Research Collaboration among Organizations: Structure and its Impact on Research Outcome in Interdisciplinary Fields

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Abstract
Emerging concern exists in the global common issues like sustainability and aging society, which must be tackled by academia by integrating diverse knowledge and skill. These complex issues we face cannot be solved within single academic discipline and therefore interdisciplinary research and collaboration among organizations and researchers are essential. In this paper, we analyze the current status of academic research collaboration among universities and research institutes in sustainability and gerontology and detect collaboration gaps. We found that collaboration community extracted by clustering of co-authorship network tends to be located in physically proximate regions. We also analyzed the association between topological position of organizations in collaboration network and scientific impact in citedness of those organizations, and found that boundary spanning organization has positive impact on research outcome while the correlation is weak. Our results encourage scholars to collaborate more with the others in different communities, and suggest policy makers and managers to support them.

Introduction
Emerging concerns about sustainability and aging society are apparent in a number of societal sectors, including the political and economic sectors, universities, and the public at large. Reflecting the importance of these issues for society, economics, and the environment, sustainability science and gerontology are becoming distinct research fields. The characteristics of these fields are interdisciplinarity, because the issues require us to consider wide range of aspects from environmental, social, technological and human factors. For example, Ostrom et al. (2007) characterized sustainability science as an applied science, and stated that if sustainability science is to grow into a mature applied science, we must use the scientific knowledge acquired in the separate disciplines of anthropology, biology, ecology, economics, environmental science, geography, history, law, political science, psychology, and sociology to build diagnostic and analytical capabilities.
Because of such a diverse nature of fields, the importance of research collaboration and network among organizations is well recognized by scholars in those fields. And the necessity of building network to bridge existing but distant networks is also well documented, which is called as 'Network of Networks' (NNs), which is schematically shown in Figure 1. The concept of creating an ecological "network of networks" to study global climate change and other broad-scale phenomena dates back already to decades ago (Bledsoe and Barber 1993). A network is expected to serve as a conduit of knowledge and a platform for collaboration. However, as we are all aware, even through networking it is not always easy to secure sufficiently broad capabilities to achieve our objectives because the members of a network are often limited to those who are already in the same circle. Therefore, we need to go a step further: connect these networks and create a NNs to link otherwise mutually isolated research institutes and sectors, thereby promoting a higher level of integration and securing a broader base of capabilities.
One of approach to bridge existing networks is research collaboration. Research collaboration has increased during the past decades because of the necessity of sharing cost, decreasing transportation and communication cost, required specialization of research skills, growing importance of interdisciplinary fields, and the other social and political factors. Research

collaboration is expected to contribute sharing of knowledge, skills and techniques, transfer of knowledge or skills, cross-fertilisation of ideas, intellectual companionship, and therefore to research outcome and visibility (Katz & Martin, 1997). Although science is generally viewed as competitive in that individual researchers compete intensely in an "economy of reputation" to be the first to make unique and groundbreaking discoveries, in areas where resources are concentrated at a small number of locations or controlled by a small group researchers are prompted to collaborate with the others (Birnholtz, 2007). In addition, commonality emergence of sustainability and aging society can work as a motive of research collaborations in those fields.

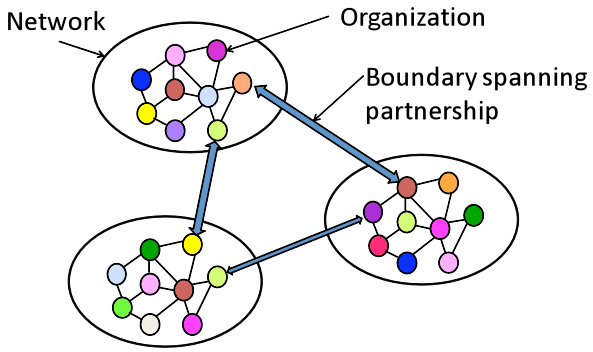

Figure 1. Network of Networks (NNs)

We can expect that research collaboration brings us high research outcome especially in interdisciplinary fields. Qin et al. (1998) empirically showed research collaboration is significant in interdisciplinary research fields. In addition, as collaboration involved more organizations and countries, the degree of interdisciplinarity became higher. This might be the cause of the observation that although for entire science there is no clear correlation or even negative correlation between the level of interdisciplinarity of articles and their citation rates (Levitt & Thelwall, 2008), there are nonetheless some disciplines in which a higher level of interdisciplinarity is related to a higher citation rates (Larivière & Gingras, 2010).

In this paper, we analyze the current status of academic research collaboration among universities and research institutes in sustainability and gerontology. The primary concern is in the structure of research collaboration network and NNs. The co-authorship networks are divided into 'networks' by clustering. We also analyzed the topological position of each organization to know which organization contributes to connect distant 'networks' and therefore to build NNs by boundary spanning partnership with the other 'network' (Figure 1). Then, we analyze the impact of such a boundary spanning collaboration among organizations on research outcome measured by citedness of those organizations. We focus of the effect of bridging 'networks' on average citations of papers by each organization. Then, we discuss the opportunities for further collaboration.

Research Methodology

Data

Research collaboration has been studied by using co-authorships of scientific articles (Melin & Persson, 1996). We also use co-authorship to represent research collaborations. We collected data including records including co-authorships from Science Citation Index (SCI) Expanded and the Social Sciences Citation Index (SSCI) compiled by the Institute for Scientific Information (ISI) in Thomson Reuter. We used Web of Science, which is a Web-

based user interface of ISI's citation databases. When we have the same record both in SCI-Expanded and SSCI, we regard them as one node in the citation network.
As for sustainability science, we searched the papers using sustainab* as the query where * means wildcard, which was also used in the previous paper (Yarime et al., 2010). Therefore, the corpus built by us includes papers that include sustainability and sustainable. The retrieved data includes bibliographic records of 61,309 papers relating sustainability science. The data includes bibliographic records of papers published from 1927 to 2010.
Regarding gerontology, we used the combination of two groups of terms as the query. One is relating 'aging' like aging, old, elder, and etc. Another is component for active aging listed in a report by World Health Organization (WHO) like housing, social inclusion, and etc. (WHO, 2007). The query we used is; (aging or elder* or "older people*" or "older adult*" or senior* or "old man" or "old men" or "old woman" or "old women") and ((wellbeing or welfare or happiness or humanity) or (urbanization or age-friendly or "active aging") or (outdoor space* or building*) or (transportation*) or (housing*) or (esteem* or "social inclusion*") or (social participation*) or (communication*) or ("civic participation*" or employment*) or ("community support*" or "health service*")). As a result, we have 15,107 papers for gerontology. The data includes bibliographic records of papers published from 1932 to 2010.

Structure of co-authorship networks

After obtaining the above data, the co-authorship networks were created. We weighted link between a pair of organizations by the number of co-authorships between them. To analyse the structure of research collaboration network, the non-directed and weighted network is divided into clusters using the topological clustering method (Good et al., 2010) based on Newman-Girvan modularity, Q (Newman & Girvan, 2004; Clauset et al., 2004). In weighted network, modularity is defined as (Newman, 2004);

$$Q = \frac{1}{2m}\sum_{ij}\left[A_{ij} - \frac{k_i k_j}{2m}\right]\delta(c_i, c_j)$$

where m is the total number of links, A_{ij} is an element of the adjacency matrix of the network, k_i is the number of links that node i has, δ function $\delta(u,v)$ is 1 if $u=v$ and otherwise 0, c_i is the cluster to which node i is assigned. Here, we have the following relationships; $m = \frac{1}{2}\sum_{ij} A_{ij}$, $k_i = \sum_j A_{ij}$. A_{ij} is the number of co-authorships between i and j. Q means the fraction of links that fall within clusters, minus the expected value of the same quantity if the links fall at random without regard for the clustered structure. Since a high value of Q represents a good division, we stopped joining when ΔQ in each clustering step became minus. A good partition of a network into clusters means there are many intra-cluster links and as few as possible inter-cluster links. This modularity maximization works well above the resolution limit of $(m/2)^{1/2}$ (Fortunato & Barthélemy, 2007). When k_i is less than $(m/2)^{1/2}$, we cannot have a good partition for c_i. After clustering, we investigated composition of organizations in each cluster to know an overall structure of current research collaborations.

Topological position of organization in collaboration network

Clustering of co-authorship network reveals modular 'network' structure. In the following, we will investigate networking of 'networks' and extract organizations having boundary spanning partnerships with organizations in the other 'networks'. We analyzed the topological position of each organization to know which organization contributes to connect distant 'networks' and therefore to build NNs.

Such a task to identify brokerage organization is not a rudimentary one. The task is similar to the one to define interdisciplinarity of individual paper, which is currently under active discourses. Bibliometric approaches have been used to analyze interdisciplinarity (Leydesdorff, 1995; Porter et al., 2007). Researchers often use the SC in JCR to define the disciplines and measure interdisciplinarity (ex. van Leeuwen & Tijssen, 2000, Porter & Rafols, 2009). But it cannot be applied to our case because each organization do not have such a classification *a priori*. To overcome the limitation, we regard the community structure extracted by the above clustering step as 'network' and count the diversity of links each organization has to represent the extent of boundary spanning partnership that each organization has.

We used the following indicators to measure the contribution in connecting distant 'networks' and building NNs. One of them is betweeness centrality (B), which is often used to represent interdisciplinarity of individual papers (Leydesdorff, 2007). B is the fraction of the shortest paths going through a given node, which is given by;

$$B = \sum_{s \neq i \neq t \in V} \frac{\sigma_{st}(i)}{\sigma_{st}}$$

where σ_{st} is the total number of shortest paths from node s to node t, and $\sigma_{st}(i)$ is the number of shortest paths from s to t going through i (Freeman, 1977). B becomes high when each organization is located in a position on the shortest path connecting any pairs of organizations in the collaboration network.

We also calculated the indicators representing the distribution of partnerships among different 'network'. We used participation coefficient (P) is defined by (Guimerà & Amaral, 2005)

$$P = 1 - \sum_{s=1}^{N_M} \left(\frac{\kappa_{is}}{k_i} \right)^2$$

where κ_{is} is the number of links of node i to nodes in cluster s, and N_M is the number of clusters. The participation coefficient P_i is close to 1 if partnerships of the organization is uniformly distributed among all 'networks' and 0 if all of them are within its own 'network'.

The distribution of partnerships of partners are also calculated by number of clusters (N), Shannon's quantities of information (H), Simpson's diversity (I), Stirling's diversity (S) which are introduced in the previous paper to measure interdisciplinarity of individual papers (Rafols & Meyer, 2010). N is the number of 'networks' which partners of partners (PoP) belong to. The other indicators, H, I, and S are defined by;

$$H = -\sum_i p_i \ln p_i$$

$$I = 1 - \sum_i p_i^2$$

$$S = 1 - \sum_{i,j} s_{i,j} p_i p_j$$

where p_i is proportion of PoP in each 'network' and $s_{i,j}$ is the distance between cluster i and j. S_{ij} is defined as the number of links between cluster i and j normalized by the number of links of each cluster.

Citedness of organizations

Finally, we evaluated the impact of research collaboration on citedness of papers written by authors in each organization. Citedness is simply assumed as the average times cited of the papers by each organization. We do not exclude self-citation. However, for organizations having less publications can distort the results, and therefore we set the threshold in the

number of publications by each organization as 2. In the analysis of correlations between citedness and indicators, we analyze organizations who have at least 3 publications.
In the analysis, we used the number of publications by each organization (N_p). N_p is regarded as an indicator representing the extent of research activity by each organization. We can expect that active organization having large number of publications gain large citedness, because knowledge and skill are accumulated by active research and large number of publications enhance the visibility of the organization. It is straightforward to expect the positive relationship between N_P and citedness even without research partnership. We also expect that number of partners, i.e., degree in the collaboration network, D, has a positive impact on the citedness. This is because of the number of benefits of collaborations in interdisciplinary field described in Introduction. Therefore, N_p and D are used as a benchmark to evaluate the effect of boundary spanning. N_p represents research activity and D does partnership activity, which does not mean the strength of boundary spanning partnership.
To evaluate the effect of boundary spanning partnership, we used 6 indicators described in the above. They are expected to be able to shed light on boundary spanning partnership from different angles. B represents the role of organization as a hub in collaboration network. B becomes high when the organization is located in a position on the shortest path among organizations, and therefore, such an organization is expected to be effective to obtain different information from distant organization. N and P are similar indicators. They both consider the variety of partnerships among different communities. When the partners are distributed in different communities extracted by clustering, they both become high. But P is more sensitive. Although N just counts the number of cluster where the partners belong, P considers the proportion of partnerships with different clusters. P becomes high when the organization has equal partnership with different clusters. Other indicators, H, I, S, are also similar. H, I, and S are calculated by the position of PoP in collaboration network. These indicators become high when partner of partner of the organization are distributed in different clusters. Therefore, we assume that these indicators can evaluate boundary spanning partnerships by their partners, which bring the spillover effect from their partners to the focal organization.

Results and discussions

International structure of co-authorship networks

By dividing organizational networks, we obtained main 4 clusters in sustainability science. In Table 1, we show the main countries where organizations in each cluster belong, number of organizations in each cluster for each country (No.) and its share. The total numbers of organizations which each cluster has are 4,117 (Cluster 1), 3,713 (Cluster 2), 2,713 (Cluster 3), and 2,659 (Cluster 4). The size of cluster sharply drops after 5th cluster having 649 organizations. In each cluster, the organizations have strong partnerships with other clusters in the same cluster but have few with the organizations outside the cluster.
As can be seen in the Table 1, the largest cluster, Cluster 1, has a number of organizations located in EU. Other countries below the rank of 10 include other EU countries like Norway, Denmark, Finland, England, Israel, Hungary, Poland, Portugal. This high concentration of EU countries and relatively even share might be due to the existence of Framework Programme encouraging research partnerships whose participants are from more than 3 countries.
In the second largest cluster, Cluster 2, over than half organizations are in U.S.A. We can see other North and South American countries, i.e, Canada, Brazil, and Mexico, which reflects physical proximity. Compared to the other clusters, this cluster has uneven distribution of countries.

Organizations in Cluster 3 are apparently located in Asia-Pacific region including Australia, China, Japan, New Zealand, and so on. Below the rank of top 10th, we can see other Asian countries including Pakistan, Singapore, South Korea, India, Malaysia, Philippines, Vietnam, Bangladesh, Sri Lanka, and Nepal, while they are not listed in the table. These results accord with those in the previous paper (Yarime, et al., 2010).
It is noteworthy to mention that England takes a specific position. In Cluster 4, we can see England is at the top, while England is nor ranked within 10 in Cluster 1. Other countries in Cluster 4 are South Africa and Nigeia. Therefore, the cluster seems to show the strong partnerships between England and African countries. Other countries not ranked in Top 10 of this cluster are Kenya, Tanzania, Uganda, Egypt, Cameroon, Ghana, Zambia, and so on.

Table 1. Structure of collaboration network in sustainability science.

Rank	Cluster 1			Cluster 2			Cluster 3			Cluster 4		
	Country	No.	Share	Country	No.	Share	Country	No.	Share	Country	No.	Share
1	Germany	526	12.8%	USA	2146	57.8%	Australia	731	26.9%	England	665	25.0%
2	France	488	11.9%	Canada	416	11.2%	China	571	21.0%	USA	223	8.4%
3	Netherlands	347	8.4%	Brazil	108	2.9%	Japan	341	12.6%	South Africa	161	6.1%
4	Italy	302	7.3%	Mexico	98	2.6%	USA	115	4.2%	Scotland	125	4.7%
5	Switzerland	189	4.6%	India	45	1.2%	New Zealand	108	4.0%	France	103	3.9%
6	Spain	172	4.2%	France	43	1.2%	Taiwan	65	2.4%	Brazil	67	2.5%
7	Sweden	157	3.8%	England	40	1.1%	Germany	52	1.9%	Germany	60	2.3%
8	Belgium	128	3.1%	Germany	40	1.1%	England	39	1.4%	Netherlands	54	2.0%
9	India	98	2.4%	China	38	1.0%	Thailand	39	1.4%	India	53	2.0%
10	Austria	91	2.2%	Spain	35	0.9%	Indonesia	37	1.4%	Nigeria	53	2.0%

Table 2 shows structure of collaboration network in gerontology. In Table 2, the top 4 clusters, while the other clusters are enough large not to be neglected. The total numbers of organizations that those cluster have are 1,442 (Cluster 1), 811 (Cluster 2), 553(Cluster 3), and 423 (Cluster 4). But other clusters have comparative number of organizations as 362 (Cluster 5 and Cluster 6), 281 (Cluster 7), 271 (Cluster 8), and 270 (Cluster 9).
As can be seen in Table 2, each cluster is occupied by a specific country as U.S.A. (Cluster 1), England (Cluster 2), Sweden and Netherlands (Cluster 3), and Canada (Cluster 4). The other clusters are also occupied by a specific country like U.S.A. (Cluster 5), Australia (Cluster 6), Finland (Cluster 7), Taiwan and South Korea (Cluster 8), Japan (Cluster 9), and Germany (Cluster 10).

Table 2. Structure of collaboration network in gerontology.

Rank	Cluster 1			Cluster 2			Cluster 3			Cluster 4		
	Country	No.	Share	Country	No.	Share	Country	No.	Share	Country	No.	Share
1	USA	1296	89.9%	England	395	48.7%	Sweden	131	23.7%	Canada	286	67.6%
2	Italy	13	0.9%	Scotland	54	6.7%	Netherlands	117	21.2%	USA	47	11.1%
3	Japan	12	0.8%	USA	42	5.2%	Israel	45	8.1%	France	14	3.3%
4	Germany	11	0.8%	Germany	31	3.8%	Germany	34	6.1%	Spain	14	3.3%
5	China	9	0.6%	Belgium	26	3.2%	USA	25	4.5%	Germany	11	2.6%

There are distinct differences between sustainability science and gerontology in the structure of collaborations. In sustainability science, organizations tend to collaborate within some regions like EU, U.S.A. and Asia-Pacific. However, in gerontology, collaborations are

confined within a country. Compared to the result in sustainability science where most of organizations belong to top 4 clusters and the rest clusters are peripheral, we cannot determine the core clusters in gerontology because the size of cluster steadily decreases.

Effect of boundary spanning partnership on citedness

Before investigating the effect of boundary spanning partnership on citedness of organizations, we checked the interdependence of indicators by creating correlation coefficient matrix among them as shown in Table 3 and Table 4. We can see three groups. The first group is *D*, *B*, and *N*. Correlation coefficients among *D*, *B*, and *N* are high both in sustainability science and gerontology. The second one is *P*, which has low correlation coefficients with the other indicators. The third one is *H*, *I*, and *S*. All of those are indicators derived by PoP. And therefore it is reasonable that *H*, *I*, and *S* are highly correlated with each other. Correlations among indicators are quite similar in sustainability science and gerontology.

Table 3. Correlation coefficient among indicators in sustainability science.

	D	B	N	P	H	I	S
D	1	0.923	0.903	0.165	0.228	0.146	-0.219
B		1	0.734	0.147	0.189	0.136	-0.148
N			1	0.200	0.324	0.186	-0.482
P				1	0.549	0.549	-0.334
H					1	0.929	-0.677
I						1	-0.679
S							1

Table 4. Correlation coefficient among indicators in gerontology.

	D	B	N	P	H	I	S
D	1	0.853	0.730	-0.085	0.224	0.180	-0.223
B		1	0.603	-0.018	0.162	0.121	-0.164
N			1	-0.104	-0.045	-0.053	0.064
P				1	0.382	0.279	-0.443
H					1	0.965	-0.843
I						1	-0.822
S							1

Table 5 shows the correlation coefficients between average citation of papers and each indicator. Sample size is 2,922 who published at least 3 papers in sustainability science, and it is 787 in gerontology. We can see similar trends in both cases. Research activity, i.e., N_p, has a positive impact on citedness, while it is not significant in sustainability science. This means that papers written by the authors who belong to the organizations having more publications tend to be cited more than papers by organizations having less publication. Partnership activity, *D*, has also a positive impact on citedness. Papers by organization that has more research partner are cited more. This might be due to number of network effect, like sharing diverse knowledge, cross-fertilisation of ideas, and increasing visibility.

Indicators of boundary spanning activity have both positive and negative effects, while each indicator tends to have similar effect. *B* and N have statistical significant effect to increase citedness of organizations. This means that organizations connecting different communities are cited more in both sustainability science and gerontology. However, *P* has a negative impact. While *N* of an organization just counts the number of clusters where research partners of that organization belong, *P* considers the bias of such a boundary spanning activity. If an organization has an equal partnership with the other clusters, *P* becomes high. However, our results indicate that such a partnership strategy has even a negative impact of citedness. According to the above results, organizations should collaborate intentionally with some specific communities outside their own community in a manner that not loses diverse partnerships with the other communities. Other indicators, *H*, *I*, *S*, are calculated by the position of PoP in collaboration network. Among them, *H* and *I* have a negative contribution in increasing citedness, but the correlation is not so high and in gerontology they are not statistically significant. The existence of partners who are actively conducting boundary spanning activity does not have a positive influence. Therefore, we should not expect the spillover effect from their partners in boundary spanning activity. However, *S* has a positive impact in sustainability science. Although the mechanism behind it is not clear, it might be because S takes the distance between communities into account while *H* and *I* do not consider it.

Table 5. Effect of boundary spanning partnership on citedness.

Construct	Indicator	Sustainability Science	Gerontology
Research activity	N_p	0.028	0.103**
Partnership activity	D	0.085**	0.153**
Boundary spanning activity	B	0.039*	0.170**
	N	0.107 **	0.085*
	P	-0.074**	-0.173**
	H	-0.070**	-0.013
	I	-0.084**	-0.012
	S	0.118**	0.003

* p<0.05, ** p<0.01

Our results encourage scholars to collaborate more with the others in different communities. As shown in Table 5, research partnerships with organizations in different communities enhance their citedness. Organizations should have strong partnerships with specific organizations in different communities. Simultaneously, organizations should keep partnerships with diverse communities, although equal proportion of partnerships in different communities does not have positive impact. Organizations should not expect the spillover effect from their partners, they must, by themselves, bridge different communities to whom they are not familiar with. And it is expected policy makers and managers to support them. Communities are divided by regions in sustainability science and countries in gerontology, and research partnerships with different geographical regions and countries and institutions supporting them are essential. NNs is the concept for such a boundary spanning expertise. Framework Program in EU is one of good practice, and future expertise not only in EU but also in the other regions are necessary to challenge our common global issues like sustainability and aging society.

Conclusion

In this paper, we investigated structure of research collaboration in sustainability science and gerontology by analyzing co-authorship of academic publications by organizations. We found that research communities are divided by regions in sustainability science and countries in gerontology. We analyzed the impact of research activity, partnership activity, and boundary spanning activity on citedness of organizations. We found that number of papers and partners have positive influence on the citedness. We also found that betweeness centrality in collaboration network and number of communities where partners belong increases citedness of organizations. Therefore, further research partnerships connecting different regions and countries and support the realization of network of networks are essential to challenge our common global issues like sustainability and aging society.

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