

# ***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**

**George Mason University**

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# Why Study International Scientific Cooperation (ISC)?

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## ◆ 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)

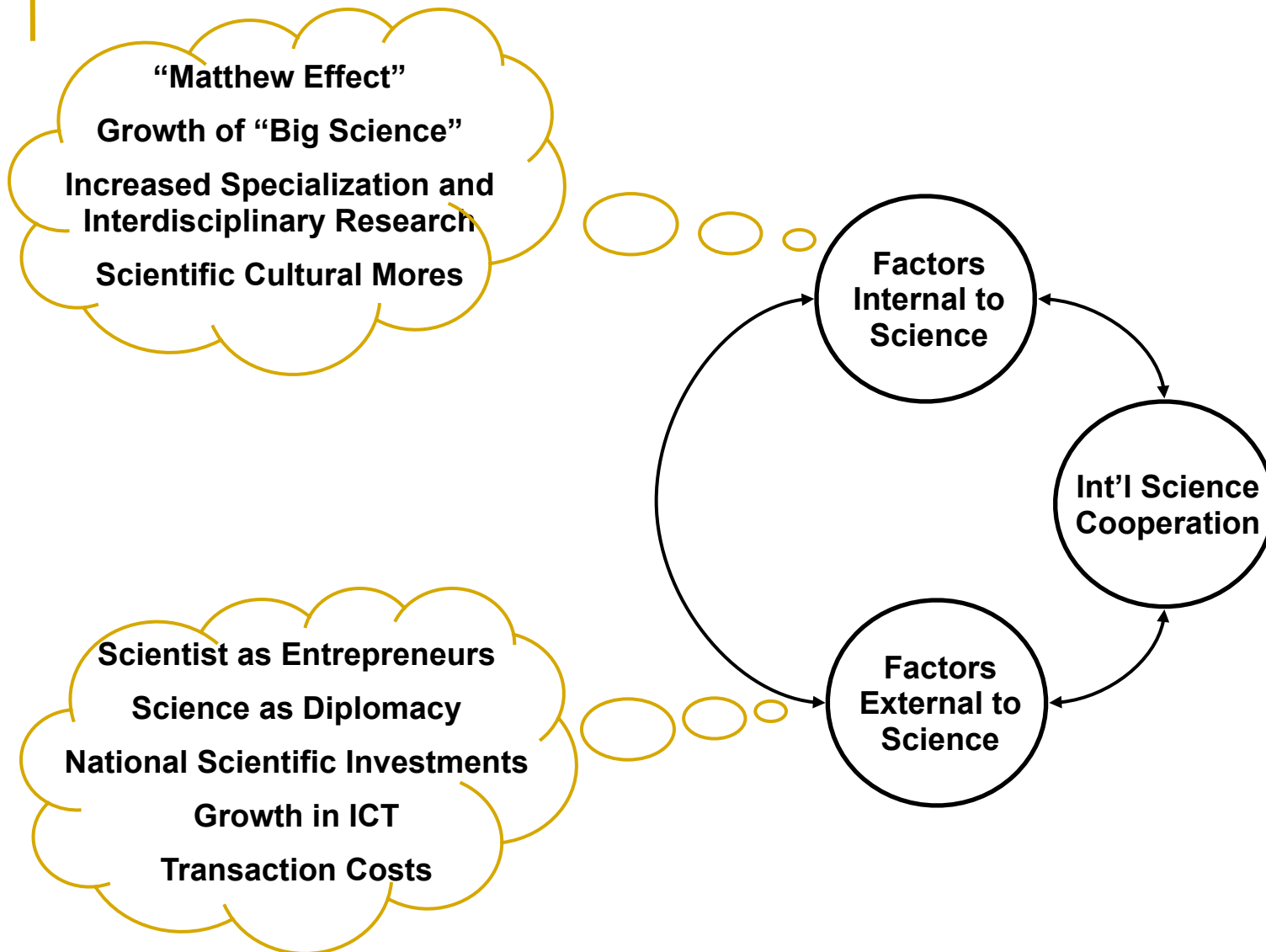
## ◆ Why International?

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

## ◆ Strong Policy Implications

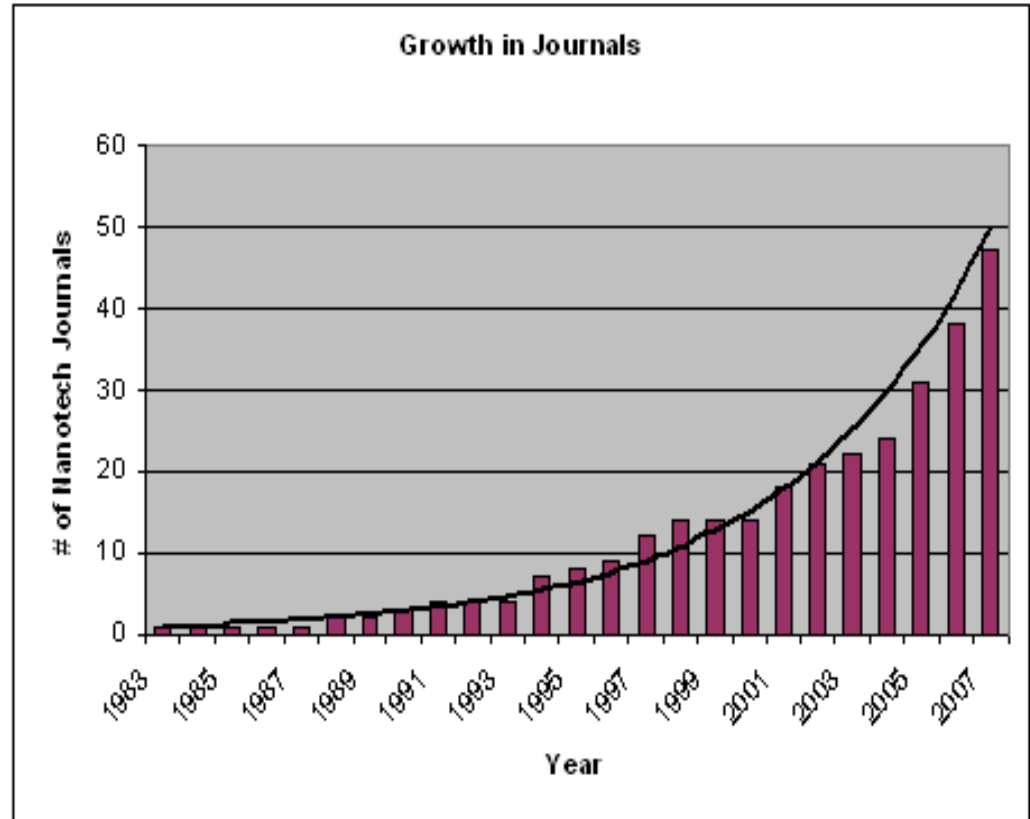
- Growth in international science has direct impact on national systems supporting science
- A fuller understanding of the factors contributing to this growth could aid the governance and management of national and international investments in science

# What is driving International Scientific Cooperation?



# Why Study Nanotechnology?

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



# Research Questions

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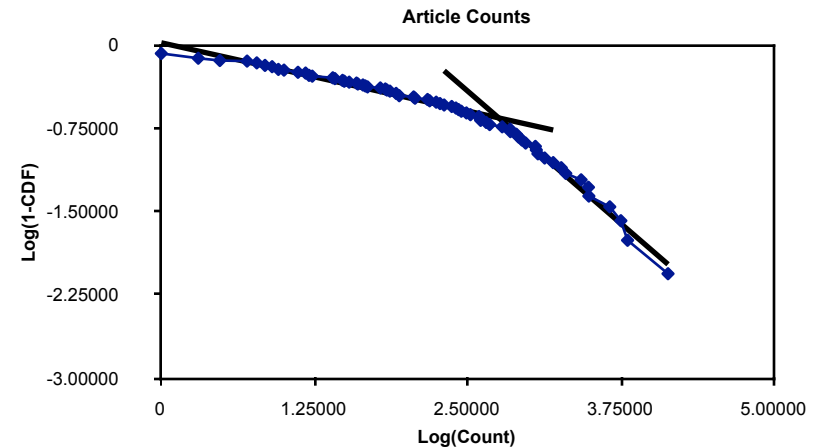
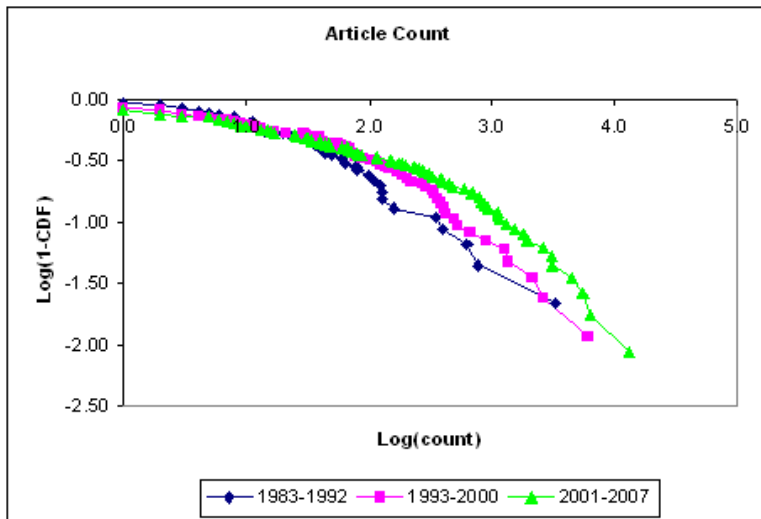
- ◆ **Is international collaboration growing?**
- ◆ **What is the pattern of collaboration over time?**
- ◆ **To what extent has nanotechnology research diffused?**
- ◆ **What countries have access to the best and the brightest**

# 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**

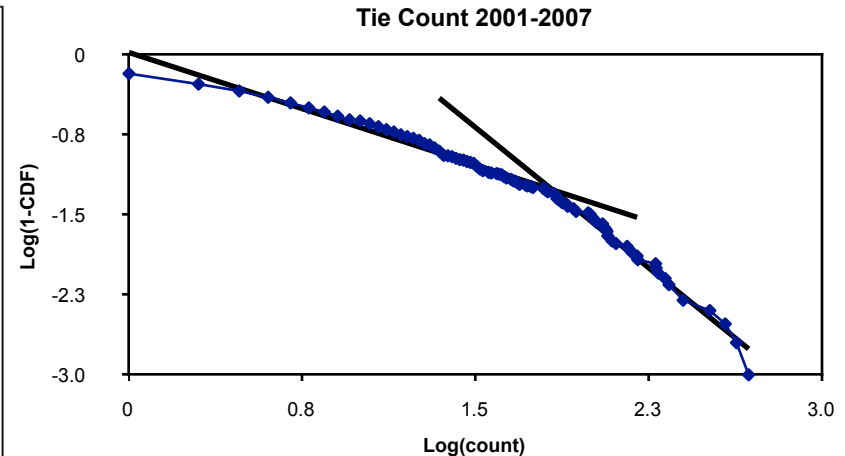
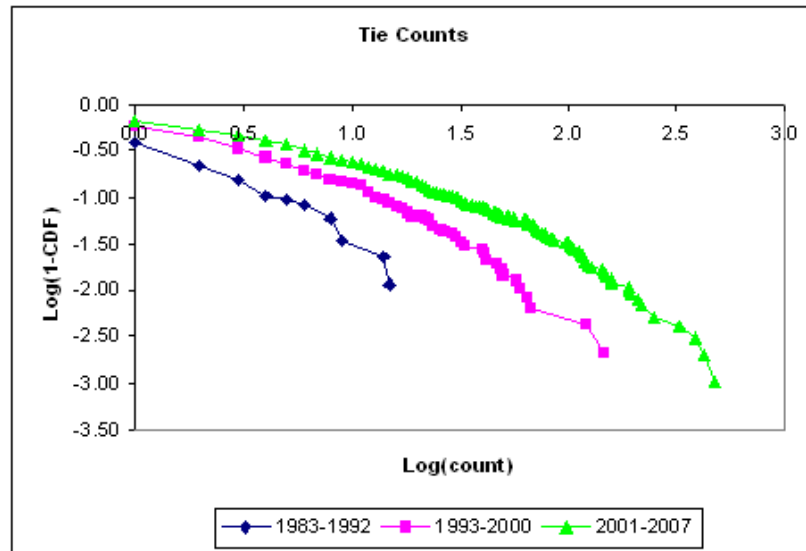
	<b>1983-1992</b>	<b>1993-2000</b>	<b>2001-2007</b>	<b>All</b>
<b>Total Records</b>	6718	19366	48946	74997
<b>Total Records w/ Country Data</b>	6701	19216	48838	74755
<b>Average number of countries per paper</b>	1.02	1.12	1.23	1.19
<b>Average Citation per paper</b>	15.91	10.23	5.28	7.52
<b>Average Collaborators per paper</b>	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	<b>0.046</b>	0													
Japan	<b>0.044</b>	<b>0.042</b>	0												
South Korea	<b>0.051</b>	0.018	<b>0.039</b>	0											
Germany	<b>0.061</b>	0.028	0.021	0.013	0										
France	<b>0.034</b>	0.015	0.021	0.005	<b>0.056</b>	0									
United Kingdom	<b>0.042</b>	0.028	0.026	0.015	<b>0.042</b>	<b>0.041</b>	0								
Italy	<b>0.031</b>	0.004	0.009	0	<b>0.032</b>	<b>0.054</b>	<b>0.031</b>	0							
Spain	0.029	0.004	0.01	0	<b>0.048</b>	<b>0.057</b>	<b>0.037</b>	<b>0.036</b>	0						
Canada	<b>0.049</b>	0.014	0.012	0.005	0.02	0.023	0.028	0.015	0.011	0					
Russia	<b>0.048</b>	0.007	0.018	0.012	<b>0.084</b>	<b>0.04</b>	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	<b>0.031</b>	0.004	0.012	0.002	0.013	0.019	0.007	0.001	<b>0.029</b>	0.01	0.012	0.002	0.008	0	
Sweden	0.018	0.012	0.01	0.004	<b>0.035</b>	0.02	0.024	0.011	0.02	0.006	<b>0.034</b>	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

## 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%

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  - **Geography matters!**

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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%

◆ **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

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- ◆ **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**