

A Bibliometric Mapping of the Scientific Landscape on Taiwan

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This study makes an attempt to explore the scientific landscape on Taiwan. Through bibliometric citation analysis and mapping techniques the main actors at the university level are identified and the structure of the national research and development (R&D) system is described with respect to article production and publication patterns. Special attention is paid to patterns of research collaboration, nationally as well as internationally. This paper concludes that Taiwan is well integrated in the international scientific macro-networks. However, the findings do not give support to the idea that Asian science and scientific thinking would differ from Western science; on the contrary, Taiwan has developed quickly into a science nation of significance by adapting Western scientific traditions and becoming integrated in international scientific networks.

KEYWORDS: bibliometrics; co-authorship; research collaboration; Taiwan R&D; scientific networks

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There are a number of countries in Pacific Asia that have developed quickly as scientific nations during the past few decades. A handful of Asian countries are now established as science nations with a research production equivalent to many European countries of comparable size. These countries will most likely continue to develop along with the traditionally strong science nations in the West. Some studies argue that the twenty-first century belongs to Asian science rather than Euro-originated science.¹ According to Goonatilake, the ideas of the scientific revolution of the seventeenth and eighteenth centuries are in transition and Asian scientific thinking and knowledge production are to take over. Goonatilake's arguments rely heavily on the emergence of information technologies and the rise of postmodern thinking along with the demise of modernism. In this process of shifting technology and shifting thinking, three realms of information—in culture, genes, and computers—will merge together and Asia is argued to be the part of the world which will provide the key to this process and host its new scientific centers.

Others have noted the difference between Asia and the West in scientific tradition and scientific thinking as well. Staal describes the three main scientific traditions of the Eurasian continent.² In short, Staal argues that the European tradition is characterized by an emphasis on nature and development of theory and empiricism as scientific fundamentals, while Chinese science is characterized by concreteness, experimentation, and a historical outlook, partly in contrast to Indian science which is characterized by abstraction and an emphasis on human theory.

How is the scientific landscape structured in leading science nations in Asia today? Do we find any empirical indications of a shift from Western science traditions toward Asian ones? Do we see the scientific centers of the future being established in Asia? One first step to answering such questions could be to look at quantitative and statistical patterns. Sigurd-

¹S. Goonatilake, "A Post-European Century in Science," *Futures* 31 (1999): 923-27

²F. Staal, "Concepts of Science in Europe and Asia," *Interdisciplinary Science Reviews* 20 (1995): 7-19.

son and Persson investigated Pacific Asia's patterns of patenting in the United States and co-publishing with the European Union and the United States.³ Clearly, the region is accelerating its patenting and has overtaken Europe in absolute numbers since 1985. In terms of scientific publishing the region is still at a much lower level than the United States and the European Union, but enjoys a greater rate of increase than both. Sigurdson and Persson predict that over the next twenty years the gap in scientific publishing between Pacific Asia and the other two regions will narrow dramatically.

However, is Asian science different from American and European science? Taiwan is one of the countries in the region that have gone through a remarkable development, showing a dramatic increase based on a count of the number of scientific papers that Taiwan's academic institutions are publishing. Needless to say, a published document of some kind is the first and most obvious outcome of academic research. During the 1990s, the Taiwanese publication output has approximately tripled. The strong development of Taiwan has been further commented upon by Okubo and others,⁴ who made a study of publication trends particularly in Southeast Asia. These researchers found a clear overall shift toward an American-style pattern, indicating that recently established scientific nations as well as traditionally strong ones are developing similar publication patterns, often copied from the dominating science nation of today, the United States.

Bearing the above-mentioned perspectives in mind, a closer look at the Taiwanese research system provides one example of Pacific Asia science and what structures are at hand. This study examines how Taiwan's academic landscape is shaped, which institutions are represented there, and who the major actors are. The research also explores the status of the

³J. Sigurdson and O. Persson, "The New Technological Landscape in Pacific Asia: An Inquiry into the Dramatic Changes in Patenting and Scientific Publishing," *Research Evaluation* 7 (1998): 31-38.

⁴Y. Okubo, J. C. Dore, T. Ojasoo, and J. F. Miquel, "A Multivariate Analysis of Publication Trends in the 1980s with Special Reference to Southeast Asia," *Scientometrics* 41 (1998): 273-89.

collaborative network, both within Taiwan and internationally. Are the cooperative contacts mostly with the United States or are other countries represented to a significant degree as well? What is the status of collaboration with the Pacific Asia neighboring countries in general and the Chinese cultural hemisphere in particular: the People's Republic of China (PRC) and the Hong Kong Special Administrative Region? To what level has Taiwan developed research collaboration with the EU countries? All together, is Taiwan's research and development (R&D) system different from what we would find in Western countries, indicating a difference in Asian science versus American and European science?

There are many ways to quantitatively measure scientific production and research collaboration. This study uses a bibliometric method where published journal articles listed in a database are measured as the outcome of research and institutional co-authorships are seen as indicators of collaboration. We cannot claim that this study will reveal a complete picture of either the research output or the collaborative ventures. Rather, this work will reveal some of the patterns and give some indications of what the academic landscape in Taiwan looks like. There are a large number of bibliometric studies of national science systems available. The design of this study has several parallels with many of these studies.⁵

Data

All 19,222 records containing the word "Taiwan" in the address field were downloaded from the *Science Citation Index*TM, CD-ROM edition 1995-97. At the time of data collection, later year's editions were not yet available. Then, we decided only to include papers in journals that have been cited at least one hundred times between 1981 and 1996 according to

⁵D. Hicks and S. Katz, "Where Is Science Going?" *Science, Technology & Human Values* 21 (1996): 379-406; S. Katz and B. Martin, "What Is Research Collaboration?" *Research Policy* 26 (1997): 1-18; G. Melin and O. Persson, "Hotel Cosmopolitan: A Bibliometric Study of Collaboration at European Universities," *Journal of the American Society for Information Science* 49 (1998): 43-48; O. Persson, G. Melin, R. Danell, and A. Kaloudis, "Research Collaboration at Nordic Universities," *Scientometrics* 39 (1997): 209-23.

Journal Performance Indicators on Diskette (JPIOD-1997; Institute for Scientific Information, Philadelphia), in order to exclude less significant *SCI* journals.

In this study, we use the *journal impact factor* as an alternative measure of impact, because we have no citation data for individual Taiwanese papers. The journal impact factor is calculated by dividing the number of times the articles of a journal are cited by the number of articles the journal publishes. First of all, important is to publish in a journal with a certain level of reputation, a measure which is fairly well indicated by the citation impact of the journal. Secondly, provided that we have a fairly large number of papers, the mean journal impact of the papers should be a reasonably good predictor of future citation impact of the papers. Still, we have to consider the fact that some units, even whole countries, may perform significantly better or worse than expected, given the journal impact factor.

When calculating the journal impact factor, the cited and citing time window may vary. In the *Journal of Citations Reports (JCR)*, which is frequently used to rank journals by impact, the citing year is the base year and the cited years the two previous years. In this longitudinal study we will use journal impact factors taken from a database called *JPIOD*. Here the journal impact factors are based on the average number of times the articles published in the journals in 1981-96 have been cited during the same time period.

Hence, we are not looking for a sample as close to the total output as possible, but a sample that can reveal current patterns and structures of the international and national performance of Taiwanese journal article publication. In addition to the number of papers, we also used the impact factors for the journals used for publication. These impact factors are based on the 1981-96 citing/cited time window, which implies that the impact factors in this study have higher numerical value than those found in *JCR*, which are calculated on a two-year basis. This study deals with the "university" level of analysis, indicated by institutional co-authorships and co-occurrences in our sample. This level also includes hospitals or other institution-like units like Academia Sinica, which technically are not universities but clearly belong to the university level (in comparison to the departmental level, for instance).

Academic hospitals have been treated as separate institutions. This means that in some cases a paper co-authored between National Taiwan University and National Taiwan University Hospital will count as one paper for each. A paper written by National Taiwan University Hospital will not be included in the count for National Taiwan University. Therefore, the risk of double counting is minimal and will only occur if an author from the hospital uses the address of the university.

The bibliometric data were analyzed with a bibliometric toolbox named *Bibexcel*TM, developed at Inforsk, Umeå University, Sweden. The maps of collaboration are generated via a Multi-Dimensional Scaling (MDS) program, which takes a matrix of the number of co-authored papers as the input and then finds the best fitting two-dimensional representation of that matrix. This is a standard methodology in bibliometric analysis, and the technical aspects of the approach have been analyzed elsewhere.⁶

Results

Major Actors

In Taiwan, the public universities, which all receive financial support from the government, are called "national universities." Along with these national universities, there are a number of private universities ranging from large to small. Few private universities receive significant support from the government; many rely heavily upon tuition fees for their survival. The public universities are traditionally the most prestigious ones, in contrast to the situation in the United States, for instance.

The number of occasions each university is present in our sample as an article-producer is shown in table 1. Using SPRU Main Areas of Science (SPRU: Science Policy Research Unit, University of Sussex, United Kingdom), we get an indication of their research profiles as well. The SPRU classification is a classification of journals rather than separate

⁶T. Luukkonen, R. J. W. Tijssen, O. Persson, and G. Sivertsen, "The Measurement of International Scientific Collaboration," *Scientometrics* 28 (1993): 15-36.

Table 1
Presence of Major Actors in Taiwanese Paper Production 1995-97

Institution	SPRU Main Areas of Science				
	Engineering and Materials	Life	Multidis- ciplinary	Natural	Total
Total	4,181	11,627	4,680	12,271	32,759
National Taiwan Univ.	554	1,229	560	987	3,330
National Tsing Hua Univ.	373	159	383	855	1,770
Academia Sinica	38	600	234	803	1,675
National Cheng Kung Univ.	468	397	324	458	1,647
National Chiao Tung Univ.	334	9	288	685	1,316
National Yang Ming Univ.	9	787	61	30	887
Chang Gung Memorial Hospital	3	765	25	6	799
Veteran General Hospital	8	731	29	12	780
National Taiwan Univ. Hospital	15	686	30	1	732
National Central Univ.	158	4	168	361	691
National Chungshing Univ.	102	175	103	199	579
National Sun Yat-sen Univ.	117	59	112	267	555
National Taiwan Inst. of Technology	197	11	114	213	535
Kaohsiung Medical College	0	349	56	49	454
National Defense Medical Center	2	354	39	11	406
National Taiwan Ocean Univ.	54	136	86	60	336
National Chung Cheng Univ.	63	11	46	174	294
Chung Yuan Christian Univ.	72	17	54	132	275
Taichung Veteran General Hospital	4	241	18	6	269
Chang Gung Medical College	3	231	31	3	268
Chang Gung College of Medicine & Technology	19	161	36	34	250
Industrial Technology Research Inst.	106	3	52	85	246
National Taiwan Normal Univ.	14	28	18	172	232
Tatung Inst. of Technology	64	22	26	88	200
Tamkang Univ.	36	6	41	110	193
Feng Chia Univ.	67	3	46	50	166
Yuan Ze Inst. of Technology	43	0	61	52	156
Taipei Medical College	2	115	24	14	155
Chung Shan Inst. of Science & Technology	57	2	26	57	142
Univ. of Illinois (USA)	12	30	12	87	141
Univ. of California Los Angeles (USA)	13	34	4	83	134
Johns Hopkins Univ. (USA)	1	33	10	88	132
China Medical College	1	94	17	5	117
Mackay Memorial Hospital	0	113	3	0	116
Harvard Univ. (USA)	0	24	6	86	116
Purdue Univ. (USA)	16	5	10	84	115
Univ. of Michigan (USA)	8	14	2	85	109
National Cheng Kung Univ. Hospital	0	101	6	0	107
National Research Inst. of Chinese Medicine	0	57	31	19	107
MIT (USA)	3	3	4	97	107
Chung Cheng Inst. of Technology	28	0	19	58	105

journal articles.⁷ Thus, each *SCI* paper is classified according to the subject content of the journal in which it is published. Such a classification works well at the highest aggregated level, but less so at the level of single disciplines, since a journal may cover more than one research field. Consequently, some journals are classified as multidisciplinary, such as *Science* and *Nature*.

National Taiwan University was present in about 3,300 papers in the three-year period, which is about 18 percent of the Taiwanese output of scientific papers. Then follow four medium-sized universities: National Tsing Hua University, Academia Sinica, National Cheng Kung University, and National Chiao Tung University, all of which were present in some 1,300-1,700 papers. Then there are a fairly great number of smaller universities in terms of papers in scientific journals. Perhaps these organizations are more education- than research-oriented, or perhaps they have been established quite recently. We also know that there are a few Taiwanese universities that have a strong social science profile, something that cannot be seen in our sample (for example, Soochow University and National Cheng-chi University). Also interesting to note is that among the major actors we find a few prestigious American universities. Although these American universities are present in less than one percent of the Taiwanese papers, they are a sign of the close collaborative links that Taiwan has with America in science. Whether these American universities are more similar to Taiwanese universities than other American universities in terms of research profile is unknown to us. All of these American universities are research-intensive universities known for their high quality and therefore ought to be of great interest as a source of contacts for Taiwanese scientists, but no clear pattern emerges.

In table 2 the relative position of each university in each main area is calculated. This distribution helps to reveal the profile of each university. Quite revealing is how the research profiles of the universities look: National Taiwan University, for a start, scores well in all areas except the natural sciences. Academia Sinica's low relative rate or score in engineering

⁷Hicks and Katz, "Where Is Science Going?" 379-406.

Table 2
Relative Research Activity

Institution	SPRU Main Areas of Science				
	Engineering and Materials	Life	Multidis- ciplinary	Natural	Total
Total	1.00	1.00	1.00	1.00	1.00
National Taiwan Univ.	1.30	1.04	1.18	0.79	1.00
National Tsing Hua Univ.	1.65	0.25	1.51	1.29	1.00
Academia Sinica	0.18	1.01	0.98	1.28	1.00
National Cheng Kung Univ.	2.23	0.68	1.38	0.74	1.00
National Chiao Tung Univ.	1.99	0.02	1.53	1.39	1.00
National Yang Ming Univ.	0.08	2.50	0.48	0.09	1.00
Chang Gung Memorial Hospital	0.03	2.70	0.22	0.02	1.00
Veteran General Hospital	0.08	2.64	0.26	0.04	1.00
National Taiwan Univ. Hospital	0.16	2.64	0.29	0.00	1.00
National Central Univ.	1.79	0.02	1.70	1.39	1.00
National Chungshing Univ.	1.38	0.85	1.25	0.92	1.00
National Sun Yat-sen Univ.	1.65	0.30	1.41	1.28	1.00
National Taiwan Inst. of Technology	2.89	0.06	1.49	1.06	1.00
Kaohsiung Medical College	—	2.17	0.86	0.29	1.00
National Defense Medical Center	0.04	2.46	0.67	0.07	1.00
National Taiwan Ocean Univ.	1.26	1.14	1.79	0.48	1.00
National Chung Cheng Univ.	1.68	0.11	1.10	1.58	1.00
Chung Yuan Christian Univ.	2.05	0.17	1.37	1.28	1.00
Taichung Veteran General Hospital	0.00	0.02	0.00	0.06	1.00
Chang Gung Medical College	0.00	0.02	0.01	0.03	1.00
Chang Gung College of Medicine & Technology	0.00	0.01	0.01	0.36	1.00
Industrial Technology Research Inst.	0.03	0.00	0.01	0.92	1.00
National Taiwan Normal Univ.	0.00	0.00	0.00	1.98	1.00
Tatung Inst. of Technology	0.02	0.00	0.01	1.17	1.00
Tamkang Univ.	0.01	0.00	0.01	1.52	1.00
Feng Chia Univ.	0.02	0.00	0.01	0.80	1.00
Yuan Ze Inst. of Technology	0.01	—	0.01	0.89	1.00
Taipei Medical College	0.00	0.01	0.01	0.24	1.00
Chung Shan Inst. of Science & Technology	0.01	0.00	0.01	1.07	1.00
China Medical College	0.00	0.01	0.00	0.11	1.00
Mackay Memorial Hospital	—	0.01	0.00	—	1.00
National Cheng Kung Univ. Hospital	—	0.01	0.00	—	1.00
National Research Inst. of Chinese Medicine	—	0.00	0.01	0.47	1.00
Chung Cheng Inst. of Technology	0.01	—	0.00	1.47	1.00

Note: The relative activity is calculated by dividing the percentage of papers in a field for a given university with the corresponding percentage for all Taiwanese organizations. A ratio above 1 indicates a relatively stronger position in the specific area than statistically expected.

and materials sciences is a proof of the basic research orientation of the institute. Furthermore, we can see the clear orientation toward technology and natural sciences for which National Tsing Hua, Cheng Kung, and Chiao Tung universities are known. On the other hand, in regard to life sciences the universities usually are relatively weak while the research-intensive hospitals show up with high scores as medical sciences are included in the life science area. There are also a number of slightly smaller universities that show high scores: National Central University, National Chunghsing University, National Chung Cheng University, Chung Yuan Christian University, and National Sun Yat-sen University. With some exceptions, we can see that the even smaller universities in table 2 do not score as high as the larger ones.

The profile of Academia Sinica is a special case; the academy is not a university but a non-private research institution of university size that supplements the national university system, and is devoted to basic research and without students. Doctoral students can be affiliated with the institute but must be formally accepted to a regular Ph.D. program at another university. Academia Sinica's relatively strong position in the natural sciences, together with its almost complete lack of presence in engineering, is a sign of the basic research orientation. If social sciences and humanities were included, most likely is that Academia Sinica would also present a strong showing as well.

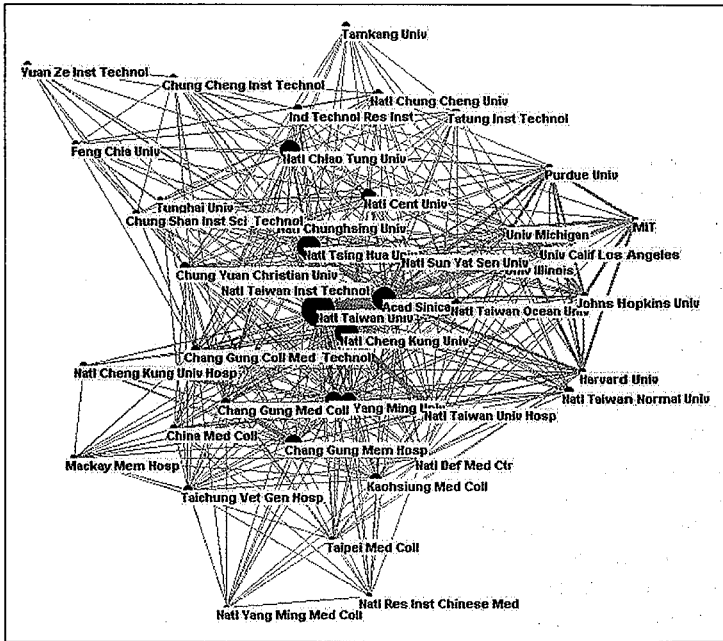
Next we looked at the impact factor of the journals in which these universities publish. Each university's mean journal impact value was calculated and the comparisons between the universities can be seen in table 3. In general, there are rather small journal impact differences among the universities. There appears to be a weak positive correlation between size of output and journal impact, especially in the natural sciences where there are significant differences. Academia Sinica scores high in all areas but engineering and materials. In the multidisciplinary journal category, National Yang Ming University has a high rank. According to table 2, National Taiwan University exhibits a relatively weak orientation toward the natural sciences compared to the other large universities. In table 3, however, we can see that the journal impact factor is fairly good for National Taiwan University in the natural sciences. An interpretation is that

Table 3
Mean Journal Impact Factor for Papers by Major Actor

Institution	SPRU Main Areas of Science			
	Engineering and Materials	Life	Multidis- ciplinary	Natural
Total	4.2	11.1	8.1	12.5
National Taiwan Univ.	4.0	11.2	7.8	8.8
National Tsing Hua Univ.	4.4	11.7	6.4	8.7
Academia Sinica	—	14.4	15.2	11.3
National Cheng Kung Univ.	4.1	11.8	7.2	7.1
National Chiao Tung Univ.	4.8	—	5.4	7.8
National Yang Ming Univ.	—	12.0	21.7	—
Chang Gung Memorial Hospital	—	8.9	—	—
Veteran General Hospital	—	11.8	—	—
National Taiwan Univ. Hospital	—	11.0	—	—
National Central Univ.	4.4	—	5.3	7.4
National Chungshing Univ.	3.8	7.8	8.4	7.8
National Sun Yat-sen Univ.	3.9	7.1	4.8	9.0
National Taiwan Inst. of Technology	4.0	—	4.6	5.9
Kaohsiung Medical College	—	8.8	11.7	—
National Defense Medical Center	—	12.3	—	—
National Taiwan Ocean Univ.	3.9	6.6	7.3	7.4
National Chung Cheng Univ.	4.2	—	—	7.5
Chung Yuan Christian Univ.	4.1	—	5.1	6.6
Taichung Veteran General Hospital	—	9.7	—	—
Chang Gung Medical College	—	10.1	—	—
Chang Gung College of Medicine & Technology	—	14.1	—	—
Industrial Technology Research Inst.	3.9	—	4.4	5.9
National Taiwan Normal Univ.	—	—	—	6.7
Tatung Inst. of Technology	4.3	—	—	5.2
Tamkang Univ.	—	—	—	6.2
Feng Chia Univ.	3.9	—	—	5.9
Yuan Ze Inst. of Technology	4.4	—	4.2	6.4
Taipei Medical College	—	9.9	—	—
Chung Shan Inst. of Science & Technology	4.3	—	3.9	6.0
China Medical College	—	9.4	—	—
Mackay Memorial Hospital	—	8.6	—	—
National Cheng Kung Univ. Hospital	—	12.0	—	—
National Research Inst. of Chinese Medicine	—	8.2	—	—
Chung Cheng Inst. of Technology	—	—	—	4.8

Note: Cells with less than fifty papers are excluded to avoid insignificant results.

Figure 1
Co-authorships among Major Actors in Scientific Papers from Taiwan



Note: Circle area is proportional to the number of papers produced by an organization, and the thickness of a line is proportional to the number of co-authored papers.

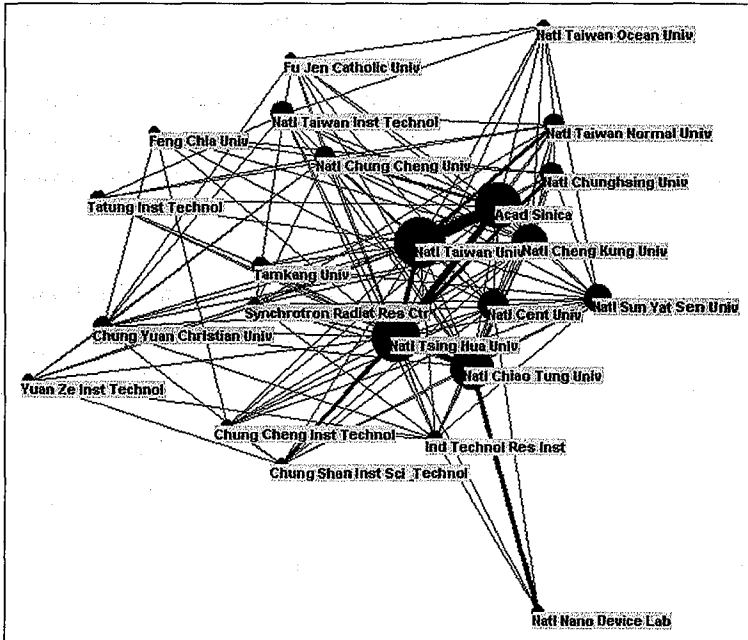
the natural science that is carried out at National Taiwan University is of high quality and published in journals with high rank.

Collaboration Networks

With these data as the background, we went on to create co-authorship maps based on Taiwanese paper output. Figure 1 shows the national research collaboration network of the major actors in Taiwan. Circle area is proportional to the number of papers produced by an organization. As we use the number of papers as a proxy for size of university research activities, large dots mean relatively strong paper production. Also, thick lines mean relatively many co-authorships. Again, a few large science paper producers are especially apparent and fairly well positioned in the center of the map, surrounded by a number of medium-sized and smaller

Figure 2

Co-authorships among Major Actors in Scientific Papers from Taiwan in the Natural Sciences



Note: Circle area is proportional to the number of papers produced by an organization, and the thickness of a line is proportional to the number of co-authored papers.

universities. The close collaborative links between National Taiwan University and Academia Sinica are clearly visible as well as between National Taiwan University and its hospital. Also interesting to see is how the hospitals and the medical colleges/universities cluster together at the bottom of the map; their similarity in terms of research and their joint collaborative activities is revealed in the map. Again, we find that a few American universities are present, and the reason is the same as before: the collaborative links are so extensive that they show up even though we are dealing with a Taiwanese sample. Further comments are given in the conclusions.

In order to examine this picture a bit further, we separated the "natural sciences" according to SPRU Main Areas. Figure 2 shows the resulting

map that is somewhat clearer than the complete map in figure 1. The map in figure 2 displays the universities with an orientation toward natural sciences, and when considered together with the results especially from tables 2 and 3, this map visualizes the collaborative network of universities in the natural science area.

Table 4 shows the international collaboration network. For purposes of comparison, we also have included the country collaborations for Denmark, a country which has about the same volume of papers as Taiwan. For

Table 4
Percent of Taiwanese and Danish Papers Co-authored with Other Countries

Co-authorships with	Percent of Papers with		No. of Papers	
	Denmark	Taiwan	Denmark	Taiwan
United States	14.3	12.3	2,985	2,362
Japan	1.5	1.7	313	334
Canada	2.1	1.0	436	183
PRC	0.7	0.9	147	165
United Kingdom	10.2	0.8	2,133	154
Germany	7.1	0.7	1,488	136
Italy	3.6	0.6	759	121
France	4.4	0.5	921	102
Hong Kong	0.1	0.5	24	104
Australia	1.2	0.4	261	72
South Korea	0.4	0.4	81	70
Switzerland	2.5	0.3	531	61
Russia	2.2	0.3	468	64
India	0.3	0.3	71	51
Singapore	0.1	0.3	16	58
Sweden	7.1	0.2	1,477	35
Netherlands	3.6	0.2	747	36
Spain	2.5	0.2	531	39
Finland	2.2	0.1	459	28
Belgium	1.8	0.1	387	10
Brazil	0.6	0.1	125	21
Israel	0.6	0.1	116	21
Hungary	0.3	0.1	66	25
South Africa	0.2	0.1	41	13
Ukraine	0.2	0.1	40	13
Thailand	0.1	0.1	27	15
Romania	0.1	0.1	18	20
Bulgaria	0.1	0.1	16	19
Philippines	0.0	0.1	9	11
Cyprus	0.0	0.1	0	17

Table 4 (Continued)

Co-authorships with	Percent of Papers with		No. of Papers	
	Denmark	Taiwan	Denmark	Taiwan
Norway	3.1	0.0	651	4
Poland	1.3	0.0	275	9
Greece	1.2	0.0	251	6
Austria	1.2	0.0	251	3
Czech Republic	0.7	0.0	145	7
Portugal	0.7	0.0	149	3
Slovakia	0.5	0.0	106	4
Slovenia	0.5	0.0	98	0
Iceland	0.4	0.0	78	3
New Zealand	0.3	0.0	66	8
Ireland	0.3	0.0	70	1
Argentina	0.2	0.0	46	6
Tanzania	0.2	0.0	41	0
Kenya	0.2	0.0	37	0
Mexico	0.1	0.0	29	6
Turkey	0.1	0.0	28	4
Gambia	0.1	0.0	27	0
Latvia	0.1	0.0	27	0
Zimbabwe	0.1	0.0	25	0
Chile	0.1	0.0	23	0
Lithuania	0.1	0.0	23	0
Indonesia	0.1	0.0	15	7
Sudan	0.1	0.0	22	0
Croatia	0.1	0.0	19	0
Guinea Bissau	0.1	0.0	19	0
Ghana	0.1	0.0	18	0
Estonia	0.1	0.0	17	0
Byelarus	0.1	0.0	12	4
Egypt	0.1	0.0	14	2
Armenia	0.1	0.0	11	3
Luxembourg	0.1	0.0	11	1
Senegal	0.1	0.0	12	0
Malaysia	0.0	0.0	3	8
Vietnam	0.0	0.0	5	5
Bangladesh	0.0	0.0	7	1
Malta	0.0	0.0	7	1
Uzbekistan	0.0	0.0	5	3
Yugoslavia	0.0	0.0	7	1
Colombia	0.0	0.0	6	1
Greenland	0.0	0.0	7	0
Iran	0.0	0.0	1	6
Nigeria	0.0	0.0	4	3
Peru	0.0	0.0	7	0
Saudi Arabia	0.0	0.0	5	2

Table 4 (Continued)

Co-authorships with	Percent of Papers with		No. of Papers	
	Denmark	Taiwan	Denmark	Taiwan
Jamaica	0.0	0.0	5	0
Jordan	0.0	0.0	2	3
Mozambique	0.0	0.0	4	1
Venezuela	0.0	0.0	3	2
Cote Ivoire	0.0	0.0	3	1
Cuba	0.0	0.0	4	0
Mongolia	0.0	0.0	4	0
Morocco	0.0	0.0	3	1
Sierra Leone	0.0	0.0	4	0
Sri Lanka	0.0	0.0	4	0
Zambia	0.0	0.0	4	0
Ecuador	0.0	0.0	3	0
Kuwait	0.0	0.0	2	1
Macao	0.0	0.0	1	2
Papua New Guinea	0.0	0.0	2	1
Tunisia	0.0	0.0	3	0
Uganda	0.0	0.0	3	0
Algeria	0.0	0.0	2	0
Costa Rica	0.0	0.0	2	0
Ethiopia	0.0	0.0	2	0
Guatemala	0.0	0.0	2	0
Lebanon	0.0	0.0	0	2
Madagasy Republic	0.0	0.0	2	0
Malawi	0.0	0.0	2	0
Nepal	0.0	0.0	2	0
Niger	0.0	0.0	2	0
Oman	0.0	0.0	2	0
Trinidad & Tobago	0.0	0.0	2	0
United Arab Emirates	0.0	0.0	2	0
Uruguay	0.0	0.0	2	0
Albania	0.0	0.0	1	0
Bolivia	0.0	0.0	1	0
Bosnia/Herzegovina	0.0	0.0	1	0
Centeal African Republic	0.0	0.0	1	0
Dominican Republic	0.0	0.0	1	0
Liberia	0.0	0.0	1	0
Monaco	0.0	0.0	1	0
Northern Ireland	0.0	0.0	0	1
Pakistan	0.0	0.0	1	0
Republic of Georgia	0.0	0.0	1	0
Rwanda	0.0	0.0	1	0
Togo	0.0	0.0	1	0
Sum of bilateral links	100.00	100.0	17,462	4,487
Number of papers	20,919	19,222		

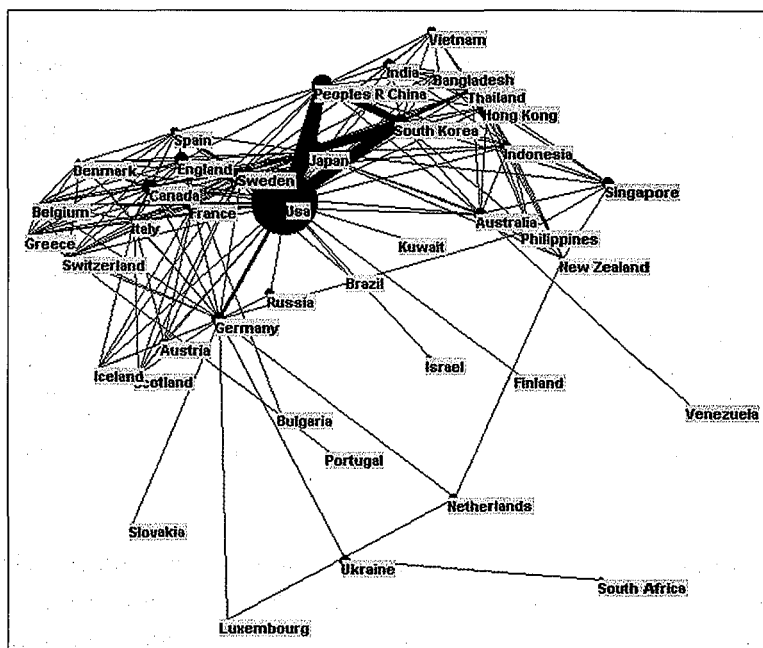
Table 5
Internationality of Taiwanese Universities

Institution	All papers	Internationally co-authored	Percent Internationally co-authored
National Taiwan Univ.	3,330	570	17.1
National Tsing Hua Univ.	1,770	217	12.3
Academia Sinica	1,675	545	32.5
National Cheng Kung Univ.	1,647	211	12.8
National Chiao Tung Univ.	1,316	110	8.4
National Yang Ming Univ.	887	108	12.2
Chang Gung Memorial Hosp.	799	116	14.5
Veteran General Hosp.	780	119	15.3
National Taiwan Univ. Hosp.	732	88	12.0
National Central Univ.	691	134	19.4
National Chungsing Univ.	579	122	21.1
National Sun Yat-sen Univ.	555	99	17.8

both these countries the United States is the most frequent partner, and the United States is present with close percentage shares in both Taiwanese and Danish papers. The second largest partner is Japan, with whom Taiwan and Denmark have about the same share of collaborations. However, in addition to the cases of the United States and Japan, Denmark has many collaborations with other major science nations all over Europe. For Taiwan, European countries do play a significant role but on a much lower level in comparison with Denmark. Interesting to note is that Taiwan and Denmark has about the same amount of collaborative efforts with a set of nations proximate to Taiwan—such as the PRC and South Korea. What can be concluded from this overall picture is that Taiwan should increase its collaboration with European countries in order to strike a more balanced integration in the global scientific network.

Some universities in Taiwan are more internationally oriented than others. Table 5 shows that Academia Sinica has 32.5 percent of its papers co-authored with other countries, which is about ten percentage points higher than any other organization. In fact, Academia Sinica has an international collaboration level that comes close to that of the world's most internationalized universities in countries of comparable size and with

Figure 3
Country Collaboration Map of National Taiwan University

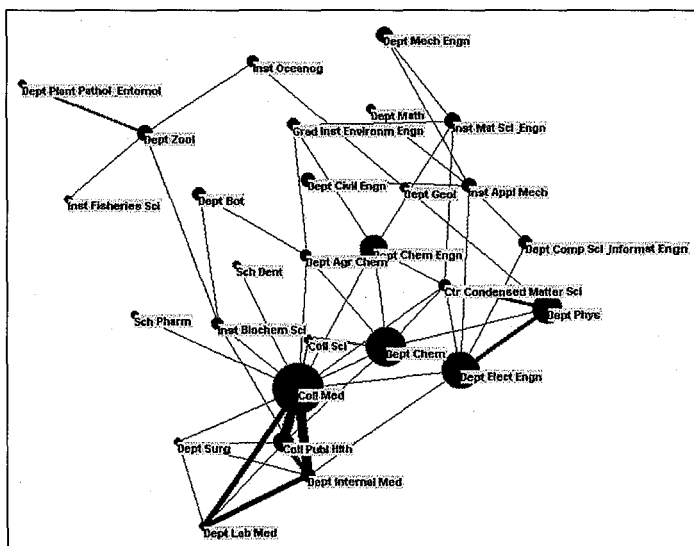


Note: Countries with at least two co-authorships are included.

comparable scientific output. Still Academia Sinica is mostly involved with the United States and Canada, with Europe having only a quite modest presence. American institutions appear in about 25 percent of the papers from Academia Sinica. The corresponding share for Japan and Canada is 6 percent, 4 percent with Italy, 3 percent with the PRC, 2 percent with Switzerland and Germany, and 1 percent with France and the United Kingdom.

Helpful at this point is to step one level down in the system and check the international network from a university's point of view. As National Taiwan University (NTU) is the largest and most comprehensive Taiwanese academic organization in terms of research areas, the authors naturally chose NTU as the exemplar. Figure 3 shows the international collaborative network of NTU.

Figure 4
Departmental Collaboration Map of National Taiwan University



We find that the most important actors of NTU's international network are the United States, PRC, Japan, and South Korea. These countries are surrounded (in the map of figure 3) by a number of countries in Europe and Pacific Asia. Quite clear is how the Western nations cluster together to the left of the map while the Asian countries make a cluster to the right.

When we turn to the internal collaborative structure of NTU (figure 4), evident is that the sample is limited to the natural and medical science fields. We find that there is significant collaboration between the medical departments at the university (to the lower left of the map), and between engineering sciences at the technical departments (to the right of the map). The left corner of the map represents traditional green biology.

Conclusions

We have found that Taiwan's academic landscape consists of a relatively large number of actors, ranging from very small universities to a few

internationally large ones. Even though the Taiwanese population now only slightly exceeds 22 million inhabitants, in international comparison, there are a relatively large number of academic institutions in Taiwan. Even though there are many such actors (of which most are universities), however, we can see that the academic landscape is dominated by a handful of large universities. A couple are located in Taipei (National Taiwan University and Academia Sinica); a couple are located in the research-intensive city of Hsinchu (National Tsing Hua University and National Chiao Tung University); the last main organization is National Cheng Kung University in Tainan, southern Taiwan. These five universities contribute approximately one-third of the Taiwanese scientific paper output. All are non-private universities.

A closer look at the natural sciences only confirms the above-mentioned impression. The five universities dominate the national arena of the natural sciences but are closely followed by National Sun Yat-sen University and National Central University. We find the most collaborative links between National Taiwan University and Academia Sinica; second are the significant number of links between Academia Sinica and National Tsing Hua University; and third are those between Tsing Hua and neighboring National Chiao Tung University. The explanation behind this pattern remains unknown to us. It appears that size is a major factor forming the network. The geographical distance between the universities is on the whole quite small, which could be seen as a relative advantage for Taiwan. Relatively easy should be to establish research collaboration between the universities and profit from complementary resources.

Taiwan seems also to be well integrated in the international research collaboration network. Although Taiwan by tradition relies heavily on co-operation with the United States⁸ and a vast number of the academic faculty staff have a Ph.D. degree from America, the country has developed extensive collaboration links with a wide range of other countries as well.⁹ Not

⁸Jaw-Ling Joanne Chang, ed., *R.O.C.-U.S.A. Relations, 1979-1989* (Taipei: Institute of American Culture, Academia Sinica, 1991).

⁹Shen Cen-Chu and Song Yann-Huei, eds., *EC Integration and EC-ROC Relations* (Taipei: Institute of European and American Studies, Academia Sinica, 1995).

only are the countries in Western Europe and neighboring countries in Pacific Asia represented to a significant degree, but we also find a significant representation of countries in Eastern Europe as well. Still, however, the most developed cooperative contacts are with the United States, and there are a number of American universities that are so often represented as co-authoring institutions that they appear in our list of Taiwanese major academic actors and on our maps. This is a consequence of the method we use where each occasion a university is represented as authoring institution is counted. There must be extensive co-authorship between Taiwanese and foreign institutions if the foreign institutions turn up in a frequency list of the most prolific institutions.

The results of this study do not give any support to the idea that Asian science today would differ from Western science. Neither is there any evidence that a different Asian science is about to take over the leading role from Euro-originated science. The main argument for our point of view is that Taiwan is well integrated in international scientific macro-networks with much international collaboration and therefore more reasonable is to argue that the Western way of doing science is rapidly spreading to Asia. On the other hand, this study is not extensive enough to prove our argument; further studies are needed for that and not only of a statistical kind. Our interpretation from this study is that in a very short time Taiwan has won success by adapting Western scientific traditions. We believe that likely is that Euro-originated science traditions will ride on the wave of internationalization and globalization (still loosely defined) and soon fully permeate Asia just as well as Europe and North America.

The picture our data reveals refers to the years 1995-97 only. The trend during the whole of the 1990s, however, has been one of an increasing number of collaborations, nationally as well as internationally. Our guess is that Taiwanese academic institutions are even more closely integrated in the international scientific networks today than our present study shows.

A final remark of policy interest: All the main scientific actors in Taiwan are public universities, all of which receive significant financial support from the government. This is a situation that is more similar to the way of organizing a scientific system as found in Europe rather than in the United States. The countries in Northern Europe especially have very few

private universities or colleges. The close contacts between Taiwan and the United States, not only in science but in most societal areas, would lead us to expect more of an American order in the Taiwanese higher education and research system. This seems not to be the case, however. For example, we would have expected a larger number of private actors among the major science paper producers in our data.

Thus, we can draw the conclusion that a traditionally weak scientific nation can certainly develop into a significant science-centered nation. Required, however, is that government show a sincere will to make the necessary financial and other commitments to establish universities and research facilities and create an intellectual and innovative atmosphere at these research facilities. Taiwan ought to serve as a promising example to many other countries that still await their entrance to and participation on the international scientific stage.