Science and Public Policy, volume 29, number 3, June 2002, pages 189–200, Beech Tree Publishing, 10 Watford Close, Guildford, Surrey GU1 2EP, England

Emerging technology

Measuring national 'emerging technology' capabilities

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How can national capabilities to develop emerging technologies be measured? We use INSPEC and EI Compendex class codes to examine 33 countries' research and development activity. We select candidate emerging technologies based on the Rand Corporation's categories. We screen these to tally those that show strong recent, and increasing, R&D publication rates. The resulting measures show strong convergence; indeed, their lack of divergence is unsettling. Our measures suggest that China now stands forth as an 'emerging technology' research power comparable to Germany, the UK, and France. A number of other nations evidence a striking lack of R&D activity, posing questions about their longer-range high-tech competitiveness.

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TECHNOLOGY INDICATORS aim to measure capabilities to allow tracking of changes over time, to inform technology policy (Godin, 1996; Mani, 2000; Sirilli, 1997; van Raan, 1988). Effective technological innovation indicators (Hansen, 1999) tap into capabilities that drive economic development (Antonelli and de Liso, 1997; Archibugi and Michie, 1998; WCY 1998–2000; Mani, 2000; OECD, 1999; OECD, 2000). In turn, these should help in policy formulation (Porter and Stern, 1999).

In recent years, the world has become increasingly interested in tracking national capabilities for technological innovation and for technology-based exports. National level technological indicator developments include creation of the European Innovation Scoreboard [http://www.cordis.lu/itt/itt-en/01-5-spec/overview.htm], UNIDO's (UN Industrial Development Organization) forthcoming Industrial Development Scoreboard, and the UN Commission for Science and Technology for Development's forthcoming Indicators of Technology Development.

Technology is the key driver of economic competitiveness (Archibugi *et al*, 1999; Clark and Guy, 1998). 'Science-driven' technologies are increasing their industrial role relative to incremental technological gains (Lane and Makri, 2000; Grupp, 1995). Emerging technologies are defined here as those that could exert much enhanced economic influence in the coming (roughly) 15-year horizon. The challenge is to devise ways to measure national propensities in this regard (Sirilli, 1997).

Since the mid-1980s, Georgia Tech's Technology Policy and Assessment Center has been generating

 0302-3427/02/030189-12 US$08.00 © Beech Tree Publishing 2002

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'high tech indicators' (HTI) of national competitiveness. These are produced every three years to inform the US National Science Foundation's *Science and Engineering Indicators*. Elsewhere, we discuss HTI conceptual bases (Roessner *et al*, 1992), country contrasts (Porter *et al*, 1996), and comparisons with other national indicators of innovation and of competitiveness (Roessner *et al*, 2002; see also Porter and Stern, 1999). The 1999 HTI are available at our website [http://tpac.gatech.edu], along with the developing 2002 HTI.

HTI now address 33 industrialized and industrializing nations. Our four input and three output indicators combine statistical and expert opinion measures. The input indicators are national orientation (to pursue technology-based economic competitiveness), socio-economic infrastructure, technological infrastructure, and productive capacity. The output indicators are technological standing (competitive performance), technological emphasis, and rate of technological change.

Considerable inertia resists change in the composition of the indicators, so as to enable comparisons over time. However, we have recently been engaged in a significant conceptual overhaul. With support from the National Science Foundation,[1] we are addressing:

- a review of additional statistical measures to enrich the indicators' formulation;
- how to take into account 'high-tech' services as well as products, since these increasingly cross national borders;
- suitable patent measures;
- various methodological refinements; and
- measures of emerging technologies.

This paper shares our ideas on the last of these. We want to engage others in considering how best to measure national capabilities to take potentially economy-transforming technologies to market.

We seek new component measures to include in our technological infrastructure (TI) indicator ("the institutions and resources that contribute to a nation's capacity to develop, produce, and market new technology"). The TI indicator incorporates measures of scientific and engineering manpower, electronic data processing purchases, relationship of R&D to industrial application, and ability to make effective use of technical knowledge. It lacks measures of R&D output.

The HTI series is sufficiently consistent from 1990 that we can examine the predictive relationships between the input indicators in 1990 and the key output indicator, technological standing (TS), in 1999. TI for 1990 correlates 0.81 with TS-1999. However, if we partition our 33 countries, we find this apparent strength of relationship is misleading. TI-1990 correlates 0.94 with TS-1999 for 12 highly developed countries, but only 0.39 for 14 industrializing countries (Porter *et al*, 2001). Improving the predictive validity of TI motivates our examination of 'emerging technology' and patent measures.

This paper examines national R&D publication rates as a way to measure emerging technology capabilities. As we set forth on this examination, we ask you to think about which half-dozen countries you would expect to be most actively researching emerging technologies. We will develop our answer and return to this question in the "Observations" section.

Challenges

We focus on R&D activity measures to tap emerging technology readiness. Obviously, the presence of research activity in frontier areas is not a sufficient condition to assure commercial innovation. However, the premise is that countries with such activity should be better poised to proceed into emerging technology product, process, and service commercialization. R&D bibliometrics (counts of literary activity) appear the most suitable candidate measures, with certain considerations:

- we want a broad, relatively simple measure;
- the measure should remain available over time;
- citations are really only accessible for the *Science Citation Index* (SCI) and this does not appear 'technological' enough for our purposes;
- research expenditures (current) across our 33 nations would be tough to obtain for emerging technologies;
- patents, while of great interest, seem less apt to anticipate path-breaking emerging technologies out to a 15-year horizon (but possible patent measures could also be very interesting).

Our current investigation suggests intriguing trade-offs among candidate national patent measures:

1. patent applications anywhere (home or abroad);
2. foreign patent applications;
3. patent applications in the country by nationals;
4. patent applications in the country by foreigners.

The advantage of patent applications over patents issued is the considerably reduced lag time. Measures 2 and 3 offer attractive complementarities between a nation's indigenous capabilities (3) and its attractiveness as a market (4); disparities between the two can be astounding (Canada: 4,192 patents filed in 1997 by nationals vs 50,254 by foreigners — World Intellectual Property Organisation (WIPO), Industrial Property Statistics CD). Measure 2 is especially attractive as an indicator of indigenous capabilities with external technological commercialization intent. We briefly compare patent with publication measures for our countries later.

Given these considerations, we focus on publication counts for national emerging technology measures. Publication counts offer several advantages: we can tabulate these measures on a timely basis from available electronic R&D abstract databases, for all of our 33 countries; measures can adapt to changing emerging technologies over time; and we can elicit topical comparisons of interest in addition to overall composites.

On the other hand, some disadvantages lurk in counting R&D publications: we have to compile these ourselves; determining categories of emerging technologies requires judgment; categorizing publications into those categories is not unambiguous; compilation of journal articles and conference papers in databases lags conduct of the research on the order of a couple years; and the databases favor English language publication.

Emerging technologies need to be specified. We seek something more specific than general R&D. Which technologies are considered to have greatest economic transformation potential? RAND Corporation analyses (Popper *et al*, 1998) offer an attractive starting point, most notably from their survey of corporate leaders. Their issues of most concern address "how technology enhances functionality and fits into a larger business process." That said, their priority current (as of 1998) emerging technologies include:

Using publication counts we can: tabulate national emerging technology measures on a timely basis from available data; measures can adapt to changing emerging technologies over time; and we can elicit topical comparisons and overall composites

- Software
- Microelectronic and telecommunications technologies
- Advanced manufacturing technologies
- Materials
- Sensor and imaging technologies.

The RAND group also addresses "Over the horizon: technologies in evolution and revolution." Major emerging technology classes are:

- Software
- Computer hardware (data storage, displays)
- Manufacturing equipment used to make computer components (lithography)
- Communications technologies
- Biotechnology (relating to medicine, agriculture, the environment, communications)
- Materials (making old materials new ways; environmentally friendly materials)
- Energy (considerably fewer mentions).

We start with the first six of these RAND "over the horizon" areas, albeit recognizing the desirability of an ongoing classification scheme (there is no assurance that this RAND Science and Technology Policy Institute activity will be regularly redone). We choose not to include energy because it received considerably fewer mentions from the business leaders responding to the RAND inquiries.

Data resources for publication tabulations must be determined. We favor use of established databases as filtered and focused collections. Excellent R&D databases are available. We propose to use two that together cover 'technology' R&D publication very effectively — INSPEC[2] and EI Compendex.[3]

Depending on the elaboration of science-based and biomedical technologies, we would consider extension to MEDLINE and SCI in the future.

Given general targeting to the RAND categories, we need to determine how to identify emerging technology records in the two databases. We considered searching on explicit terms in keywords (subject index terms) and/or titles, but decided this was too detailed and problematic. There are so many specific communications technologies, biotechnology tools and applications, advanced materials, and so on. Instead, we use the database class codes to get national counts on publications in approximate target areas.

Time frame presents another set of choices. For what time periods should we tally publication activity? We favor recent activity, but with reasonably robust measures. Examination of counts, by country, over time, confirms that annual tallies work satisfactorily for general emerging technology categories.

We further focus on 'hot' R&D areas — those that show both strong recent, and increasing, research interest. The rationale is that technology, especially emerging technology, is increasingly science-driven (Lane and Makri, 2000). Hence, active research and development efforts appear highly salient to developing emerging technology capabilities.

In these initial empirical analyses, we operationalize this by computing two measures. First, we include only technology class codes for which some 10%, or more, of the total articles occur in the most recent full year (of those published in journals or presented at conferences since 1969 for INSPEC and since 1970 for EI Compendex). Second, we calculate the ratio of publications in a technology category in the most recent full year (1999) to those three years earlier (1996).

Scanning our emerging technology categories, we find a ratio of at least two to be an effective screen. We recognize that changes in class code terminology can affect this determination, but such changes should align roughly with technologies being perceived as emerging and important.

We also experimented with limiting analyses to class codes containing at least 10,000 records. Instead, we found that we could explore sub-classes of the INSPEC and EI Compendex codes to select 'hot' ones, then recombine these to constitute reasonably robust measures.

Initial empirical results

We examined the INSPEC and EI Compendex class codes to identify those relating to the first six 'over the horizon' RAND categories noted. We then tallied hits (records) for each category to see which met the 'hot' technology tests mentioned — our threshold levels for recent (10% in the most recent year) and increasing (two times the publications of three years ago) evolved through this empirical exploration. These initial examinations used partial thesauri for the INSPEC and EI Compendex class codes, so they are not exhaustive; we will re-examine before determination of final measures for use in HTI for 2002. However, as will become clear, this does not seem to matter much.

Table 1 presents the results. For this analysis, 'manufacturing equipment used to make computer components' was combined with 'advanced materials' to approximate 'advanced materials pertaining to computer/communications manufacturing.' This has some intuitive appeal, but, more critically, we did not identify manufacturing technologies meeting our 'recent and growing' R&D criteria. This reduces our target emerging technologies from six to five.

The top few rows show the overall database scope. These two databases capture a significant portion of the world's open literature (journal papers and conference papers) concerning technology R&D. Each year the two databases together capture about 500,000 new contributions.[4]

Table 1 conveys the sense that the dual criteria work — a sizable percentage of the R&D on a technology having been published in the most recent year (the current 10% value would need to be re-examined as a database grows) and strong growth (double the number of articles of three years back). For present analyses, we override these in some instances. Most notably, we include software, even though the growth criterion is violated badly, because this seems a vital emerging technology domain. Future refinement will be needed to handle such anomalies. In general, the dual criteria are helpful in screening out mature from emerging elements within these technology categories.

Examination of Table 1 yields interesting observations. All the communications technologies identified as 'emerging' (those flagged with a 'y' in the last column) are optics-related. The biotechnology set is appealing; it requires elimination of certain EI Compendex classes that appear different in nature — general health and medical, and human engineering — even though they meet the dual criteria.

Our resulting emerging technologies, excepting software, derive exclusively from EI Compendex. We will revisit why INSPEC categories seem not to meet our criteria, since INSPEC generally tends to be more research oriented than EI Compendex (which exhibits more applied research and engineering development). This may reflect different rates of classification code revision by the two databases.

If, in the future, we include both relevant INSPEC and EI Compendex codes for certain emerging technologies, there could be significant duplication. We often see these two databases giving 20% or so overlap on certain topics. We would expect duplication rates to be generally comparable for countries, so this should not bias either national or temporal comparisons. We need to beware that counts could overstate activity where they combine results from both

Table 1. Exploration of Emerging Technologies in INSPEC and EI Compendex

Over-the-horizon technologies	Tallies on or about 20 Jan 2001	INSP codes	ENGI codes	All years total	1999	1996	Percent 1999/total	Ratio 99 to 96	Use?
	ENGI database (1970–2000)			5,300,000	219128	239899			
	INSPEC database (1969–2000)			6,700,000	328994	322153			
Software	software	c61$		440974	36414	35246	8.26	1.03	y
	info science & documentation	c72$		80982	7941	4468	9.81	1.78	
Computer hardware	data comm equip & techniques	c56$		106027	7308	6665	6.89	1.1	
	comp peripheral equip	c5540		15008	88	387	0.59	0.23	
	analog & digital computers & sys	c5470		19659	1598	1382	8.13	1.16	
	printed circuit, thin & thick films, hybrid ICs	b22$		52265	2398		4.59		
	semiconduct. devices & materials	b25$		289028	19705	19565	6.82	1.01	
	telecommunications	b62$		290421	18363	17007	6.32	1.08	
	electronic components & tubes		714	180000	1981	460	1.10	4.31	
			714.$	117635	23233	8141	19.75	2.85	
	semiconductor devices & ICs		714.2	103034	20276	7319	19.68	2.77	y
Comm technologies	waveguides		714.3	11095					
	electro-optical communications		717	40089	1692	589	4.22	2.87	
	optical communications		717.1	10796	1940	707	17.97	2.74	y
	optical equipment		717.2	4214	855	397	20.29	2.15	y
	light, optics & optical devices		741	231873	4401	1414	1.90	3.11	
	light optics		741.1	109186	22848	6586	20.93	3.47	y
	non-linear optics		741.1.1	9082	1788	424	19.69	4.22	y
	fiber optics		741.1.2	15016	3335	1048	22.21	3.18	y
	optical devices & systems		741.3	77733	15770	4006	20.29	3.94	y
	holography		743	8064	377		4.68		
	holographic applications, etc		743.$	2642	389		14.72		
	semiconductor lasers		744.4.1	11546	1966	850	17.03	2.31	y
Advanced materials for comp/comm tech	rare metals — sum of		543.$	<10,000					
	silicon, tellurium & zirconium		549.3	23982	4835	1378	20.16	3.51	y
	electronic & thermionic materials		712	99214	26	18	0.03	1.44	
	semiconductor materials		712.1	28064	6110	1882	21.77	3.25	y
	thermionic materials		712.2	1183	35		2.96		
Biotech	bio materials, engineering		461.$	86070	17109	6409	19.88	2.67	
	bioengineering		461	107605	194		0.18		
	biomedical engineering		461.1	26125	5072	2120	19.40	2.39	y
	biological materials		461.2	31100	5904	2620	19.00	2.25	y
	biomechanics		461.3	7271	1647	545	22.70	3.02	y
	human engineering		461.4	10609	1466	544	13.80	2.69	
	human rehabilitation engineering		461.5	3069	732	337	23.90	2.17	
	medicine		461.6	20109	4276	2217	21.30	1.93	
	health care		461.7	6994	1519	617	21.70	2.46	
	biotechnology		461.8	10069	1875	778	18.60	2.41	y
	biology		461.9	16154	4350	850	26.90	5.12	y
	biological equipment		462	38448	5	7	0.00	0.71	
	biomedical equipment (general)		462.1	5745	886	501	15.40	1.77	
	Biomaterials		462.5	5537	768	598	13.90	1.28	

Note: ENGI = EI Compendex

databases. (This is not a problem in the present tabulations since each component is measured in only one or the other database.)

Database biases

We wondered how badly database biases (especially toward English) might distort country comparisons? To address this issue we ran a four-country tally on two emerging technologies — software and advanced computing/communication materials. We prepared tables presenting the results for 1998, 1999, and 2000 for India, China and Hong Kong, Thailand, and Brazil. These four nations touch a range of possible concerns. China poses language and inclusion concerns (Hong Kong separately searched and included; Taiwan not considered here). India provides contrasting stronger familiarity with English. Brazil poses strong language concerns — the possibility that Portuguese would be less likely to be indexed in INSPEC and EI Compendex. Thailand is of interest because the counts are so low.

We listed the leading institutions and publication outlets for each of the four countries. We then asked knowledgeable persons from these countries: 1) how much significant publication from their country would they estimate occurs in journals or conferences not included? and 2) do they know of important R&D organizations likely to publish elsewhere that we seem to be missing? Table 2 tabulates the sense of the responses.

We interpret these reviews as reassuring. Certainly we shall miss some important R&D because of database coverage emphases, but it does not

Table 2. Observations on national coverage

Country	How much publication appears to be missed (based on journals and conferences included)?
India	fair amount — but respondent points to theses (this is not a real national bias) not very much — points to 1 international and 1 Indian technical series likely that most are covered; all significant publications would be in English only a little; all significant research in India published in English
China	20–40% seems not to be collected by INSPEC and EI Compendex don't know extent of loss of Chinese language publications; many researchers do publish in international journals a little
Thailand	very little very little little a lot (but we inferred considerable institutional loyalty coloring this person's response)
Brazil	20–25% missed Very little several locally important contributions, but all those most important globally are included in these periodicals
	Are we missing the work of significant R&D organizations?
India	technical reports from government, semi-government agencies, corporations (this is not a national bias) no not applicable surely abstracted in INSPEC and EI Compendex
China	most important R&D organizations like to publish in places abstracted, especially into EI Compendex maybe military R&D institutes don't publish some not applicable not applicable
Thailand	not applicable all important R&D organizations seem to be included notes three Thai annual journals and proceedings
Brazil	lists ten organizations apt to publish in Portuguese, less likely to be abstracted in INSPEC and EI Compendex lists three organizations not appearing in our list some good Portuguese journals probably not abstracted

Note: Each line summarizes an observation of one reviewer from that country upon reviewing our tallies of emerging technology R&D publications for these countries

appear severe. Furthermore, coverage should be relatively comparable for a given country over time so that within-country comparisons should be good. Concerns about 'classes' of important R&D institutions not represented well do not seem qualitatively different than would be the case in countries such as the USA.

An intriguing sidenote to this exploration was our surprise at the relative software-related publication from China and India. We would have hypothesized that India would dominate because of its English language usage and its extensive software development activity. Not so; overall in INSPEC, we identified 12,766 software-related papers from China (and Hong Kong) versus 2,713 for India. The disparity appeared even greater most recently as we found 1,920 Chinese software publications in the year 2000 versus 133 Indian.

We were surprised at the relative software-related publication from China and India: at least in this instance, international literature contributions do not seem heavily determined by national usage of the English language

So, at least in this instance, international literature contributions do not seem heavily determined by national usage of the English language. Researchers in many countries seem to be encouraged to report their work in international journals or conferences, and those tend to favor English, but we have not systematically assessed the extent of this.

Emerging technology R&D activity by country

A mundane, but difficult, issue concerns how best to identify country of authors. Both INSPEC and EI Compendex only provide the institutional affiliation and country of the first author. In some (few) cases country is not indicated. These do not present a major 'indicators' problem for us, but users of these measures should recognize there is some loss of information — we won't tally 'all' a country's R&D.

Certain countries provide particular challenges. The UK, for instance, may also be indicated as England, Scotland, Northern Ireland, or Wales. However, just finding the string "Wales" in the affiliation field does not guarantee the UK — it may reflect New South Wales, Australia. This requires development of country thesauri for INSPEC and for EI Compendex to capture most national records while minimizing noise. We have developed initial such thesauri. Changing country designations, such as USSR, East Germany, could cloud historical tracking. In the case of Hong Kong, we extract its records separately, then combine with China for most purposes.

Results are interesting. Table 3 shows the counts for our 33 countries. Countries are grouped as in HTI to facilitate comparisons among industrialized and industrializing nations and among regions as follows:

- The 'Big Three' — United States, Japan, and Germany
- Western Europe (UK, France, Netherlands, Italy, Switzerland, Sweden, Spain, and Ireland)
- English Heritage Nations + Israel (Canada, Australia, South Africa, New Zealand, and Israel)
- Eastern Europe (Russia, Poland, Hungary, and Czech Republic)
- Asian Tigers (Singapore, South Korea, and Taiwan)
- Asian Cubs (Malaysia, China, Thailand, Indonesia, Philippines, and India)
- Latin America (Mexico, Brazil, Argentina, and Venezuela).

The first column shows each country's total number of articles and conference papers abstracted by EI Compendex for 1999. The following five columns break out each of our five emerging technologies. The last two columns sum these, with or without software included (since 'software' does not meet our dual criteria of recent and growing R&D activity).

Figure 1 depicts the results for the sum of the five emerging technologies (next to last column of Table 3), leaving out the 'research superpowers,' USA and Japan, to improve scaling. The most striking observation concerns China's strong presence — it is one of the research powerhouses for these emerging technology areas, along with Germany, UK, and France. Figure 1 suggests we could identify tiers in research activity on emerging technologies:

Table 3. National 'emerging technology' R&D publication activity for 1999

Counts	**ENGI total** (no)	**Optical comm** (ENGI)	**Comp hdwr** (ENGI)	**Semi mtls** (ENGI)	**Biotech** (ENGI)	**Software** (INSPEC)	**Sum** (mix)	**Sum '4 ETs'** (ENGI)
USA	57479	8790	6591	2224	4637	9627	31869	22242
Japan	22686	4527	2808	1870	1042	2820	13067	10247
Germany	11616	2375	1216	852	634	2520	7597	5077
UK	11349	1720	839	489	710	2681	6439	3758
France	8397	1588	817	548	411	1436	4800	3364
Netherlands	2886	483	261	120	261	588	1713	1125
Italy	5652	990	550	304	300	1122	3266	2144
Switzerland	1959	403	268	108	130	393	1302	909
Sweden	2798	360	269	151	233	397	1410	1013
Spain	3553	599	261	206	177	616	1859	1243
Ireland	222	48	37	10	21	96	212	116
Canada	6469	716	417	165	484	982	2764	1782
Australia	3594	521	165	113	222	897	1918	1021
South Africa	666	49	39	31	35	80	234	154
New Zealand	560	50	8	11	54	125	248	123
Russia	5182	1421	341	315	305	264	2646	2382
Poland	2115	437	160	136	77	227	1037	810
Hungary	665	84	37	33	55	88	297	209
Czech Repub	671	152	42	35	49	93	371	278
Singapore	1873	311	249	110	68	307	1045	738
South Korea	4975	918	665	348	142	748	2821	2073
Taiwan	4608	576	610	219	191	598	2194	1596
Malaysia	211	26	13	1	6	35	81	46
China	13890	2292	757	550	366	1656	5621	3965
Thailand	217	20	8	3	13	50	94	44
Indonesia	62	8	4	5	6	2	25	23
Philippines	35	5	0	0	2	3	10	7
India	4462	575	266	279	207	229	1556	1327
Mexico	1257	309	120	78	76	95	678	583
Brazil	2169	312	126	109	109	339	995	656
Argentina	521	79	12	32	24	41	188	147
Venezuela	196	26	6	12	8	19	71	52
Israel	1564	270	94	64	125	238	791	553

Notes: Detailed class codes consolidated into the counts shown appear in Table 1
'Optical comm' here corresponds to 'Comm technologies' in Table 1
'Comp hdwr' is computer hardware
'Semi mtls is advanced materials for computing/communication technologies
'Sum' adds the five separate emerging technologies
'Sum – 4 ETs' excludes software

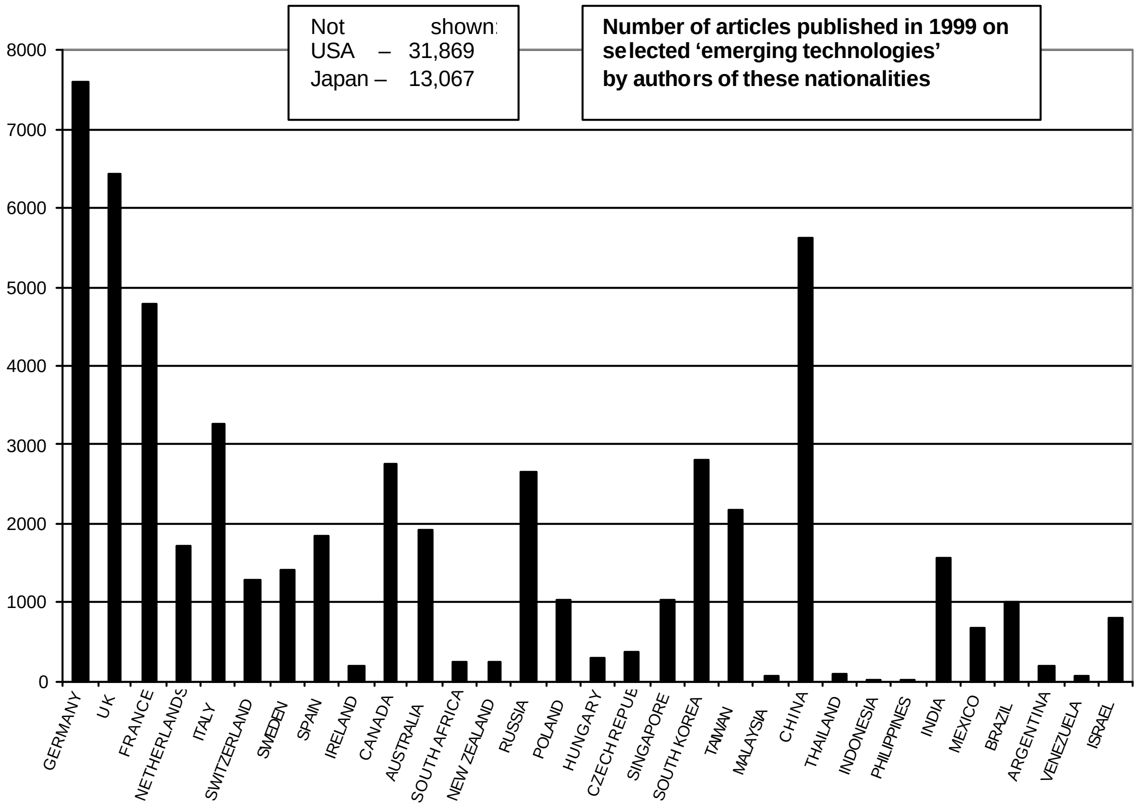

Figure 1. Emerging technology publication activity by country

- Superpowers: USA and Japan
- research powerhouses: Germany, UK, China, and France
- strong players (those with over 2,000 annual publications): Italy, South Korea, Canada, Russia, Taiwan
- solid presence: 11 countries with 670–2000 annual publications — Australia, Spain, the Netherlands, India, Sweden, Switzerland, Singapore, Poland, Brazil, Israel, Mexico
- laggards (those with about 200–400 annual publications): the Czech Republic, Hungary, New Zealand, South Africa, Ireland, Argentina
- those lacking critical research mass (<100 publications): Thailand, Malaysia, Venezuela, Indonesia, and the Philippines.

Keeping in mind that the 33 countries profiled are chosen for their high-tech proficiency or promise, these results raise concerns about the ability of those without a critical emerging technology research enterprise to participate early and strongly in attendant technology-based competition in the future. (Note also that the 33 countries selectively sample the heavily industrialized and industrializing nations; they do not cover all such countries.) Possibly most notable in this apparent research weakness is Malaysia, which scores strongest among the Asian Cubs on our High Tech Indicators, close on the heals of the Tigers — Singapore, South Korea, and Taiwan. However, were we to place stock in a measure of emerging technology R&D activity, the gap from Malaysia to the others becomes pronounced.

Normalizing the data

In constructing an indicator, we face choices as to how best to normalize the data. Note the tremendous range for our 33 countries in the sum of their annual emerging technology R&D publication activity — from 10 papers for the Philippines to almost 32,000 for the USA — over three orders of magnitude. We might consider *per capita* (or per scientist and engineer) metrics, but HTI prefers total national activity measures as more salient to export competitiveness. Should readers wish to explore other relationships in these data, Table 3 provides raw counts of items (nearly all journal articles and technical conference papers) indexed by the database (either EI Compendex or INSPEC).

HTI reports indicators as 'S-scores' — scaling the 33 countries on a relative basis with the leader on a particular variable as '100.' This is to make it easier to quickly compare countries' relative performance (the early HTI indicators reported values as Z-scores — how many standard deviations a country was from the mean — that proved awkward for many people to assimilate easily). In recent technological indicators development, UN Commission on Science and Technology for Development (UNCSTD) and UNIDO use a similar scaling approach.

For HTI expert opinion response variables scaled from 1–5, for instance, a perfect score of all 5s would transform to an S-score of 100; whereas a worst score of all 1s would transform to 0. However, all the present data are numerical. So the highest country score becomes 100 and the minimum is taken as 0. In other words, S-scores on the present data are the country's fraction of the highest country value, multiplied by 100 to scale from 0–100, that is, S-score is the percentage of the highest country.

For instance, look at the USA and Japan emerging technology 'Sum' (next to last column of Table 3). Japan's 13067 divided by the USA's 31869 = 0.41 or 41%. Note Japan's S-score for the sum is 45.99 (last column of Table 4). That is because this is the average of Japan's S-score (percentage of the leading country) on each of the five emerging technologies that contribute to the sum. In each case the USA is the leader, so we simply compute Japan/USA and average: (51.5 + 42.6 + 84.1 + 22.5 + 29.3)/5 = 46 (corresponding to 45.99). Note here that Japanese and American emphases are not identical across these five emerging technologies.

S-scores for the sum of emerging technology publications in 1999 reflect the huge disparity in research activity levels. For instance, pegging the USA as 100, the Philippines score 0.03 (last column of Table 4); its contribution to the open research literature on these five technologies is minimal.

We consider two bolder alternatives to explore research publication — ranks and logarithms. These certainly reduce the skewness, but reinforce the sense of high correlation across the five emerging technology areas. For ranks, correlation of each emerging technology with each other for 1999 publication, across countries, ranges from 0.90 (for software with semiconductor materials) to 0.99 (optical communication with semiconductor materials), with a mean of 0.95. For logarithms, the mean correlation between pairs of the five emerging technology publication counts, across countries, is again 0.95, with a range of 0.89 (software with semiconductor materials) to 0.98 (optical communication with computer hardware). Rank and log data for the 33 countries show strong correspondence. Raw counts show a similar mean correlation of 0.95, ranging from 0.90 (software with biotech) to 0.98 (three pairs).[5]

Moreover, these emerging technology emphases are strikingly similar to overall activity level in the EI Compendex database (Table 1). Correlations of raw counts for EI Compendex with each of the five emerging technologies average 0.97 (range of 0.93 to 0.99). Correlations of ranks with each of the five also average 0.97 (range of 0.95 to 0.99). In terms of indicator development, this lack of discrimination among the emerging technologies and with overall engineering R&D publication is somewhat discouraging.

Table 4. National 'emerging technology' R&D publication ranks and average S-score for 1999

Ranks	ENGI	Optical comm (ENGI)	Comp hdwr (ENGI)	Semi mtls (ENGI)	Biotech (ENGI)	Software (INSPEC)	Average S-score (5 ETs)
USA	1	1	1	1	1	1	100.00
Japan	2	2	2	2	2	2	45.99
Germany	4	3	3	3	4	4	24.73
UK	5	5	4	6	3	3	19.49
France	6	6	5	5	6	6	15.78
Netherlands	15	15	15	16	10	13	5.32
Italy	8	8	9	10	9	7	10.28
Switzerland	19	17	13	17	17	15	4.08
Sweden	16	18	12	15	11	14	4.82
Spain	14	11	15	13	15	11	6.05
Ireland	28	28	25	27	28	23	0.60
Canada	7	10	10	11	5	8	8.51
Australia	13	14	18	19	12	9	5.52
South Africa	24	27	24	26	26	27	0.83
New Zealand	26	26	29	28	24	22	0.73
Russia	9	7	11	7	8	18	8.96
Poland	18	16	19	14	20	21	3.51
Hungary	25	24	25	24	23	26	1.02
Czech Repub	23	23	23	23	25	25	1.19
Singapore	20	20	17	20	22	17	3.38
South Korea	10	9	7	9	16	10	9.40
Taiwan	11	12	8	12	14	12	7.20
Malaysia	30	29	27	30	31	30	0.21
China	3	4	6	4	7	5	17.48
Thailand	29	31	29	31	29	28	0.26
Indonesia	32	32	32	32	31	33	0.11
Philippines	33	33	33	33	33	32	0.03
India	12	13	14	8	13	20	5.99
Mexico	22	21	21	22	21	24	2.29
Brazil	17	19	20	18	19	16	3.25
Argentina	27	25	28	25	27	29	0.69
Venezuela	31	29	31	29	30	31	0.26
Israel	21	22	22	21	18	19	2.51

Patent measures

As mentioned, we are also developing patent measures, and these can differ dramatically with each other. We compared non-resident patent applications for each nation as a whole (not by technology categories) for 1997 with our measures. Correlations of the patent S-scores with our emerging technology S-scores ranged from 0.42 for biotech to 0.51 for software — much lower than the publication intercorrelations just noted.

Patent S-scores correlated more highly with R&D publication ranks (ranging from 0.68 with optical communications to 0.76 for software). Ranking moderates the extremes of the publication statistics. In fact, we would not expect these measures to correlate highly — this patent measure reflects market attractiveness, while our publication measures get at indigenous generation of emerging technology developments.

On the other hand, patent applications by nationals of one country anywhere (home or abroad) better reflects indigenous development activity. This measure correlates very highly with our five emerging technology publication rates — from 0.84 for semiconductor materials to 0.98 for biotech. This broadly distributed measure (ranging from 576 Argentinean patents in 1997 to 1.5 million American ones) mirrors the extreme distribution of R&D publications across countries. (This patent measure correlates much less with the toned down publication rank measures, ranging from 0.50 to 0.54.)

Overlap

A reviewer of this article wondered how much overlap there was among the articles in our emerging technology categories. For the four categories drawn from EI Compendex, we can provide that information. The biotech category overlaps only about 1% with the computer hardware and semiconductor materials categories, but 14% with optical communications. Those three categories — computer hardware, semiconductor materials, and optical communications — overlap heavily with each other, ranging from 23% to 32% common records. Those are certainly not mutually exclusive, so it should not be very surprising that there is high correlation given this commonality.

National emphases

For rank data, the overall R&D publication patterns reaffirm the similarity in national emphases across the five emerging technology categories. Table 4 shows that the USA ranks #1 for all; Japan, #2 for all (as well as for overall EI Compendex publication in 1999). In general, R&D activity levels across these five emerging technology categories are very similar. Some interesting variability does surface:

- Russia ranges from 7th (optical communication) to 11th on four of the five, but lags at 18th on one (software).
- India surprisingly shows strongest at 8th (semiconductor materials) to weakest at 20th (software).
- South Korea peaks at 7th (computer hardware), ranging down to 16th (biotech).
- Taiwan shows as a steady 12th to 14th on four of the five, showing notably higher on computer hardware (8th).
- Canada seems surprisingly strong at 5th on biotech and 8th on software, ahead of its placement on the other three (10th or 11th).
- Australia shows relatively high variability, with 9th on software and 12th on biotech, but only 18th and 19th, respectively, on computer hardware and semiconductor materials.

Observations

Emerging technologies do not stay constant. One advantage of the proposed approach is that the set of emerging technologies would be continually adapted to seek 'frontier' technology R&D. The dual criteria of strong recent emphasis and growth in activity provide good bases for this adaptation. In this initial exploration, we augmented these with judgment based on categorical intent (for instance, excluding human engineering from biotechnology, and including software despite failure to meet the dual criteria).

The level of specificity for emerging technologies could be set broader or finer (consider Table 1). We think the current algorithm is at about the right level for national comparisons as an indicator of 'technological infrastructure' that enables countries to partake in the commercialization of potentially economically potent new technologies. In practical terms, each additional class code adds about 50 searches (33 countries plus complicated country designators, for instance, UK includes England, and so on). So, for HTI we cannot pursue too much detail.

Once search algorithms are finalized, we should

Emerging technologies do not stay constant: in this approach the set of emerging technologies is continually adapted to seek 'frontier' technology R&D; dual criteria of strong recent emphasis and growth in activity are good bases for this adaptation

be able to write a macro (script the steps) to perform a large set of searches and the subsequent analyses quickly and reproducibly. This could be used to generate periodic updates (such as every year) to alert to pronounced national initiatives in particular emerging technologies. Differential activity measures (showing extent of change over time for each nation) might prove indicative of shifting R&D emphases.

While we therefore plan to pursue this emerging technology measure as indicated, we hope that others will be stimulated to explore alternatives. In particular, finer categorizations (for instance, agricultural biotech vs medical biotech) could provide useful R&D policy metrics. One might also want to pursue issues such as "what percentage of a country's engineering research is in these emerging technologies?" Figure 2 shows the profile for the 1999 emerging technology publications (next to last column of Table 3) as a percentage of the country's overall engineering research (first column of Table 3).

Given the categorization issues involved, it is necessary to be cautious in interpretation. Furthermore, the low numbers of publications of countries such as Ireland preclude making too much of this measure. Nonetheless, it is interesting to see which countries show greater relative emphasis on these emerging technologies, and which show less.

We plan to average relative national standing for these five emerging technologies (as shown in the last column of Table 4) to report this as a measure of national emerging technology capability. We considered the possibility of differential weighting for the five component categories; however, the overall similarity among the five for these countries obviated the need for special weighting. This measure of research activity in five emerging technologies would become a component of our Technological Infrastructure 'High Tech' Indicator for 2002. In future years (for instance, 2005), the specific technological classes would be revised to reflect most recent publication emphases.

The current tabulation incorporates some 16 specific technological classes of research publication from EI Compendex and INSPEC relating to five emerging technologies. Our 33 nations account for 80–90% of the research publications in the four 1999 EI Compendex samples. This is surprisingly high, considering we do not include all the OECD (Organization for Economic Cooperation and Development) countries.

For each of these four emerging technologies (not including software), 1999 accounts for 20–21% of the total records from 1970–2000. The ratio of hits in 1999 to those in 1996 is 2.7 for biotech, 3.46 for optical communications technology, 3.36 for semiconductor materials, and 2.77 for computer hardware. In contrast, the software category shows a ratio of 1.03. So, the amount of publication in these 'over the horizon' technology categories has increased about three-fold from 1996 to 1999. That is hot. The steady research level in software could warrant further examination of changes in topical emphases and approaches within this category. (While class codes and total records abstracted change over time, the changes over this time period were quite moderate.)

Yet to what degree does lack of research publication activity portend lack of high-tech economic competitiveness for nations? How does it fit in national and global systems of innovation (Archibugi et al, 1999)? These are open questions. To illustrate the contrasts more specifically, consider the biotech area. For 1999, our tally for the class codes

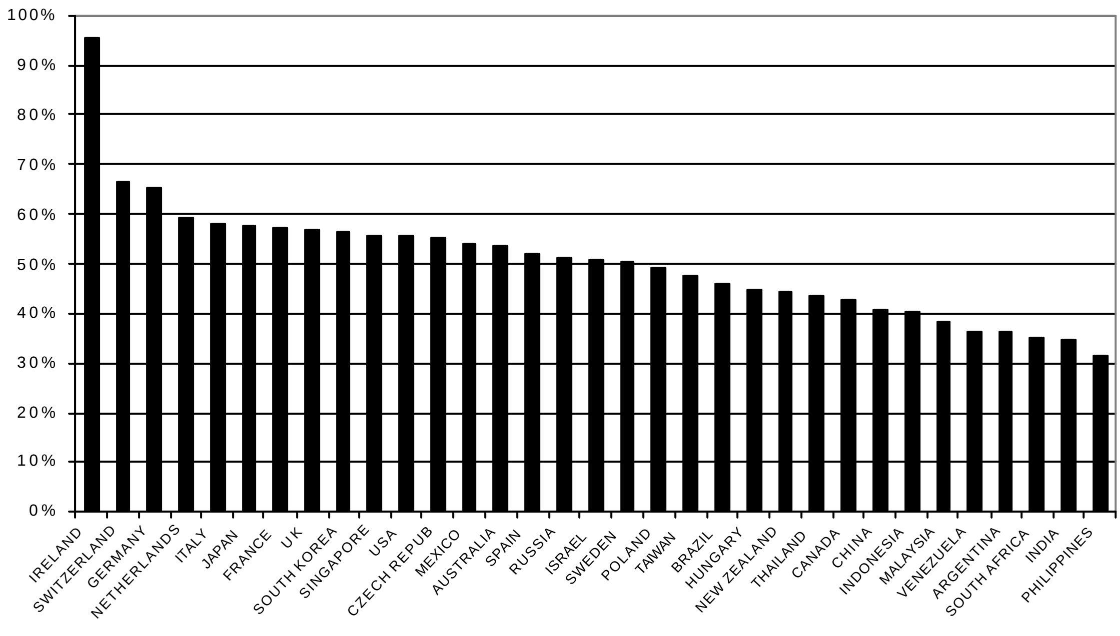

Figure 2. Emerging technology emphasis by country

comprising this domain was 13,974 (EI Compendex abstract records). Of those, our 33 countries account for 80%, led by the USA (33% itself — 4637 publications). In contrast, four of our countries had fewer than ten biotech publications each, using this coding. That would seem to severely constrain their potential to commercialize this emerging technology.

The implications of this measure merit exploration. Our overall 'high tech indicators' (HTI) point toward a dramatic broadening of high-tech competitiveness across these 33 nations. This 'emerging technology' measure points to a markedly different future in which relatively few of these nations dominate technological competitiveness over a 15-year or so horizon. In terms of relative (S) scores, six nations score 15 or higher; 27 score under 10, and of those, a dozen score about 1 or under (publishing fewer than 400 papers per year in these areas).

This disparity challenges those who would set national policy to foster technological competitiveness (Clark and Guy, 1998; Kim, 2000). Do the industrializing nations need to bolster their R&D in emerging technologies to enable them to compete economically in these areas in the future?

Recalling our earlier question, the leading countries based on our measures are: USA; Japan; Germany; UK; China; and France (compare, any of Table 3 'sum,' Table 4 'average S-score,' Figure 1). The surprise to us is China. In the past few years China has moved up dramatically on Georgia Tech's HTI. Her strength in emerging technologies suggests this nation may well power forward into a leadership role in next generation technologies.

Notes

1. NSF project #9901310, "Indicators of Technology-based Competitiveness," J D Roessner, Principal Investigator.
2. INSPEC: our analyses emphasize abstract records from the past five years (just over 1.5 million records). INSPEC is produced by IEE (<http://www.iee.org.uk/publish/inspec/>). It abstracts articles from over 4000 science and technology journals, plus about 2000 conference proceedings, and other technical sources. The database includes physics, electrical engineering, communications, computing, and information technology.
3. EI Compendex (also called *Engineering Index*) — is produced by Engineering Information (<http://www.ei.org>). It abstracts articles from about 2600 journals, conference proceedings, and technical sources — for 1995–1999, over 1.1 million records. It covers all engineering disciplines.
4. As of January, 2001, when these tallies were made, the year 2000 activity was not fully indexed. The EI Compendex tally for the year 2000 was 176,022 (vs about 230,000 for 1998 or 1999); the INSPEC tally was 230,009 (vs about 325,000 for 1998 or 1999). That is why we are using 1999 as our most recent full year in this analysis.
5. S-scores give exactly the same correlations as raw scores. Converting raw values to S-values preserves the relative ordering identically.

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