New Bibliometric Analysis of Research Institutions Network

Kazuya Tanaka[1], Ichiro Sakata[2]
[1]Department of Technology Management for Innovation, Graduate School of Engineering,
The University of Tokyo, Tokyo, Japan
[2]Innovation Policy Research Center, Institute of Engineering Innovations, School of Engineering,
The University of Tokyo, Tokyo, Japan

Abstract--**To understand academic research, bibliometric analysis is tremendously important at any aspects. Research institutions such as university, institution and research center, are focal point of academic research. We have used simple and quantitative bibliometric analysis for the evaluation of research institutions. Nowadays some study show qualitative and network-based bibliometric analysis has been implemented for this purpose as a new approach. As such a new approach, this research shows network-based bibliometric analysis to understand research institutions characteristics qualitatively and show new standard for the evaluation of research institutions, using co-authorship analysis. As a result and discussion, we suggested some network index may represent their institutions' academic situation and power on their field and country.**

I. INTRODUCTION

To understand academic research, bibliometric analysis is tremendously important at any aspects. Especially, to capture the whole structure, research paper analysis is one of the well-known methodology, because the recent main output of scientific activities lies in a number of journal papers. And these scientific publications play an important role as the primary "raw material" building scientific knowledge to accelerate technological innovation. In addition to that, the research paper analysis including citation network may detect emerging research front.[1] So using research paper analysis and citation network analysis is crucial to grab current and future research power and potential.

Research institutions including universities, national laboratories and companies are key driving unit to make innovation in science and technology fields. As an example of general standards for research instructions, university is a big scope of the evaluation. There are some university rankings for general evaluation of their universities in terms of any aspects including education, research et al. There are several well-known rankings such as Academic Ranking of World Universities (ARWU), also known as Shanghai Ranking[2] and QS World University Rankings[3]. These ranking includes research aspects as well, and for the evaluation for research situation, they have used number of research papers and citation numbers using Scopus[1], part of Elsevier, or Web of Science Core Collections[2], part of Thomson Reuters. As a different evaluation example, country governments tend to evaluate their own universities such as, Japanese government issues university ranking report including academic power recently [4]. As of now, number of research papers and citation numbers are one of the key factor for research power.

For research instructions discussion, there are less indicators to cover all academic institutions, so we examined for these scope. These university ranking cover universities only, do not cover non-universities' academic focal point such as national laboratories. In addition to that, mainly many governmental standards focus on their local, not focus on global perspectives so much (some of them may include their oversea research as a comparison purpose) and they tend to evaluate the national lab with their specific mission and purpose. (for example NIH and Boston Children's Hospital may be evaluated by different standard because their academic identity is so much different).

As explained before at university and research instructions discussion, it would be difficult to compare all academic organization comprehensively as an academic power and potential for making innovation in science and technology fields. (For example, university rankings definitely have non-research perspective, and such a university ranking is too simplistic way instead of considering global knowledge interactivity in a comprehensive way.)

To achieve the difficult problem, as methodology perspective in research paper analysis, number and citation of papers are crucial factor on understanding research importance. It means, number of citation of papers is powerful tool to compare such a university and research institutions such as Nature Index Table[3] and InCites[4]. As such indexes, network analysis for citation may detect cutting-edge and emerging leading paper. [5] However citation lag is always a problem for understanding recent cutting-edge, and we definitely need diverse standard to capture real academic research power and potential.

Co-authorship is also powerful tool to understand research group. Co-author analysis can be used, for example, as an important tool in evaluative bibliometric in order to make a first identification of research groups in 'unknown' universities or organizations. [6] Co-authorship can be understand in different way from citation network; time lag and laboratory culture perspective.

[1] http://www.scopus.com/
[2] http://thomsonreuters.com/en/products-services/scholarly-scientific-research/scholarly-search-and-discovery/web-of-science-core-collection.html
[3] http://www.nature.com/nature/journal/v522/n7556_supp/fig_tab/522S34a_T2.html
[4] http://incites.isiknowledge.com/

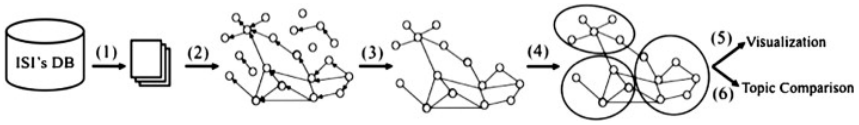


Fig. 1 Methodology in academic landscape system (Figure from [8])

This research has shown the possibility that combination analysis among citation network analysis and co-author analysis can reveal research power in terms of not only citation networked academic outputs but also less time-lag and culture perspective.

II. RESEARCH METHODOLOGY

(A) First of all, we show the previous methodology for citation network analysis. Analyzing schema is schematically depicted in following steps [7]:
Step (1) to collect data of scientific publications from Web of Science Core Collections
Step (2) construct citation network using their direct citation
Step (3) extracted largest components of networks (in terms of relevancy to the focal domain)
Step (4) apply Newman-Girvan algorithm to perform topological clustering
Step (5) use spring-model for the visualization of the entire citation network map

To implement above methodology, we used academic landscape system[5] [Fig.1] in Innovation Research Center, the University of Tokyo[6].

Datasets in this research

1. Top 1% Papers (Most 1% cited publications in search) – This way of standard are widely used as university ranking or policy evaluation based on citation importance to understand overall research trend.
2. iPS Cell – As first case study to know cutting-edge research area, we used dataset of iPS cell as relatively new dataset. In 2012, John B. Gurdon and Shinya Yamanaka won the Nobel Prize in Physiology or Medicine for the discovery that mature cells can be reprogrammed to become pluripotent[11][12]. We searched the paper using "("mature cell*" OR reprogram* OR pluripotent OR "developmental capacity of nuclei" OR "developmental capacity of nucleus")" as a query.
3. Solar Cell – Basic research at this topic is relatively old but this cover sevral key different technology such as silicon, dye-sensitized cell [9]. We searched the paper using "solar cell* or photovol*" as a query.
4. Nano-carbon – This topic includes several research topics such as fullerene[13], carbon nano-tube[14] and graphene[15] from old age to current period. We searched the paper using "(((carbon and (nano* OR micro*)) or fullerene or Buckminsterfullerene or Buckminster-fullerene or C60 or C-60 or graphene or (_lament* and carbon)))" as a query.

* All datasets include research papers published from 2006 to 2015 (At some purpose, we may divide two groups: 2006-2010 and 2011-2015)

To understand research institutions behavior and characteristics, we used following datasets in this research. Following topic rely on different timing development so that we also can analyze at chronicle way in different research filed.

(B) Secondly, we extracted above papers information and make co-authorship network composing academic institutions; Institutional co-authorship analysis.
1. Extracted data from Academic Landscape System as explained at (A).
2. Make affiliation pairs from an individual papers (top 100 institutions).
3. These pairs was analyzed as edge and nodes with weighted network (top 200 edge weight).

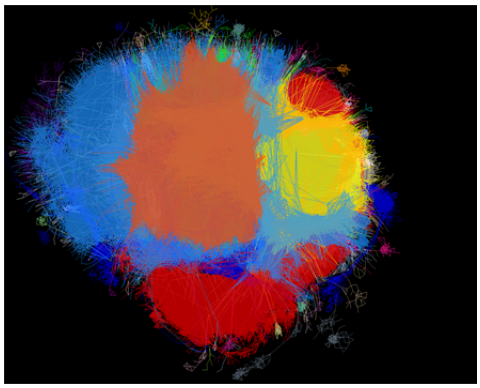
In short, we extracted top 100 institutions in terms of number of papers, and extract co-authorship information among institutions. Extracted information would be visualized with edge and nodes (top 200 edge weight). Thirdly, we created co-authorship network diagram and calculate their network index from the above database used with Gephi[7][8]. Size of nodes and edges represent their number of papers.

III. RESULT

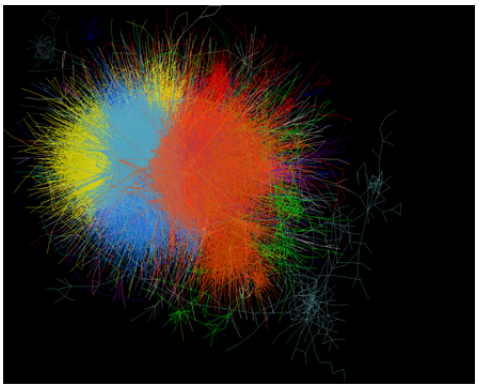
(A) Citation Network Analysis: Academic-landscape
Academic landscape systems show as below at each datasets [Fig. 2].
We have showed to divide several domains clearly as above, and extracted all data from the system for next experiment (B).

(B) Institutional Co-authorship Analysis
We succeeded following co-authorship visualization [Fig. 3, 4, 5-a, 5-b, 6-a, 6-b].

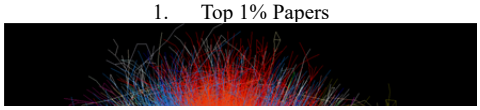
[5] http://academic-landscape.com/
[6] http://ipr-ctr.t.u-tokyo.ac.jp/jp/index.html
[7] https://gephi.org/

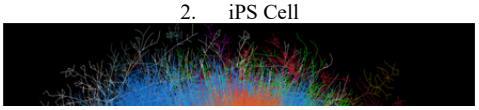


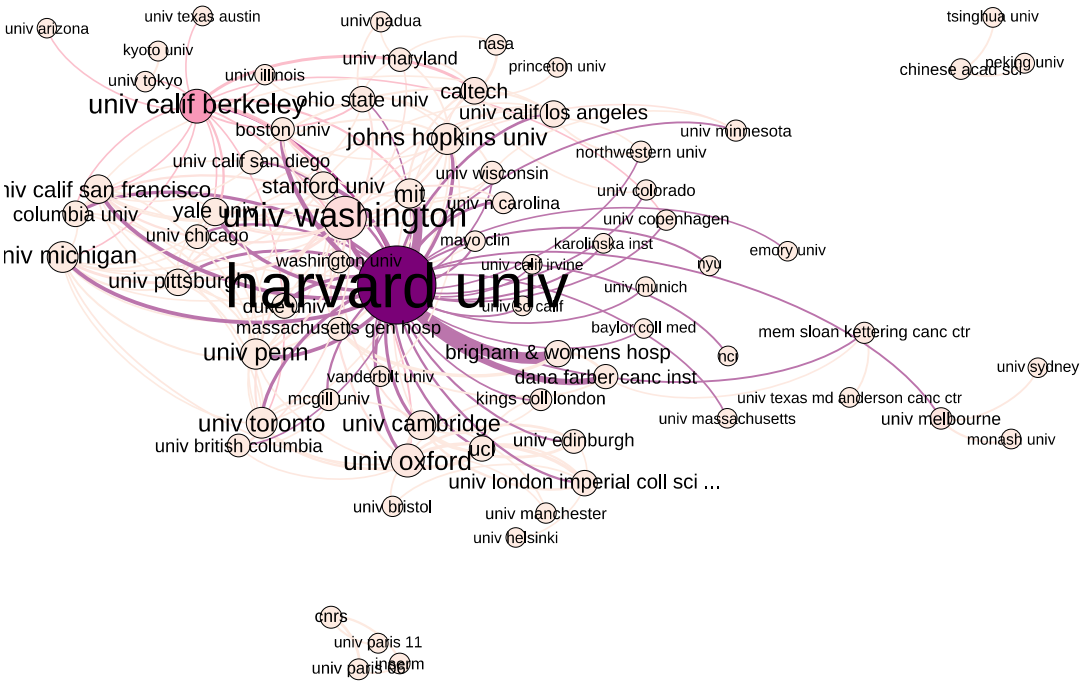
1. Top 1% Papers

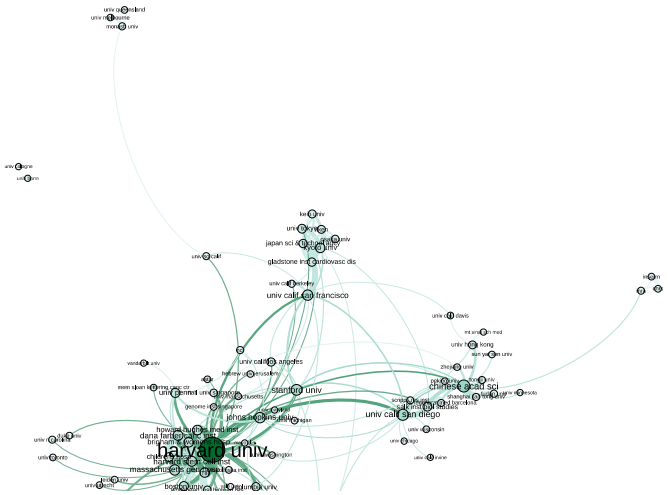


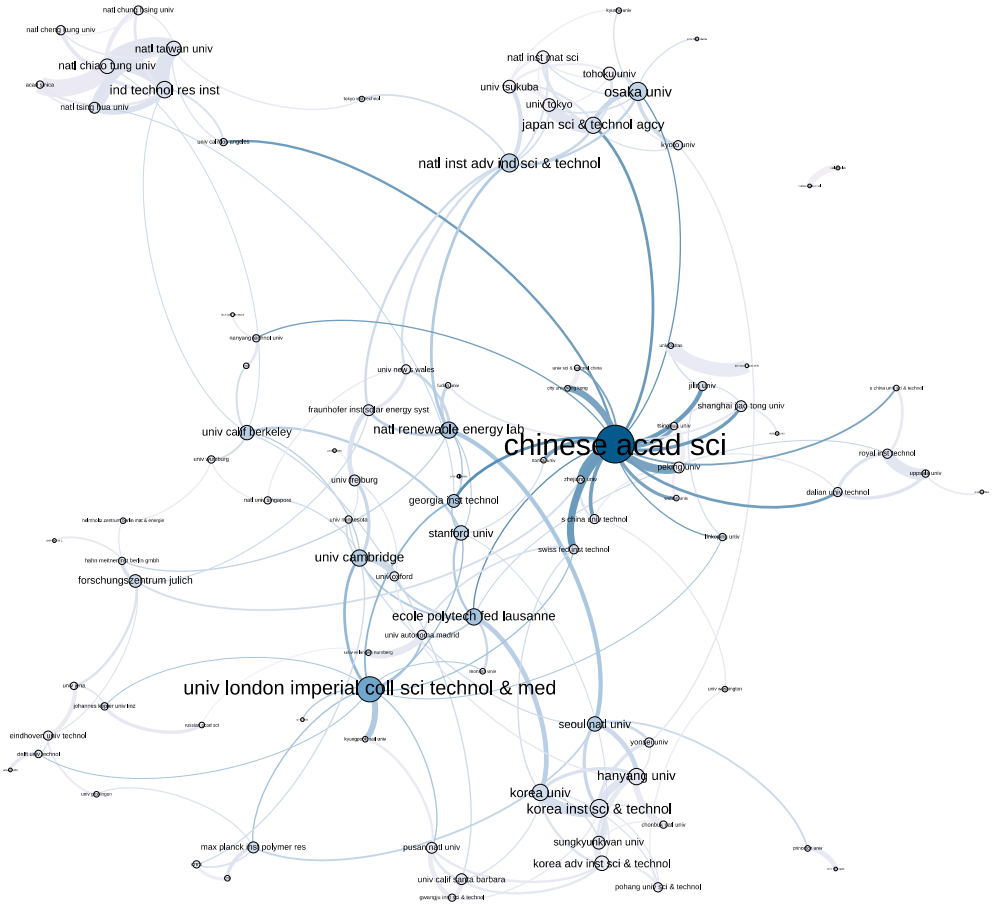
2. iPS Cell








harvard univ
stanford univ
univ calif san francisco
univ calif los angeles
univ calif san diego
chinese acad sci


natl taiwan univ
natl chiao tung univ
ind technol res inst
natl inst adv ind sci & technol
japan sci & technol agcy
osaka univ
tohoku univ
univ tokyo
univ sukuba
natl inst nat sci
chinese acad sci
natl renewable energy lab
univ calif berkeley
fraunhofer inst solar energy syst
univ wales
shanghai jiao tong univ
georgia inst technol
stanford univ
univ cambridge
ecole polytech fed lausanne
univ london imperial coll sci technol & med
seoul natl univ
hanyang univ
korea univ
korea inst sci & technol
sungkyunkwan univ
korea adv inst sci & technol
pusan natl univ
max planck inst polymer res
univ calif santa barbara
forschungszentrum julich
eindhoven univ technol
royal inst technol
dalian univ technol

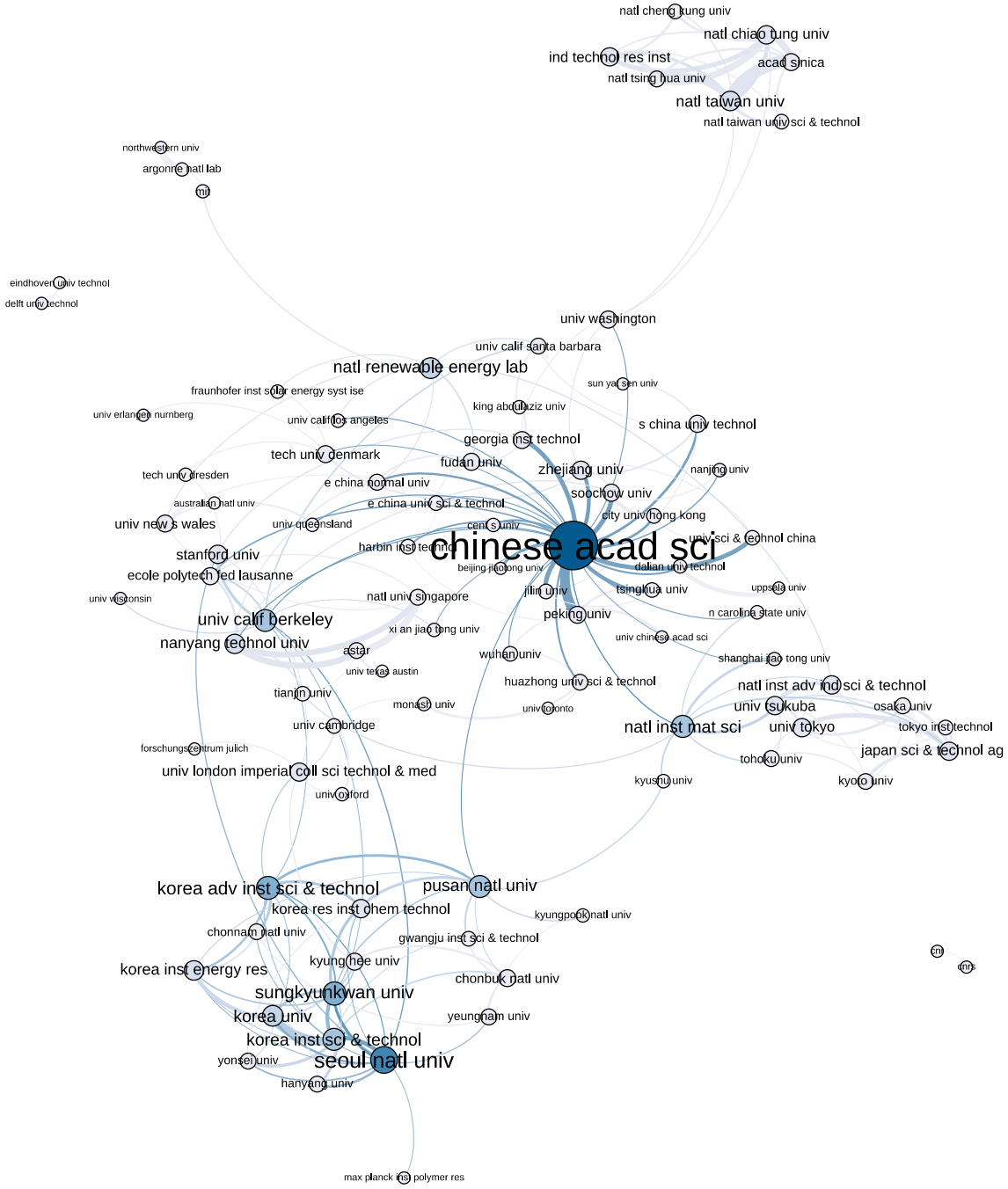


Fig. 5-b Visualization of Institutional Co-authorship at 3. Solar Cell from 2011 to 2015

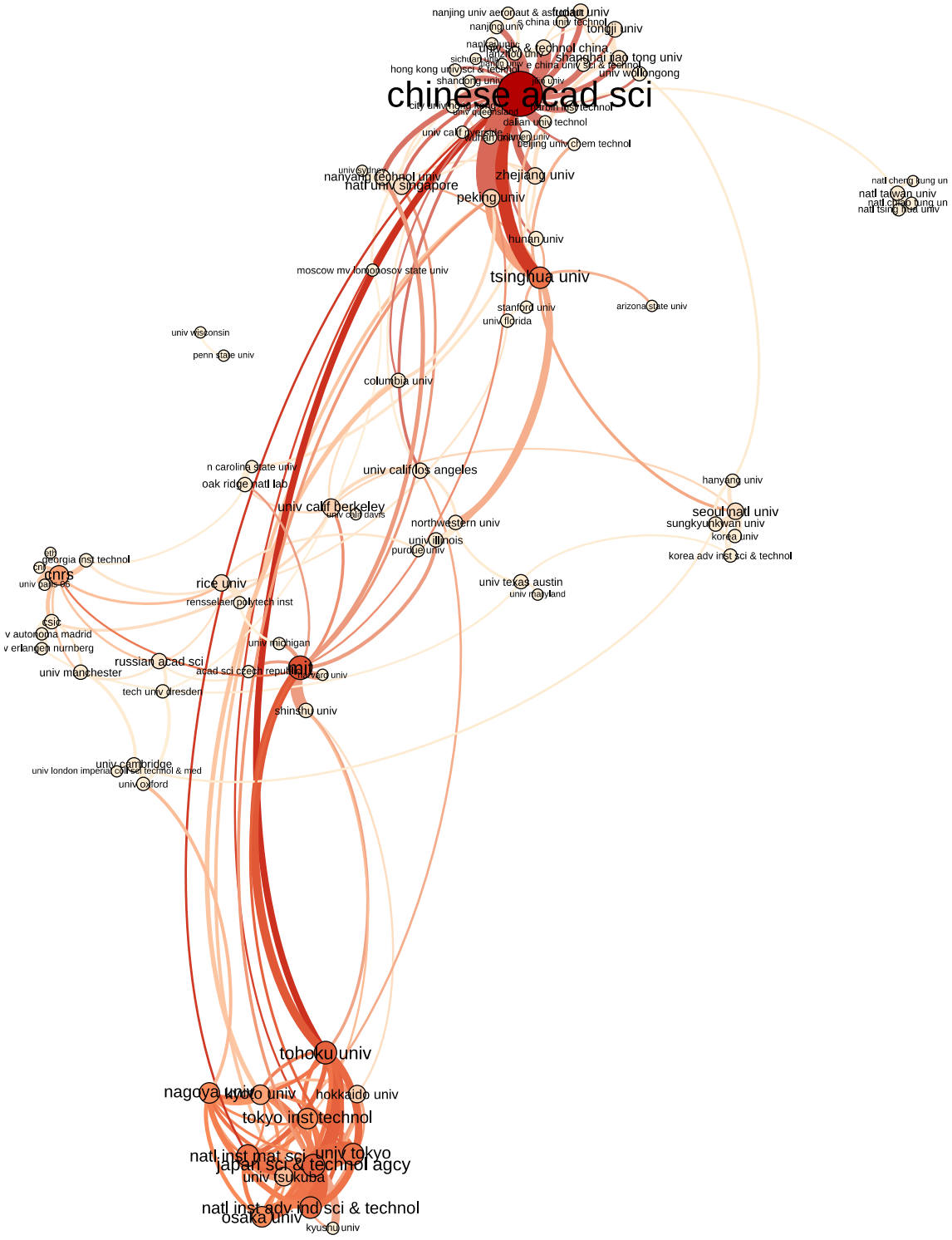
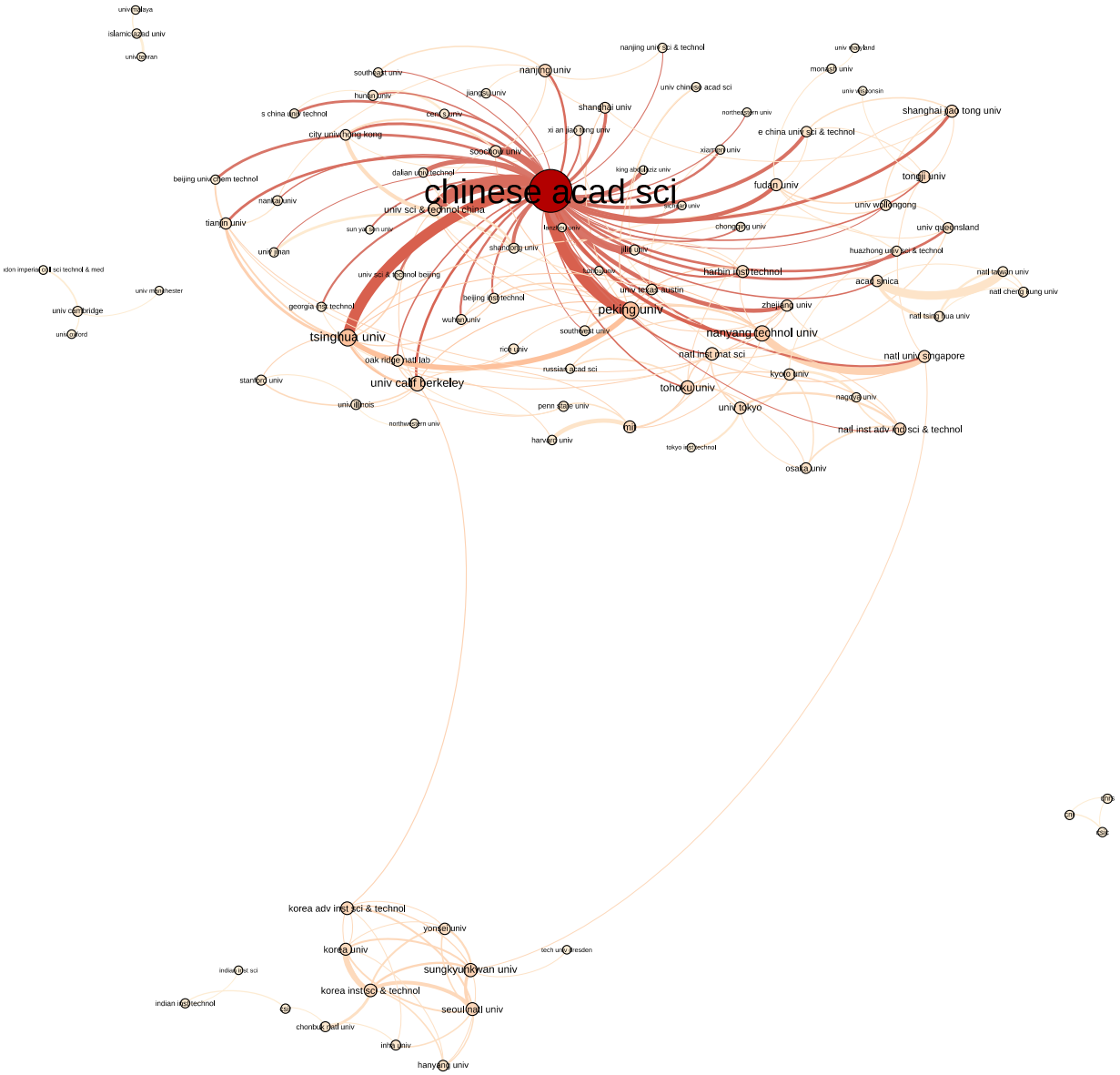


Fig. 6-a Visualization of Institutional Co-authorship at 4. Nano-carbon from 2006 to 2010



W ality
and r l by
A rank
as r of
modu
woul ence

Top 1% Paper. Left matrix is sorted by betweenness centrality and right matrix is sorted by page rank (gray-highlighted). Degree is measured by number of co-author-ed publications [Table 1].

at page rank at Solar Cell and Nano-carbon. Left matrix is sorted by page rank from 2006 to 2010 and right matrix is also sorted by page rank from 2011 to 2015 and showed the difference of ranking. Degree is measured by number of co-author-ed publications [Table 3, 4].

TABLE. 1 NETWORK INDEX OF INSTITUTIONAL CO-AUTHORSHIP AT TOP 1% PAPER FROM 2006 TO 2015

Rank	Instituions	degree	Betweenness Centrality	PageRank	Rank	Instituions	degree	Betweenness Centrality	PageRank
1	harvard univ	48	1324	0.1124	1	harvard univ	48	1324	0.1124
2	univ calif berkeley	18	331	0.0404	2	univ washington	27	193	0.0516
3	univ washington	27	193	0.0516	3	univ calif berkeley	18	331	0.0404
4	univ melbourne	3	127	0.0145	4	johns hopkins univ	15	66	0.0299
5	caltech	9	119	0.0218	5	univ oxford	14	109	0.0291
6	univ oxford	14	109	0.0291	6	univ toronto	14	27	0.0269
7	ohio state univ	9	87	0.0200	7	univ michigan	14	17	0.0264
8	univ london imperial coll sci technol & med	7	82	0.0176	8	univ penn	13	9	0.0242
9	johns hopkins univ	15	66	0.0299	9	univ calif san francisco	11	18	0.0219
10	univ tokyo	2	64	0.0089	10	caltech	9	119	0.0218
11	mem sloan kettering canc ctr	3	64	0.0110	11	univ cambridge	10	62	0.0215
12	univ cambridge	10	62	0.0215	12	cnrs	3	2	0.0201
13	univ maryland	6	37	0.0145	13	chinese acad sci	2	1	0.0200
14	mit	9	34	0.0192	14	ohio state univ	9	87	0.0200
15	univ toronto	14	27	0.0269	15	yale univ	10	6	0.0195
16	univ calif los angeles	9	19	0.0185	16	mit	9	34	0.0192
17	univ calif san francisco	11	18	0.0219	17	univ calif los angeles	9	19	0.0185
18	univ michigan	14	17	0.0264	18	univ london imperial coll sci technol & med	7	82	0.0176
19	univ colorado	2	9	0.0061	19	stanford univ	9	3	0.0175
20	univ penn	13	9	0.0242	20	univ pittsburgh	9	1	0.0173
21	dana farber canc inst	4	8	0.0119	21	columbia univ	8	1	0.0157
22	yale univ	10	6	0.0195	22	ucl	7	2	0.0154
23	brigham & womens hosp	3	5	0.0088	23	univ melbourne	3	127	0.0145
24	massachusetts gen hosp	4	3	0.0105	24	univ maryland	6	37	0.0145
25	stanford univ	9	3	0.0175	25	duke univ	7	1	0.0143
26	cnrs	3	2	0.0201	26	inserm	2	0	0.0135
27	ucl	7	2	0.0154	27	univ paris 06	2	0	0.0135
28	univ wisconsin	5	2	0.0115	28	univ chicago	6	1	0.0124
29	univ british columbia	5	2	0.0112	29	dana farber canc inst	4	8	0.0119
30	duke univ	7	1	0.0143	30	univ edinburgh	5	0	0.0116
31	univ pittsburgh	9	1	0.0173	31	univ wisconsin	5	2	0.0115
32	chinese acad sci	2	1	0.0200	32	univ british columbia	5	2	0.0112
33	columbia univ	8	1	0.0157	33	mem sloan kettering canc ctr	3	64	0.0110
34	univ chicago	6	1	0.0124	34	univ calif san diego	5	0	0.0108
35	boston univ	4	0	0.0092	35	peking univ	1	0	0.0106
36	univ so calif	1	0	0.0040	36	tsinghua univ	1	0	0.0106
37	univ paris 11	1	0	0.0077	37	massachusetts gen hosp	4	3	0.0105
38	baylor coll med	1	0	0.0040	38	kings coll london	4	0	0.0095
39	kyoto univ	1	0	0.0059	39	boston univ	4	0	0.0092
40	mayo clin	2	0	0.0057	40	univ tokyo	2	64	0.0089
41	univ illinois	2	0	0.0059	41	brigham & womens hosp	3	5	0.0088
42	karolinska inst	1	0	0.0040	42	univ paris 11	1	0	0.0077
43	univ bristol	2	0	0.0060	43	univ minnesota	3	0	0.0076
44	univ calif irvine	1	0	0.0040	44	mcgill univ	3	0	0.0076
45	univ edinburgh	5	0	0.0116	45	northwestern univ	3	0	0.0075
46	univ padua	2	0	0.0060	46	univ n carolina	3	0	0.0074
47	univ munich	1	0	0.0040	47	washington univ	3	0	0.0073
48	univ calif san diego	5	0	0.0108	48	univ sydney	1	0	0.0062
49	vanderbilt univ	2	0	0.0057	49	monash univ	1	0	0.0062
50	univ texas austin	1	0	0.0040	50	nasa	2	0	0.0062
51	univ copenhagen	2	0	0.0060	51	univ colorado	2	9	0.0061
52	princeton univ	1	0	0.0041	52	univ padua	2	0	0.0060
53	univ helsinki	1	0	0.0042	53	univ bristol	2	0	0.0060
54	kings coll london	4	0	0.0095	54	univ copenhagen	2	0	0.0060
55	mcgill univ	3	0	0.0076	55	kyoto univ	1	0	0.0059
56	northwestern univ	3	0	0.0075	56	univ illinois	2	0	0.0059
57	peking univ	1	0	0.0106	57	vanderbilt univ	2	0	0.0057
58	washington univ	3	0	0.0073	58	mayo clin	2	0	0.0057
59	univ sydney	1	0	0.0062	59	univ manchester	2	0	0.0057
60	emory univ	1	0	0.0040	60	univ texas md anderson canc ctr	1	0	0.0052
61	nyu	1	0	0.0040	61	univ helsinki	1	0	0.0042
62	univ n carolina	3	0	0.0074	62	princeton univ	1	0	0.0041
63	univ massachusetts	1	0	0.0040	63	univ so calif	1	0	0.0040
64	univ arizona	1	0	0.0040	64	baylor coll med	1	0	0.0040
65	univ minnesota	3	0	0.0076	65	karolinska inst	1	0	0.0040
66	univ texas md anderson canc ctr	1	0	0.0052	66	univ calif irvine	1	0	0.0040
67	nci	1	0	0.0040	67	univ munich	1	0	0.0040
68	monash univ	1	0	0.0062	68	emory univ	1	0	0.0040
69	tsinghua univ	1	0	0.0106	69	nyu	1	0	0.0040
70	nasa	2	0	0.0062	70	univ massachusetts	1	0	0.0040
71	inserm	2	0	0.0135	71	nci	1	0	0.0040
72	univ manchester	2	0	0.0057	72	univ texas austin	1	0	0.0040
73	univ paris 06	2	0	0.0135	73	univ arizona	1	0	0.0040

TABLE. 2 NETWORK INDEX OF INSTITUTIONAL CO-AUTHORSHIP AT 2. IPS CELL FROM 2006 TO 2015

Rank	Instituions	degree	Betweenness Centrality	PageRank	Rank	Instituions	degree	Betweenness Centrality	PageRank
1	harvard univ	47	2582	0.1080	1	harvard univ	47	2582	0.1080
2	chinese acad sci	15	794	0.0382	2	chinese acad sci	15	794	0.0382
3	univ calif san diego	13	308	0.0311	3	univ calif san diego	13	308	0.0311
4	univ so calif	3	246	0.0088	4	stanford univ	12	166	0.0247
5	johns hopkins univ	11	226	0.0246	5	johns hopkins univ	11	226	0.0246
6	univ tokyo	7	201	0.0144	6	univ calif san francisco	11	158	0.0243
7	univ cambridge	10	191	0.0235	7	univ cambridge	10	191	0.0235
8	stanford univ	12	166	0.0247	8	massachusetts gen hosp	11	16	0.0202
9	monash univ	3	166	0.0116	9	dana farber canc inst	10	16	0.0184
10	inra	3	166	0.0110	10	kyoto univ	9	80	0.0184
11	hannover med sch	2	166	0.0080	11	univ penn	8	118	0.0183
12	univ calif san francisco	11	158	0.0243	12	harvard stem cell inst	10	12	0.0182
13	univ penn	8	118	0.0183	13	mit	9	10	0.0167
14	salk inst biol studies	7	116	0.0165	14	salk inst biol studies	7	116	0.0165
15	univ hong kong	5	114	0.0146	15	howard hughes med inst	9	5	0.0163
16	max planck inst mol biomed	2	84	0.0103	16	brigham & womens hosp	9	5	0.0163
17	univ pittsburgh	3	84	0.0092	17	univ hong kong	5	114	0.0146
18	baylor coll med	2	84	0.0080	18	boston univ	8	3	0.0146
19	kyoto univ	9	80	0.0184	19	univ tokyo	7	201	0.0144
20	gladstone inst cardiovasc dis	6	73	0.0129	20	univ calif los angeles	6	35	0.0138
21	ucl	5	54	0.0124	21	columbia univ	6	38	0.0130
22	univ oxford	5	40	0.0120	22	childrens hosp	7	3	0.0130
23	columbia univ	6	38	0.0130	23	gladstone inst cardiovasc dis	6	73	0.0129
24	univ calif los angeles	6	35	0.0138	24	japan sci & technol agcy	6	2	0.0125
25	natl univ singapore	4	29	0.0115	25	ucl	5	54	0.0124
26	massachusetts gen hosp	11	16	0.0202	26	univ oxford	5	40	0.0120
27	univ edinburgh	4	16	0.0093	27	monash univ	3	166	0.0116
28	dana farber canc inst	10	16	0.0184	28	natl univ singapore	4	29	0.0115
29	kings coll london	4	16	0.0095	29	univ bonn	1	0	0.0114
30	harvard stem cell inst	10	12	0.0182	30	univ cologne	1	0	0.0114

TABLE. 3 NETWORK INDEX COMPARISON OF INSTITUTIONAL CO-AUTHORSHIP AT 3. SOLAR CELL FROM 2006 TO 2010 (LEFT) VS 2011 TO 2015 (RIGHT)

Rank	Instituions	degree	Betweenness Centrality	PageRank	Rank	Instituions	degree	Betweenness Centrality	PageRank	Difference
1	chinese acad sci	20	1638	0.0470	1	chinese acad sci	31	2533	0.0732	0
2	univ london imperial coll sci technol & med	13	846	0.0315	2	seoul natl univ	13	293	0.0245	8
3	osaka univ	9	317	0.0187	3	natl renewable energy lab	8	386	0.0210	2
4	univ cambridge	8	386	0.0185	4	natl inst mat sci	9	611	0.0204	27
5	natl renewable energy lab	8	509	0.0184	5	univ calif berkeley	9	588	0.0198	9
6	korea inst sci & technol	9	132	0.0183	6	korea adv inst sci & technol	10	182	0.0185	15
7	natl inst adv ind sci & technol	9	304	0.0181	7	sungkyunkwan univ	10	130	0.0180	18
8	ecole polytech fed lausanne	8	503	0.0181	8	pusan natl univ	9	637	0.0179	25
9	ind technol res inst	8	143	0.0167	9	nanyang technol univ	7	194	0.0168	34
10	seoul natl univ	7	382	0.0166	10	korea inst sci & technol	9	21	0.0163	-4
11	hanyang univ	8	90	0.0163	11	univ london imperial coll sci technol & med	6	226	0.0156	-9
12	forschungszentrum julich	6	239	0.0163	12	natl taiwan univ	7	251	0.0151	5
13	korea univ	8	206	0.0163	13	univ new s wales	5	121	0.0148	33
14	univ calif berkeley	7	367	0.0159	14	zhejiang univ	6	44	0.0146	47
15	japan sci & technol agcy	8	191	0.0156	15	korea univ	8	7	0.0145	-2
16	stanford univ	7	316	0.0155	16	tech univ denmark	5	199	0.0143	73
17	natl taiwan univ	7	102	0.0149	17	peking univ	5	90	0.0142	7
18	natl chiao tung univ	7	76	0.0146	18	stanford univ	6	254	0.0139	-2
19	georgia inst technol	6	461	0.0144	19	s china univ technol	5	111	0.0136	19
20	shanghai jiao tong univ	5	133	0.0144	20	natl inst adv ind sci & technol	6	184	0.0135	-13
21	korea adv inst sci & technol	7	44	0.0143	21	japan sci & technol agcy jst	6	105	0.0132	New
22	max planck inst polymer res	5	219	0.0134	22	univ tokyo	6	7	0.0132	8
23	univ freiburg	5	125	0.0129	23	ind technol res inst	6	2	0.0131	-14
24	peking univ	5	10	0.0129	24	univ tsukuba	6	50	0.0131	2
25	sungkyunkwan univ	6	69	0.0123	25	natl chiao tung univ	6	167	0.0131	-7
26	univ tsukuba	6	16	0.0121	26	korea inst energy res	7	32	0.0128	New
27	jilin univ	4	189	0.0119	27	huazhong univ sci & technol	4	210	0.0127	New
28	eindhoven univ technol	4	49	0.0119	28	soochow univ	5	8	0.0124	New
29	tohoku univ	6	7	0.0118	29	fudan univ	5	76	0.0123	48
30	univ tokyo	6	4	0.0117	30	georgia inst technol	5	177	0.0121	-11
31	natl inst mat sci	6	4	0.0117	31	ecole polytech fed lausanne	5	134	0.0117	-23
32	fraunhofer inst solar energy syst	5	134	0.0117	32	astar	4	91	0.0116	New
33	pusan natl univ	5	77	0.0116	33	univ washington	5	575	0.0114	47
34	royal inst technol	4	92	0.0112	34	korea res inst chem technol	6	44	0.0114	New
35	dalian univ technol	4	121	0.0110	35	acad sinica	5	1	0.0111	33
36	univ calif santa barbara	5	86	0.0109	36	cnr	1	0	0.0106	38
37	natl tsing hua univ	5	114	0.0109	37	eindhoven univ technol	1	0	0.0106	-9
38	s china univ technol	4	78	0.0105	38	delft univ technol	1	0	0.0106	6
39	univ autonoma madrid	4	110	0.0105	39	cnrs	1	0	0.0106	18
40	indian inst technol	1	0	0.0104	40	natl univ singapore	4	49	0.0106	22
41	natl phys lab	1	0	0.0104	41	univ calif santa barbara	4	144	0.0105	-5
42	uppsala univ	3	92	0.0100	42	chonbuk natl univ	5	44	0.0103	28
43	nanyang technol univ	3	131	0.0100	43	kyung hee univ	5	19	0.0102	New
44	delft univ technol	3	125	0.0099	44	argonne natl lab	2	88	0.0100	New
45	swiss fed inst technol	4	196	0.0096	45	e china normal univ	4	58	0.0100	New
46	univ new s wales	4	39	0.0095	46	univ cambridge	3	28	0.0095	-42
47	hahn meitner inst berlin gmbh	3	107	0.0094	47	kyoto univ	4	1	0.0092	8
48	univ oxford	4	67	0.0094	48	osaka univ	4	7	0.0092	-45
49	pohang univ sci & technol	4	40	0.0092	49	tohoku univ	4	41	0.0092	-20
50	johannes kepler univ linz	3	115	0.0092	50	natl tsing hua univ	4	0	0.0090	-13

TABLE. 4 NETWORK INDEX COMPARISON OF INSTITUTIONAL CO-AUTHORSHIP AT 4. NANO-CARBON FROM 2006 TO 2010 (LEFT) VS 2011 TO 2015 (RIGHT)

Rank	Instituions	degree	Betweenness Centrality	PageRank	Rank	Instituions	degree	Betweenness Centrality	PageRank	Difference
1	chinese acad sc	34	2037	0.0812	1	chinese acad sc	52	2628	0.1118	0
2	mit	13	858	0.0297	2	tsinghua univ	13	149	0.0264	1
3	tsinghua univ	11	529	0.0275	3	peking univ	13	130	0.0259	15
4	cnrs	9	444	0.0268	4	nanyang technc	11	152	0.0224	20
5	tohoku univ	12	306	0.0192	5	univ calif berkel	10	727	0.0210	2
6	japan sci & tech	12	69	0.0186	6	univ cambridge	3	3	0.0200	20
7	univ calif berkel	7	350	0.0180	7	tohoku univ	8	143	0.0168	-2
8	natl inst mat sc	11	161	0.0177	8	sungkyunkwan	8	394	0.0167	25
9	rice univ	6	100	0.0174	9	nanjing univ	7	7	0.0159	34
10	natl taiwan univ	4	257	0.0170	10	islamic azad un	2	1	0.0152	New
11	univ tokyo	11	87	0.0170	11	univ sci & techr	7	25	0.0147	12
12	natl inst adv inc	11	35	0.0169	12	korea inst sci &	7	223	0.0147	New
13	seoul natl univ	6	275	0.0161	13	natl inst mat sc	7	76	0.0146	-5
14	nagoya univ	10	136	0.0160	14	fudan univ	6	169	0.0146	11
15	tokyo inst techr	10	120	0.0159	15	seoul natl univ	7	8	0.0143	-2
16	zhejiang univ	6	70	0.0151	16	korea adv inst s	7	443	0.0143	26
17	osaka univ	10	2	0.0151	17	univ tokyo	6	89	0.0140	-6
18	peking univ	7	202	0.0145	18	tongji univ	6	106	0.0140	10
19	natl univ singap	6	142	0.0145	19	natl inst adv inc	6	151	0.0132	-7
20	russian acad sc	5	72	0.0143	20	shanghai jiao tc	6	12	0.0130	9
21	kyoto univ	9	17	0.0142	21	harbin inst tech	6	8	0.0129	39
22	univ texas austi	4	155	0.0139	22	mit	6	59	0.0128	-20
23	univ sci & techr	5	108	0.0132	23	natl univ singap	6	433	0.0123	-4
24	nanyang technc	5	167	0.0131	24	acad sinica	5	246	0.0123	New
25	fudan univ	5	8	0.0127	25	korea univ	6	3	0.0122	22
26	univ cambridge	4	141	0.0127	26	kyoto univ	5	13	0.0121	-5
27	univ tsukuba	8	8	0.0127	27	oak ridge natl la	5	53	0.0114	11
28	tongji univ	5	4	0.0124	28	soochow univ	5	2	0.0107	New
29	shanghai jiao tc	5	8	0.0124	29	tianjin univ	5	6	0.0106	60
30	csic	4	152	0.0121	30	cnr	2	0	0.0104	50
31	univ calif los an	5	199	0.0120	31	csic	2	0	0.0104	-1
32	univ mancheste	4	76	0.0119	32	cnrs	2	0	0.0104	-28
33	sungkyunkwan	4	84	0.0117	33	yonsei univ	5	0	0.0103	New
34	hokkaido univ	7	2	0.0112	34	zhejiang univ	5	2	0.0103	-18
35	northwestern u	4	202	0.0111	35	indian inst tech	2	84	0.0101	New
36	penn state univ	1	0	0.0110	36	e china univ sci	4	1	0.0093	19
37	univ wisconsin	1	0	0.0110	37	osaka univ	4	2	0.0093	-20
38	oak ridge natl la	4	80	0.0109	38	univ wollongong	4	1	0.0092	3
39	univ illinois	4	127	0.0108	39	univ queenslan	4	5	0.0092	51
40	hunan univ	4	102	0.0105	40	univ texas austi	4	1	0.0091	-18
41	univ wollongong	4	80	0.0104	41	chonbuk natl ur	3	246	0.0091	New
42	korea adv inst s	3	23	0.0095	42	city univ hong k	4	2	0.0091	12
43	nanjing univ	3	41	0.0092	43	univ illinois	3	84	0.0090	-4
44	tech univ dresd	3	49	0.0092	44	shanghai univ	4	2	0.0089	New
45	natl chiao tung	2	0	0.0092	45	hanyang univ	4	0	0.0086	7
46	natl tsing hua u	2	0	0.0092	46	csir	2	166	0.0085	New
47	korea univ	3	7	0.0091	47	natl tsing hua u	3	0	0.0084	-1
48	univ florida	3	68	0.0090	48	natl taiwan univ	3	0	0.0084	-38
49	columbia univ	4	98	0.0090	49	natl cheng kung	3	0	0.0084	27
50	georgia inst tec	3	15	0.0090	50	hunan univ	3	1	0.0083	-10

As above, we determined several network index at each dataset, which suggest various Discussion.

IV. DISCUSSION

(A) All visualization at these datasets have clearly divided, so it is almost impossible to progress on their research at single research group. So we defined these topics are all relevant topics to analyze inter-groups collaboration, which includes intra-institutions / inter-institutions.

(B) We successfully understand the distance among research institutions based on combination citation and institutional co-authorship network analysis.

1. To understand cutting-edge research field globally, this method reasonably comply with existing ranking such as university rankings [2][3] – for example, the advantage of American and British universities et al. Then we also have possibility to apply this standard for non-university research center. Also compared with result 2, we also can say medical research may effect heavily in terms of degree and number of papers, because of their research nature.
2. This method will comply well our historical understanding as well, e.g. the development in Kyoto University. In terms of network index, we got a possibility

that page rank complies overall global ranking, betweeness centrality comply their local citation and co-authorship – e.g. University of Tokyo has higher betweenness centrality, which may lead local / domestic co-authorship. Clearly country/language-dependency is higher to make a domain.

3. To know global capability, we used page rank based on above discussion. At this topic, basic technology does not change so much, and clearly understand emerging countries catch-up at this area such as China or South Korea. And according to previous study about solar cell research trend in 2010 [9] , there are lots of research before 2006, but we could not analyze properly the data before 2006 because we could not extract enough number of paper with Institutional co-authorship. This suggest institutional co-authorship develop very-recently and this methodology can be applied only for recent development like these 10 years. Global alliance among US, Germany and Japan in 2012[8], their alliance raised all of their page-rank from previous rank.
4. At this topic, some of basic technology may be revealed recently so comparing with 3, we can identify not only country-dependent movement but also key-player change such as Nagoya University (19>74), University of Cambridge (26>6).

In addition to each discussion, we revealed that both at Solar Cell and Nano-carbon, newer datasets show larger average clustering coefficient (Solar Cell: 0.329(old) > 0.407(new) / Nano-carbon: 0.398(old) > 0.555(new)), which indicates "small world" network[10], and means newer publication are more connected with co-authorships. This suggest co-authorship may be more and more important nowadays.

V. CONCLUSION

We have some suggestion from above cases that combination of citation and institutional co-authorship can evaluate research institutions in academic power and potential.

ACKNOWLEDGEMENTS

We thank Dr. Shino Iwami[9], Dr. Kimitaka Asarani[10] and Ms. Yuko Nakashio[11] for their help.

REFERENCES

[1] N. Shibata, Y. Kajikawa, Y. Takeda, and K. Matsushima, "Detecting emerging research fronts based on topological measures in citation networks of scientific publications," *Technovation*, vol. 28, no. 11, pp. 758–775, Nov. 2008.

[2] Shanghai Ranking Consultancy, "ARWU World University Rankings 2015 | Academic Ranking of World Universities 2015 | Top 500 universities | Shanghai Ranking - 2015." [Online]. Available: http://www.shanghairanking.com/ARWU2015.html. [Accessed: 30-Jan-2016].

[3] QS: Quacquarelli Symonds, "QS World University Rankings® 2015/16 | Top Universities." [Online]. Available: http://www.topuniversities.com/university-rankings/world-university-rankings/2015. [Accessed: 30-Jan-2016].

[4] A. Saka and T. Kuwahara, "University Research Benchmarking Series Benchmarking Research & Development Capacity of Japanese Universities 2011."

[5] S. Iwami, J. Mori, I. Sakata, and Y. Kajikawa, "Detection method of emerging leading papers using time transition," *Scientometrics*, vol. 101, no. 2, pp. 1515–1533, Jul. 2014.

[6] H. P. F. Peters and a. F. J. Raan, "Structuring scientific activities by co-author analysis," *Scientometrics*, vol. 20, no. 1, pp. 235–255, 1991.

[7] Y. Kajikawa, J. Ohno, Y. Takeda, K. Matsushima, and H. Komiyama, "Creating an academic landscape of sustainability science: an analysis of the citation network," *Sustain. Sci.*, vol. 2, no. 2, pp. 221–231, Jul. 2007.

[8] I. Sakata, H. Sasaki, M. Akiyama, Y. Sawatani, N. Shibata, and Y. Kajikawa, "Bibliometric analysis of service innovation research: Identifying knowledge domain and global network of knowledge," *Technol. Forecast. Soc. Change*, vol. 80, no. 6, pp. 1085–1093, Jul. 2013.

[9] N. Shibata, Y. Kajikawa, and I. Sakata, "Extracting the commercialization gap between science and technology - Case study of a solar cell," *Technol. Forecast. Soc. Change*, vol. 77, no. 7, pp. 1147–1155, 2010.

[10] D. J. Watts and S. H. Strogatz, "Collective dynamics of 'small-world' networks.," *Nature*, vol. 393, no. 6684, pp. 440–2, Jun. 1998.

[11] J. B. Gurdon and S. Yamanaka, "Mature cells can be reporgrammed to become pluripotent," *Nobel Lect.*, pp. 1–12, 2012.

[12] K. Takahashi, K. Tanabe, M. Ohnuki, M. Narita, T. Ichisaka, K. Tomoda, and S. Yamanaka, "Induction of Pluripotent Stem Cells from Adult Human Fibroblasts by Defined Factors," *Cell*, vol. 131, no. 5, pp. 861–872, 2007.

[13] W. Krätschmer, L. D. Lamb, K. Fostiropoulos, and D. R. Huffman, "Solid C60: a new form of carbon," *Nature*, vol. 347, no. 6291, pp. 354–358, Sep. 1990.

[14] S. Iijima, "Helical microtubules of graphitic carbon," *Nature*, vol. 354, no. 6348, pp. 56–58, Nov. 1991.

[15] K. S. K. S. Novoselov, A. K. a. K. Geim, S. V. S. V Morozov, D. Jiang, Y. Zhang, S. V. V Dubonos, I. V. V Grigorieva, and a. a. a Firsov, "Electric field effect in atomically thin carbon films.," *Science (80-.).*, vol. 306, pp. 666–669, 2004.

[8] Global Alliance of Solar Energy Research Institutes World leading solar research institutes sign agreement; Press Release - San Francisco, July 11, 2012 -- Three leading solar research institutes: the U.S. Department of Energy's National Renewable Energy Laboratory, NREL (USA), Fraunhofer Institute for Solar Energy Systems ISE (Germany) and the National Institute of Advanced Industrial Science and Technology AIST (Japan) yesterday signed a Memorandum of Understanding to form the Global Alliance of Solar Energy Research Institutes GA-SERI. https://www.ise.fraunhofer.de/en/press-and-media/press-releases/press-releases-2012/global-alliance-of-solar-energy-research-institutes

[9] Department of Physics of Complex Systems, Eötvös Loránd University, and Department of Technology Management for Innovation, Graduate School of Engineering, the University of Tokyo

[10] Department of Technology Management for Innovation, Graduate School of Engineering, the University of Tokyo

[11] Department of System Innovation, Faculty of Engineering, the University of Tokyo