

Exploring International Scientific Cooperation Using Social Network Analysis: A Case Study in Nanotechnology

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Local to Global, Global to Local

Innovation Systems and Public Policy in a Global Economy

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Why Study International Scientific Cooperation (ISC)?

◆ Why Cooperation?

- Exponential growth in the past 2 decades
- Understanding of how tacit knowledge is transferred

◆ Why Scientific?

- Co-authorship publications are one of the best available measurements of tacit knowledge transfers (Hicks and Narin 2001; Zucker, Darby, Liu and Ma 2007)

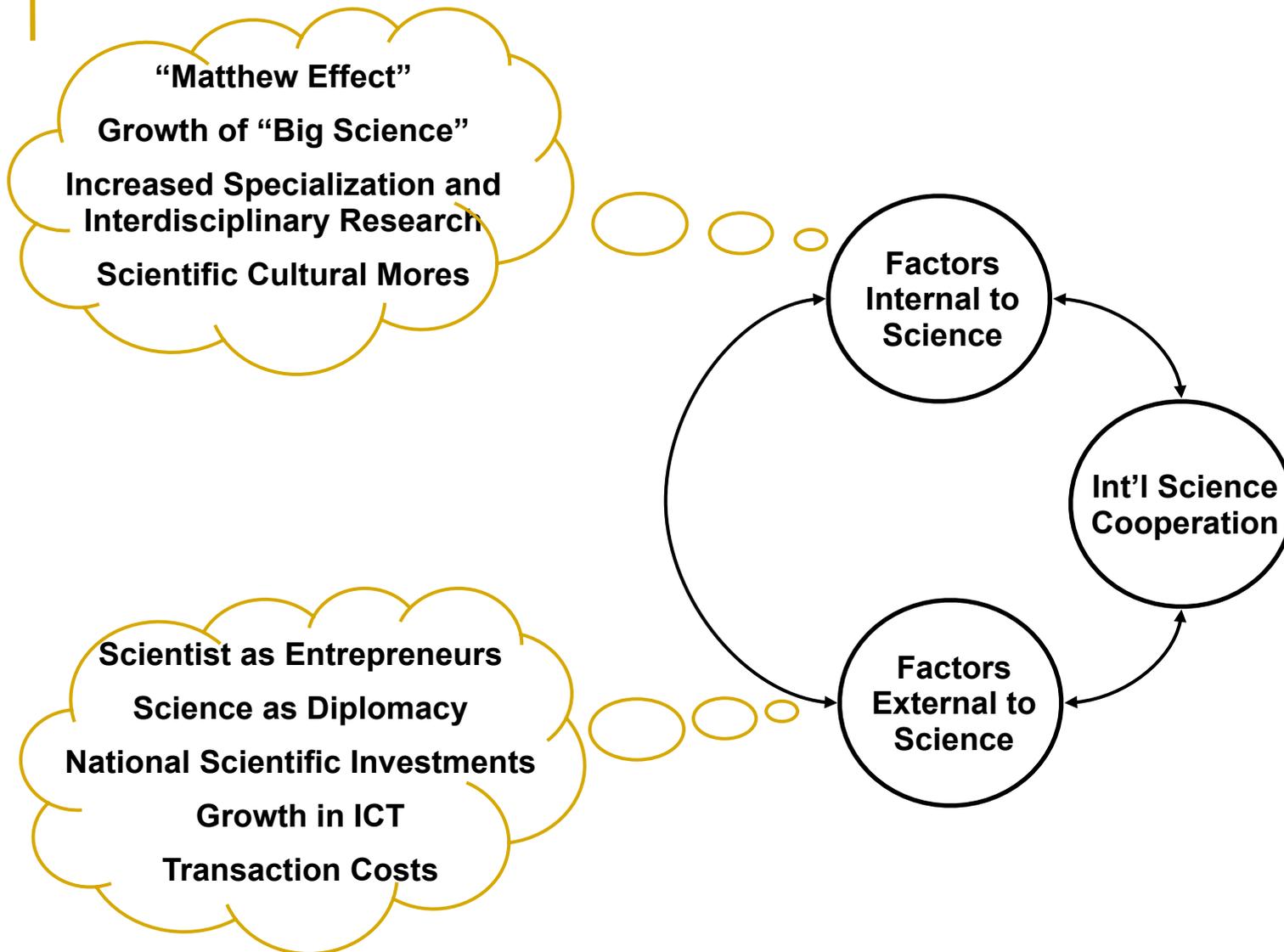
◆ Why International?

- Access to the best and brightest for developed countries
- Understand diffusion to developing countries

◆ Strong Policy Implications

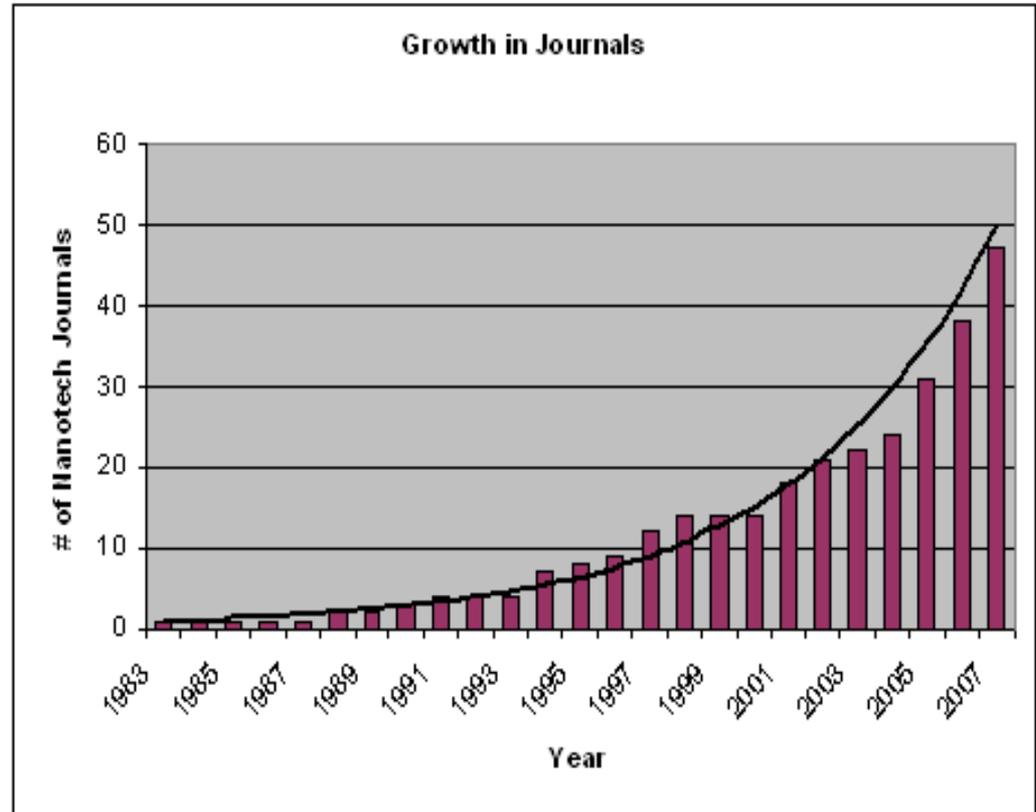
- Growth in international science has direct impact on national systems supporting science
- A fuller understanding of the factors contributing to this growth could aid the governance and management of national and international investments in science

What is driving International Scientific Cooperation?



Why Study Nanotechnology?

- ◆ Growing field
- ◆ Interdisciplinary
- ◆ Tied closely to industry
- ◆ Policy Interest



Research Questions

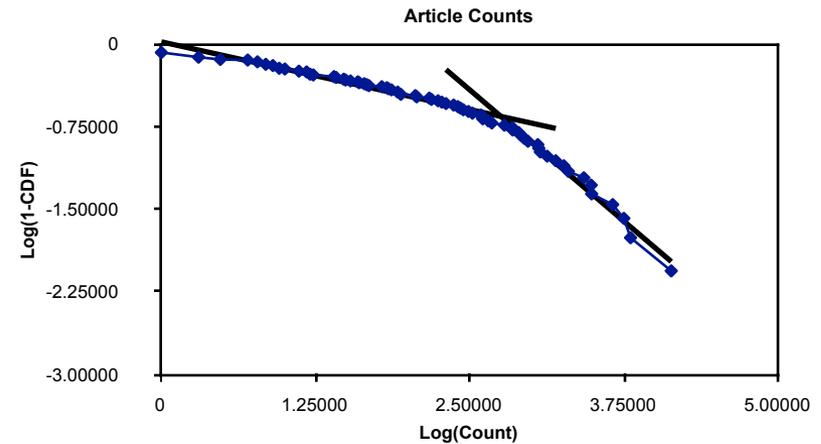
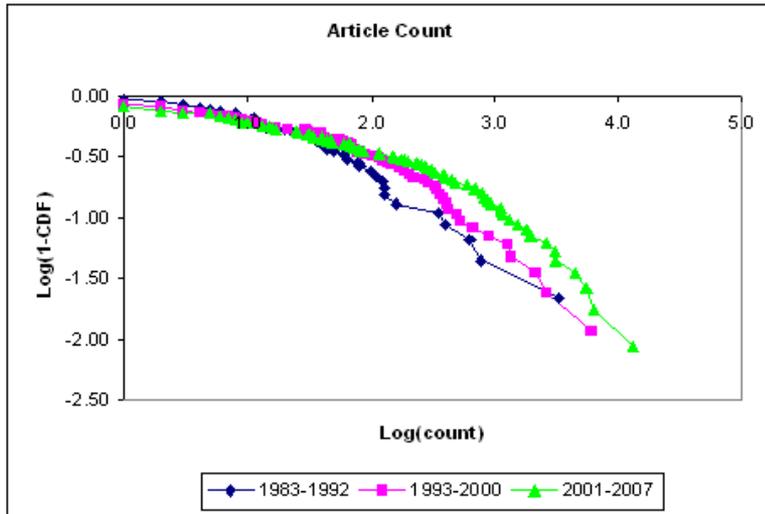
- ◆ **Is international collaboration growing?**
- ◆ **What is the pattern of collaboration over time?**
- ◆ **To what extent has nanotechnology research diffused?**
- ◆ **What countries have access to the best and the brightest**

The Data

- ◆ **Bibliometric data from 42 nanotechnology journals**
 - **Author country locations and citations**
- ◆ **Time periods:**
 - **Cold War Era – 1983-1992**
 - **Internet Boom – 1993-2000**
 - **Current Era – 2001-2007**

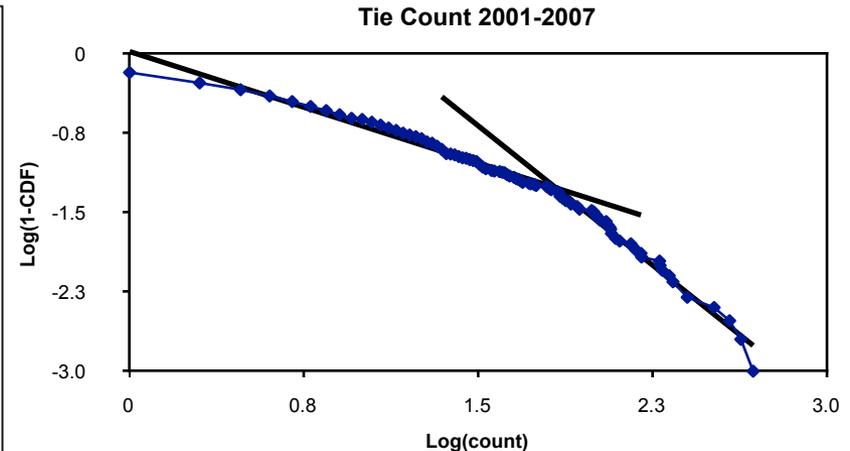
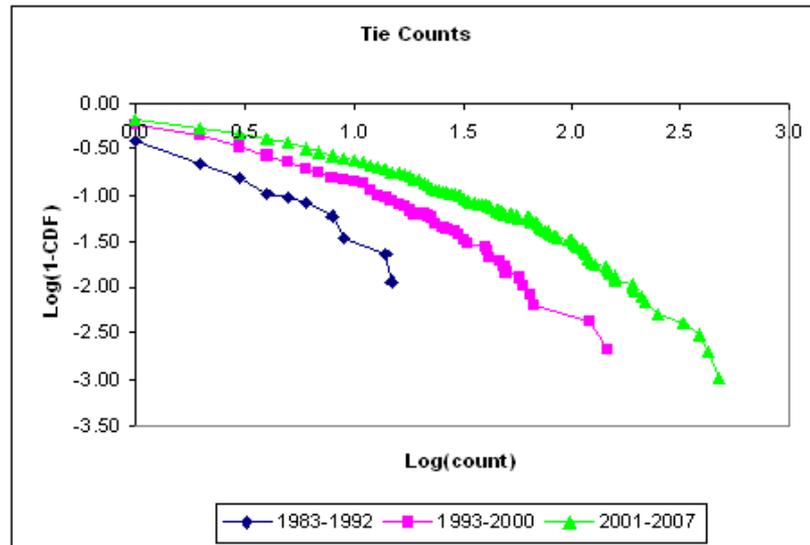
	1983-1992	1993-2000	2001-2007	All
Total Records	6718	19366	48946	74997
Total Records w/ Country Data	6701	19216	48838	74755
Average number of countries per paper	1.02	1.12	1.23	1.19
Average Citation per paper	15.91	10.23	5.28	7.52
Average Collaborators per paper	1.13	1.48	2.01	1.80

National Output of Articles



- ◆ Total number of articles in any given country (single author or co-author)
 - E.g., between 2001-2007, 13,508 articles were authored or co-authored in the US.
- ◆ Over time, the distribution is becoming a more pronounced two-tier power law
 - Highlights growing core-periphery distinction
 - Disparity of distribution in the core is significantly less than in periphery

Bilateral Collaborations



- ◆ Tie counts: number articles co-authored across 2 countries
- ◆ Distribution also follows a two-tier power law

Position	1983-1992	1993-2000	2001-2007
1	USA-Japan	USA-Germany	USA-Germany
2	USA-Germany	USA-Japan	USA-China
3	USA-France	USA-Korea	USA-Japan
4	USA-UK	USA-France	USA-Korea

Country Rankings in the Core

Rank	1983-1992	1993-2000	2001-2007
1	USA	USA	USA
2	Japan	Japan	Japan
3	Germany	Germany	Peoples R. China
4	United Kingdom	United Kingdom	Germany
5	France	France	<i>South Korea</i>
6	Canada	Peoples R. China	United Kingdom
7	Switzerland	<i>South Korea</i>	France
8	Netherlands	Switzerland	<i>Taiwan</i>
9	India	Canada	India
10	Italy	Italy	Canada
11	<i>USSR</i>	<i>Russia</i>	<i>Singapore</i>
12	Peoples R. China	Netherlands	Italy
13	<i>Australia</i>	<i>Spain</i>	<i>Spain</i>
14		<i>Sweden</i>	Switzerland
15		India	Netherlands
16		<i>Taiwan</i>	<i>Sweden</i>
17		<i>Belgium</i>	
18		<i>Australia</i>	

* *Italicized countries* do not make the core during all three time periods.

Network Centrality Rankings

	2001-2007		
Country	Article Count	Degree	Betweenness
USA	1	1	1
Peoples R China	2	9	4
Japan	3	5	5
Germany	4	4	7
France	5	2	2
South Korea	6	22	22
United Kingdom	7	3	3
Taiwan	8	33	38
India	9	15	8
Italy	10	6	6
Spain	11	7	9
Canada	12	11	11
Russia	13	15	19
Singapore	14	30	32
Switzerland	15	13	20
Netherlands	16	14	16
Belgium	17	10	15
Australia	18	18	24
Sweden	19	8	10
Brazil	20	22	23

- ◆ **European countries' network centrality rank are greater than their article output**
- ◆ **Asian countries' network centrality are significantly lower than article output**

Intensity of Collaborations of 14 Largest Countries by GDP (2001-2007)

Network3 Multidirectional Affinity (Salton's Measure)															
	USA	Peoples R China	Japan	South Korea	Germany	France	United Kingdom	Italy	Spain	Canada	Russia	India	Brazil	Mexico	Sweden
USA	0														
Peoples R China	0.046	0													
Japan	0.044	0.042	0												
South Korea	0.051	0.018	0.039	0											
Germany	0.061	0.028	0.021	0.013	0										
France	0.034	0.015	0.021	0.005	0.056	0									
United Kingdom	0.042	0.028	0.026	0.015	0.042	0.041	0								
Italy	0.031	0.004	0.009	0	0.032	0.054	0.031	0							
Spain	0.029	0.004	0.01	0	0.048	0.057	0.037	0.036	0						
Canada	0.049	0.014	0.012	0.005	0.02	0.023	0.028	0.015	0.011	0					
Russia	0.048	0.007	0.018	0.012	0.084	0.04	0.028	0.019	0.019	0.009	0				
India	0.023	0.003	0.022	0.014	0.025	0.014	0.008	0.007	0.003	0.011	0.003	0			
Brazil	0.023	0	0.005	0	0.017	0.029	0.017	0.006	0.023	0.01	0.013	0.003	0		
Mexico	0.031	0.004	0.012	0.002	0.013	0.019	0.007	0.001	0.029	0.01	0.012	0.002	0.008	0	
Sweden	0.018	0.012	0.01	0.004	0.035	0.02	0.024	0.011	0.02	0.006	0.034	0.004	0.007	0.004	0

- ◆ Intensities is an indicator of strength of bilateral collaboration using Salton's Measure
 - Strong intensities (>0.03) highlighted
- ◆ Emergent Properties
 - Regional Effects in Asia, Europe, and North America
 - Colonial Ties are pronounced
 - U.S. as the only globally intense collaborator

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Peoples R	80	10.9%	13.8%	78.7%	Japan	380	10.8%	15.8%	68.6%	Japan	250	18.2%	13.1%	138.7%	Peoples R	64	4.3%	13.8%	31.2%
Japan	159	21.6%	12.2%	177.3%	Germany	480	13.7%	12.8%	106.7%	Germany	150	10.9%	10.6%	102.5%	Japan	85	5.7%	12.2%	47.0%
Germany	48	6.5%	9.9%	65.9%	France	217	6.2%	8.7%	71.4%	France	64	4.7%	7.2%	64.7%	Germany	209	14.1%	9.9%	142.3%
France	14	1.9%	6.7%	28.5%	South Korea	326	9.3%	8.6%	108.2%	South Korea	80	5.8%	7.1%	81.6%	South Korea	14	0.9%	6.6%	14.2%
United Kin	42	5.7%	5.8%	98.8%	United Kin	250	7.1%	7.5%	95.2%	United Kin	114	8.3%	6.2%	133.4%	United Kin	117	7.9%	5.8%	136.4%
Taiwan	22	3.0%	4.3%	69.0%	Taiwan	114	3.2%	5.6%	57.9%	Taiwan	24	1.7%	4.7%	37.4%	Taiwan	9	0.6%	4.3%	14.0%
India	32	4.3%	4.0%	109.3%	India	112	3.2%	5.2%	61.9%	India	9	0.7%	4.3%	15.3%	India	32	2.2%	4.0%	54.2%
Italy	1	0.1%	3.4%	4.0%	Italy	143	4.1%	4.4%	92.0%	Italy	13	0.9%	3.7%	25.7%	Italy	118	7.9%	3.4%	232.3%
Spain	1	0.1%	2.9%	4.7%	Spain	123	3.5%	3.8%	92.8%	Spain	12	0.9%	3.1%	27.8%	Spain	116	7.8%	2.9%	267.9%
Canada	9	1.2%	2.6%	47.6%	Canada	195	5.6%	3.3%	167.0%	Canada	39	2.8%	2.8%	102.6%	Canada	43	2.9%	2.6%	112.7%
Russia	23	3.1%	2.5%	125.4%	Russia	190	5.4%	3.2%	167.8%	Russia	19	1.4%	2.7%	51.5%	Russia	75	5.0%	2.5%	202.7%
Singapore	3	0.4%	2.4%	16.6%	Singapore	123	3.5%	3.2%	110.5%	Singapore	101	7.3%	2.6%	278.8%	Singapore	6	0.4%	2.4%	16.5%
Switzerland	13	1.8%	2.0%	86.6%	Switzerland	105	3.0%	2.6%	113.3%	Switzerland	11	0.8%	2.2%	36.5%	Switzerland	99	6.7%	2.0%	326.9%
Netherland	4	0.5%	1.9%	28.6%	Netherland	97	2.8%	2.5%	112.4%	Netherland	11	0.8%	2.0%	39.1%	Netherland	47	3.2%	1.9%	166.6%
Belgium	8	1.1%	1.8%	60.9%	Belgium	102	2.9%	2.3%	125.7%	Belgium	21	1.5%	1.9%	79.5%	Belgium	79	5.3%	1.8%	297.9%
Australia	19	2.6%	1.7%	150.4%	Australia	75	2.1%	2.2%	96.2%	Australia	84	6.1%	1.8%	330.9%	Australia	12	0.8%	1.7%	47.1%

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Spain	1	0.1%	2.9%	4.7%	Spain	123	3.5%	3.8%	92.8%	Spain	12	0.9%	3.1%	27.8%	Spain	116	7.8%	2.9%	267.9%
Canada	9	1.2%	2.6%	47.6%	Canada	195	5.6%	3.3%	167.0%	Canada	39	2.8%	2.8%	102.6%	Canada	43	2.9%	2.6%	112.7%
Russia	23	3.1%	2.5%	125.4%	Russia	190	5.4%	3.2%	167.8%	Russia	19	1.4%	2.7%	51.5%	Russia	75	5.0%	2.5%	202.7%
Singapore	3	0.4%	2.4%	16.6%	Singapore	123	3.5%	3.2%	110.5%	Singapore	101	7.3%	2.6%	278.8%	Singapore	6	0.4%	2.4%	16.5%
Switzerland	13	1.8%	2.0%	86.6%	Switzerland	105	3.0%	2.6%	113.3%	Switzerland	11	0.8%	2.2%	36.5%	Switzerland	99	6.7%	2.0%	326.9%
Netherland	4	0.5%	1.9%	28.6%	Netherland	97	2.8%	2.5%	112.4%	Netherland	11	0.8%	2.0%	39.1%	Netherland	47	3.2%	1.9%	166.6%
Belgium	8	1.1%	1.8%	60.9%	Belgium	102	2.9%	2.3%	125.7%	Belgium	21	1.5%	1.9%	79.5%	Belgium	79	5.3%	1.8%	297.9%
Australia	19	2.6%	1.7%	150.4%	Australia	75	2.1%	2.2%	96.2%	Australia	84	6.1%	1.8%	330.9%	Australia	12	0.8%	1.7%	47.1%

◆ **JP = Joint Papers, SJP = Share of total joint papers, SPC = Share of Partner Country in world – Output of Country, AFF = SJP/SPC**

➤ **Affinity of 100% means partner country is just as important to the country as it to the rest of the world, >100% is a positive affinity**

◆ **Observations**

- **Geography matters**
- **Foreign Policy matters**
- **Shared culture and diasporas matter**

Unidirectional Affinities (2001-2007)

South Korea					USA					Peoples R China					France				
International Papers 737					International Papers 3510					International Papers 1375					International Papers 1486				
C	JP	SJP	SPC	AFF	C	JP	SJP	SPC	AFF	C	JP	SJP	SPC	AFF	C	JP	SJP	SPC	AFF
USA	326	44.2%	29.5%	150.0%	Peoples R	425	12.1%	17.9%	67.7%	USA	425	30.9%	31.8%	97.3%	USA	217	14.6%	29.5%	49.5%
Peoples R	80	10.9%	13.8%	78.7%	Japan	380	10.8%	15.8%	68.6%	Japan	250	18.2%	13.1%	138.7%	Peoples R	64	4.3%	13.8%	31.2%
Japan	159	21.6%	12.2%	177.3%	Germany	480	13.7%	12.8%	106.7%	Germany	150	10.9%	10.6%	102.5%	Japan	85	5.7%	12.2%	47.0%
Germany	48	6.5%	9.9%	65.9%	France	217	6.2%	8.7%	71.4%	France	64	4.7%	7.2%	64.7%	Germany	209	14.1%	9.9%	142.3%
France	14	1.9%	6.7%	28.5%	South Korea	326	9.3%	8.6%	108.2%	South Korea	80	5.8%	7.1%	81.6%	South Korea	14	0.9%	6.6%	14.2%
United Kin	42	5.7%	5.8%	98.8%	United Kin	250	7.1%	7.5%	95.2%	United Kin	114	8.3%	6.2%	133.4%	United Kin	117	7.9%	5.8%	136.4%
Taiwan	22	3.0%	4.3%	69.0%	Taiwan	114	3.2%	5.6%	57.9%	Taiwan	24	1.7%	4.7%	37.4%	Taiwan	9	0.6%	4.3%	14.0%
India	32	4.3%	4.0%	109.3%	India	112	3.2%	5.2%	61.9%	India	9	0.7%	4.3%	15.3%	India	32	2.2%	4.0%	54.2%
Italy	1	0.1%	3.4%	4.0%	Italy	143	4.1%	4.4%	92.0%	Italy	13	0.9%	3.7%	25.7%	Italy	118	7.9%	3.4%	232.3%
Spain	1	0.1%	2.9%	4.7%	Spain	123	3.5%	3.8%	92.8%	Spain	12	0.9%	3.1%	27.8%	Spain	116	7.8%	2.9%	267.9%
Canada	9	1.2%	2.6%	47.6%	Canada	195	5.6%	3.3%	167.0%	Canada	39	2.8%	2.8%	102.6%	Canada	43	2.9%	2.6%	112.7%
Russia	23	3.1%	2.5%	125.4%	Russia	190	5.4%	3.2%	167.8%	Russia	19	1.4%	2.7%	51.5%	Russia	75	5.0%	2.5%	202.7%
Singapore	3	0.4%	2.4%	16.6%	Singapore	123	3.5%	3.2%	110.5%	Singapore	101	7.3%	2.6%	278.8%	Singapore	6	0.4%	2.4%	16.5%
Switzerlan	13	1.8%	2.0%	86.6%	Switzerlan	105	3.0%	2.6%	113.3%	Switzerlan	11	0.8%	2.2%	36.5%	Switzerlan	99	6.7%	2.0%	326.9%
Netherland	4	0.5%	1.9%	28.6%	Netherland	97	2.8%	2.5%	112.4%	Netherland	11	0.8%	2.0%	39.1%	Netherland	47	3.2%	1.9%	166.6%
Belgium	8	1.1%	1.8%	60.9%	Belgium	102	2.9%	2.3%	125.7%	Belgium	21	1.5%	1.9%	79.5%	Belgium	79	5.3%	1.8%	297.9%
Australia	19	2.6%	1.7%	150.4%	Australia	75	2.1%	2.2%	96.2%	Australia	84	6.1%	1.8%	330.9%	Australia	12	0.8%	1.7%	47.1%

- ◆ **JP = Joint Papers, SJP = Share of total joint papers, SPC = Share of Partner Country in world – Output of Country, AFF = SJP/SPC**
 - **Affinity of 100% means partner country is just as important to the country as it to the rest of the world, >100% is a positive affinity**
- ◆ **Observations**
 - **Geography matters**
 - **Foreign Policy matters**
 - **Shared culture and diasporas matter**
 - **Strong affinities among EU countries**

Unidirectional Affinities - Sweden

1993-2000					2001-2007				
International Papers			78		International Papers			321	
C	JP	SJP	SPC	AFF	C	JP	SJP	SPC	AFF
USA	17	21.8%	32.2%	67.6%	Germany	62	19.3%	9.4%	205.4%
Germany	7	9.0%	11.3%	79.3%	USA	55	17.1%	28.1%	61.1%
Japan	6	7.7%	13.9%	55.4%	United Kin	33	10.3%	5.5%	187.2%
France	6	7.7%	7.2%	106.6%	Russia	30	9.3%	2.4%	394.6%
United Kin	6	7.7%	6.7%	114.7%	France	29	9.0%	6.4%	142.3%
Bulgaria	5	6.4%	0.2%	2891.6%	Peoples R	26	8.1%	13.1%	61.7%
Italy	3	3.8%	2.8%	135.7%	Denmark	23	7.2%	0.7%	1042.0%
Russia	3	3.8%	2.6%	146.6%	Japan	19	5.9%	11.6%	51.1%
Greece	3	3.8%	0.6%	639.2%	Spain	19	5.9%	2.8%	213.6%
Denmark	3	3.8%	0.5%	714.4%	Switzerlan	13	4.0%	1.9%	208.9%
Peoples R	2	2.6%	4.8%	54.0%	Finland	13	4.0%	0.6%	698.7%
Canada	2	2.6%	2.2%	114.6%	Italy	11	3.4%	3.3%	105.4%
Switzerlan	2	2.6%	2.2%	118.5%	Netherland	11	3.4%	1.8%	189.8%
Spain	2	2.6%	1.9%	133.5%	Austria	11	3.4%	1.0%	347.3%
Belgium	2	2.6%	1.5%	169.3%	Poland	9	2.8%	1.2%	224.6%
Australia	2	2.6%	1.2%	221.8%	Belgium	7	2.2%	1.7%	128.5%
Poland	2	2.6%	1.0%	258.4%	South Kore	6	1.9%	6.3%	29.7%
Ukraine	2	2.6%	0.7%	354.6%	Ukraine	6	1.9%	0.6%	293.1%
Turkey	2	2.6%	0.4%	656.5%	Romania	6	1.9%	0.3%	607.9%
Norway	2	2.6%	0.3%	809.7%	Bulgaria	6	1.9%	0.2%	1097.3%

Conclusions

- ◆ **Is international collaboration growing?**
 - **Increased reliance on collaboration**

- ◆ **What is the pattern of collaboration over time?**
 - **Growing gap between the core-periphery**
 - **Asian countries are becoming increasingly attractive**

- ◆ **To what extent has nanotechnology research diffused?**
 - **Diffuses through geographical, cultural and political lines**

- ◆ **What countries have access to the best and the brightest**
 - **US and European strategy is to have global access to talent**
 - **Asian countries strategy is to target leading countries**