they are based on "exactly the same" papers on which both the author and his or her collaborators were coauthors. But this is not always the case, especially when authors have sole-publications or for young scholars who have few collaborations with prominent authors.

As shown and expected, the coefficients for PTDI and PDI are almost equal. PTDI's slightly higher coefficient indicates that repeated collaborations with the same coauthors (even if they are prominent) do not create good social capital for them rather than having collaborations with many powerful (prominent) coauthors. The ego-betweenness centrality coefficient is higher than tie strengths and diversity measures (i.e., degree centrality, weighted degree centrality and average tie strengths). This suggests that bridging characteristics of scholars in their coauthorship network seems more important than the diversity of their coauthors and their tie strengths in regard to their performance.

Table 4
Spearman correlation rank test between scholars' centrality measures and their performance.

Scholars' social capital measures ($N = 10{,}254$)	Scholars' performance measure*	
	Citation count	*h*-index
Individual network size [degree centrality] (DC)	.219	.159
Weighted degree centrality [sum of tie strengths] (WDC)	.226	.177
Average tie strengths (ATS)	.135	.268
Individual effectiveness (IE)	.192	.292
Ego betweenness centrality (EBC)	.172	.309
Individual power–diversity index (PDI)	.446	.574
Individual power–tie–diversity index (PTDI)	.444	.573

* Correlation is significant at the .01 level (2-tailed).

6. Discussion

This study highlights the importance of the coauthorship network as a tool for evaluating scholars' performance, which is necessary in the academia. Social capital theory is used to explain how scholars' coauthorship networks affect each individual scholar's performance. Although there are several definitions for social capital, most definitions emphasize social relations that have productive benefits. Social capital is rooted in social networks and social relations and must be measured relative to each (Lin, 1999). Although multi-dimensionality and dynamicity of social capital make having a single, true measure almost impossible (Woolcock & Narayan, 2000), measuring social capital is required for its use as a development tool and several researchers have proposed different metrics.

Several measures (e.g., individual network size, tie strengths, ego-betweenness centrality, PDI, and PTDI) use network analysis metrics, which assist in quantifying social capital resulting from coauthorship through a social network. This has been considered important for research management and academic institutions, as well as for government policy makers over recent years. While several measures have been used by earlier researchers, PDI and PTDI are new and combine, respectively, two and three properties of authors in their coauthorship network, quantifying the extent of social capital gained.

The correlation of the proposed measures of authors with their research performance shows a positive significant association, although most of them (all except the new measures) had a low coefficient between 0.1 and 0.3. The results highlight the importance of scholars' social capital with respect to their performance. Significant association between scholars' PDI and performance follows, in that connecting to more powerful contacts will lead to better performance due to contacts' relative power and influence on transmitting and controlling information, as well as the popularity of an individual based on popularity of direct contacts. The PDI indicates individuals being diversely connected to prominent contacts. These kinds of actors have special strategic positions that can control the flow of information in the network.

This research conceptualized social capital in terms of network structures, articulated by the strength of weak ties theory (Granovetter, 1973, 1982), and provided valuable insight into coauthors' activities. The strength of weak ties theory suggests that the social network of any network member is the coauthor's primary resource. Moreover, this network can be viewed as being comprised of participants who vary by the relative strength of their relationship with one another. Strongly tied-together members in a network tend to be more similar to each other than different, more likely to be available for each other, share more common interests, and interact more frequently. Conversely, weakly

Table 3
Top 10 high performance scholars and their social capital measures.

	Name	*h*-index	Citation count	Network size (degree)	Weighted degree	Average tie strengths	Effectiveness	Ego-betweenness	Power–Diversity	Power–Tie–Diversity
1	M. Thelwall	9	460	17	26	1.53	16.45	245	2	4
2	H.J. Kimble	8	1125	28	40	1.43	23.68	557.3	3	4
3	Y. Wang	8	328	30	35	1.17	19.56	376	2	3
4	E.R. Dougherty	7	606	16	21	1.31	13.88	186	2	4
5	B. Cronin	6	164	4	6	1.50	4.33	12	1	2
6	C. Oppenheim	6	153	20	26	1.30	19.19	352	2	4
7	L.I. Meho	5	282	6	8	1.33	5.67	24	1	1
8	H.D. White	5	169	2	2	1.00	1.00	0	1	1
9	J.C. Principe	5	120	13	14	1.08	10.79	114	1	1
10	Y.B. Jun	5	89	6	6	1.00	5.33	26	1	1

tied members in a social network tend to communicate less frequently, are more different than similar, and provide both newer information into the network and more access to other social networks (Sawyer et al., 1999). When applied to the coauthor network, this suggests that coauthors with large social networks populated with more weak ties will have more social capital. The more resource-rich coauthors will get influential linkages and connections (via acquaintances) and be able to point to more influential coauthors who might be able to provide value-adding services.

Collecting network data has its own limitations and unfortunately this study is not an exception. Using keywords to search for scholars in a particular domain is not necessarily reflective of all people or all of the publications of the authors, but this method was used to cover more scholars active in information science. Name disambiguation (different names of authors or institutes in the affiliations) and apparent repetitive names (authors with similar names) are, unfortunately, inevitable in this kind of data collection.

7. Conclusion

The findings show that the PDI is a useful surrogate of the importance of a scholar in his or her coauthorship network by considering the diversity of contacts and also their value and power (performance). The PDI identifies individuals having direct connections to diverse powerful individuals. The PTDI identifies individuals having direct strong connections to diverse powerful individuals. These measures are indicators of the power and influence of an individual's ability to control communication and information.

Applying these new measures for other social networks to test their association with individuals' performance could be a useful extension of standard centrality measures and a suitable proxy for the performance of individuals in a network. In order to accomplish this, validation of these new measures is needed by testing it in other social networks.

References

Abbasi, A. (2013). h-Type hybrid centrality measures for weighted networks. *Scientometrics*, *96*(2), 633–640.

Abbasi, A., & Altmann, J. (2011). A social network system for analyzing publication activities of researchers. In T. J. Bastiaens, U. Baumol, & B. J. Kramer (Eds.), *On collective intelligence* (pp. 49–61). Berlin, Germany: Springer-Verlag.

Abbasi, A., Altmann, J., & Hwang, J. (2010). Evaluating scholars based on their academic collaboration activities: Two indices, the RC-index and the CC-index, for quantifying collaboration activities of researchers and scientific communities. *Scientometrics*, *83*(1), 1–13.

Abbasi, A., Chung, K. S. K., & Hossain, L. (2012). Egocentric analysis of co-authorship network structure, position and performance. *Information Processing and Management*, *48*, 671–679.

Abbasi, A., & Jaafari, A. (2013). Research impact and scholars' geographical diversity. *Journal of Informetrics*, *7*(3), 683–692.

Adler, P.S., & Kwon, S. W. (2002). Social capital: Prospects for a new concept. *Academy of Management Review*, *27*(1), 17–40.

Arregle, J. L., Hitt, M.A., Sirmon, D.G., & Very, P. (2007). The development of organizational social capital: Attributes of family firms. *Journal of Management Studies*, *44*(1), 73–95.

Borgatti, S., Everett, M., & Freeman, L. (2002). *Ucinet for windows: Software for social network analysis (version 6)*. Harvard, MA: Analytic Technologies.

Bourdieu, P. (1986). The forms of capital. In N. Woolsey Biggart (Ed.), *Readings in economic sociology* (pp. 280–291). Oxford, UK: Blackwell.

Bourdieu, P., & Wacquant, L. J.D. (1992). *An invitation to reflexive sociology*. Chicago, IL: University of Chicago Press.

Boxman, E. A. W., De Graaf, P.M., & Flap, H. D. (1991). The impact of social and human capital on the income attainment of Dutch managers. *Social Networks*, *13*(1), 51–73.

Bozeman, B., & Corley, E. (2004). Scientists' collaboration strategies: Implications for scientific and technical human capital. *Research Policy*, *33*(4), 599–616.

Burt, R. S. (1992). *Structural holes: The social structure of competition*. Cambridge, MA: Harvard University Press.

Burt, R. S. (2005). *Brokerage and closure: An introduction to social capital*. New York, NY: Oxford University Press.

Coleman, J. S. (1987). Norms as social capital. *Economic Imperialism*, 133–155.

Coleman, J. S. (1988). Social capital in the creation of human capital. *American Journal of Sociology*, *94*(1), S95–S120.

Coleman, J. S. (1990). *Foundations of social theory*. Cambridge, MA: Belknap Press.

Cummings, J. N. (2004). Work groups, structural diversity, and knowledge sharing in a global organization. *Management Science*, *50*(3), 352–364.

Dierickx, I., & Cool, K. (1989). Asset stock accumulation and sustainability of competitive advantage. *Management Science*, *35*(12), 1504–1511.

Eisenhardt, K., & Tabrizi, B. N. (1995). Accelerating adaptive processes: Product innovation in the global computer industry. *Administrative Science Quarterly*, *40*(1), 84–110.

Freeman, L. C. (1979). Centrality in social networks conceptual clarification. *Social Networks*, *1*(3), 215–239.

Frenken, K., Hardeman, S., & Hoekman, J. (2009). Spatial scientometrics: Towards a cumulative research program. *Journal of Informetrics*, *3*(3), 222–232.

Gauntlett, D. (2011). Making is connecting: The asocial meaning of creativity, from DIY and knitting to YouTube and Web 2.0. Cambridge, MA: Polity Press.

Granovetter, M. (1973). The strength of weak ties. *American Journal of Sociology*, *78*(6), 1360.

Granovetter, M. (1983). The strength of weak ties: A network theory revisited. *Sociological Theory*, *1*(1), 201–233.

Griffin, A., & Hauser, J. R. (1992). Patterns of communication among marketing, engineering and manufacturing: A comparison between two new product teams. *Management Science*, *38*(3), 360–373.

Hanifan, L. J. (1916). The rural school community center. *Annals of the American Academy of Political and Social Science*, *67*, 130–138.

Hanneman, R. A., & Riddle, M. (2005). *Introduction to social network methods*. Riverside: University of California.

Hansen, M. T. (1999). The search-transfer problem: The role of weak ties in sharing knowledge across organization subunits. *Administrative Science Quarterly*, *44*(1), 82–85.

Haque, A., & Ginsparg, P. (2009). Positional effects on citation and readership in arXiv. *Journal of the American Society for Information Science and Technology*, *60*, 2203–2218.

Havemann, F., Heinz, M., & Kretschmer, H. (2006). Collaboration and distances between German immunological institutes—A trend analysis. *Journal of Biomedical Discovery and Collaboration*, *1*(6), 1–6.

Hirsch, J. (2005). An index to quantify an individual's scientific research output. *Proceedings of the National Academy of Sciences*, *102*(46), 16569.

Krackhardt, D. (1992). The strength of strong ties: The importance of philos in organizations. *Networks and Organizations: Structure, Form, and Action*, *216–239*.

Lehmann, S., Jackson, A., & Lautrup, B. (2006). Measures for measures. *Nature*, *444*(7122), 1003–1004.

Levin, D. Z., & Cross, R. (2004). The strength of weak ties you can trust: The mediating role of trust in effective knowledge transfer. *Management Science*, *1477–1490*.

Lin, N. (1982). Social resources and instrumental action. In P. V. Marsden, & N. Lin (Eds.), *Social sructure and network analysis* (pp. 131–145). Beverly Hills, CA: Sage.

Lin, N. (1999). Building a network theory of social capital. *Connections*, *22*(1), 28–51.

McFadyen, M., Semadeni, M., & Cannella, A. A. (2009). Value of strong ties to disconnected others: Examining knowledge creation in biomedicine. *Organization Science*, *20*(3), 552–564.

Melin, G. (2000). Pragmatism and self-organization: Research collaboration on the individual level. *Research Policy*, *29*(1), 31–40.

Narayan, D., & Cassidy, M. F. (2001). A dimensional approach to measuring social capital: Development and validation of a social capital inventory. *Current Sociology*, *49*(2), 59.

Oh, W., Choi, J. N., & Kim, K. (2006). Coauthorship dynamics and knowledge capital: The patterns of cross-disciplinary collaboration in information systems research. *Journal of Management Information Systems*, *22*(3), 266–292.

Pinto, M. B., Pinto, J. K., & Prescott, J. E. (1993). Antecedents and consequences of project team cross-functional cooperation. *Management Science*, *39*(10), 1281–1297.

Podolny, J. M., & Baron, J. N. (1997). Resources and relationships: Social networks and mobility in the workplace. *American Sociological Review*, *62*(5), 673–693.

Ponds, R., van Oort, F., & Frenken, K. (2007). The geographical and institutional proximity of research collaboration. *Papers in Regional Science*, *86*(3), 423–443.

Portes, A. (1998). Social capital: Its origins and applications in modern sociology. *Annual Review of Sociology*, *24*, 1–24.

Putnam, R. D. (1993). *Making democracy work: Civic traditions in modern Italy*. Princeton, NY: Princeton University Press.

Putnam, R. D. (1995). Tuning in, tuning out: The strange disappearance of social capital in America. *PS: Political Science and Politics*, *28*(4), 664–683.

Putnam, R. D. (2001). *Bowling alone: The collapse and revival of American community*. New York, NY: Simon & Schuster.

Reagans, R., & Zuckerman, E. (2001). Networks, diversity, and productivity: The social capital of corporate R&D teams. *Organization Science*, *12*(4), 502–517.

Sawyer, S., Crowston, K., & Wigand, R. T. (1999). *ICT in the real estate industry: Agents and social capital. AMCIS 1999 Proceedings (Paper 5)*. Retrieved from http://aisel.aisnet.org/amcis1999/5

Shen, C. (2010). *The patterns, effects and evolution of player social networks in online gaming communities*. (Unpublished doctoral). University of Southern California, School of Communication Los Angeles.

Tsai, W., & Ghoshal, S. (1998). Social capital and value creation: The role of intrafirm networks. *Academy of Management Journal*, *41*(4), 464–476.

Uslaner, E. M. (2001). Volunteering and social capital: How trust and religion shape civic participation in the United States. In E. M. Uslaner (Ed.), *Social capital and participation in everyday life* (pp. 104–117). London, UK: Routledge.

Walker, G., Kogut, B., & Shan, W. (1997). Social capital, structural holes and the formation of an industry network. *Organization Science*, *8*(2), 109–125.

Wasserman, S., & Faust, K. (1994). *Social network analysis: Methods and applications*. Cambridge, UK: Cambridge University Press.

Wellman, B. (1988). Structural analysis: From method and metaphor to theory and substance. In B. Wellman, & S. D. Berkowitz (Eds.), *Social structures: A network approach* (pp. 19–61). Cambridge, UK: Cambridge University Press.

Woolcock, M., & Narayan, D. (2000). Social capital: Implications for development theory, research, and policy. *The World Bank Rresearch Observer*, *15*(2), 225.
Yan, E., & Ding, Y. (2009). Applying centrality measures to impact analysis: A coauthorship network analysis. *Journal of the American Society for Information Science and Technology*, *60*, 2107–2118.
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