The US-EU Race for Leadership of Science and Technology: Qualitative and Quantitative Indicators*

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Abstract

Both the United States and the European Union have set goals for worldwide leadership of science and technology. While the U.S. leads in most input quantitative indicators, output indicators may be more specific for determining present leadership. They show that the EU has taken the lead in important metrics and is challenging the U.S. in others. Qualitative indicators of fields of research and development, based on expert review studies organized by the authors, confirm that many EU labs are equal or better than those in the U.S.

1. Introduction

1.1. Purpose

Since the 1950s, the top science goal of the U. S. Government has been "maintaining world leadership in science, mathematics, and engineering," and there is wide acceptance in the U. S. of the premise that it is already ahead. With the new emphasis on planning mandated by the Government Performance and Results Act (GPRA), federal agencies need goals, plans for achieving them, and performance reports on their progress. While the U.S. may currently lead the world in science and technology (S&T) in some aggregated sense, research agencies must assess the status in the sub-disciplines they fund. Systematic assessments of individual fields are sparse, but the best available evidence shows that the U.S. does *not* lead the world in many important fields. In particular many European research centers now present a challenge to U.S. leadership.

In 2000 the European Union set itself a goal of becoming the most competitive and dynamic knowledge-based economy in the world by 2010. Strategies are being implemented to achieve this goal, including the tighter integration of research and development activities into a European Research Area. In addition the EU also plans to sharply increase its investment in research and development (R&D) to 3% of GDP by 2010. The EU has already made good progress in some output indicators of S&T performance, and these policy measures plus its expansion from 15 countries to 25 in the coming year are likely to accelerate that progress. This paper will compare the status of indicators of S&T leadership by U.S. versus the EU. Space here permits only the highlights, but some additional trend graphs are posted at http://itri2.org/USEU/.

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1.2. Approaches to Measurement

Objective measurement of leadership of S&T relies on interpretation of a selection of indicators of performance from the many that are available. There are two basic approaches.

Quantitative methods rely on measuring inputs to the innovation process, such as annual research investments; and outputs such as technical papers and citations to them, patents, and international trade benefits of new technologies. Sometimes composite indicators are used, which are merely weighted sums of individual ones.

More input indicators are available in the literature than outputs. Here however, the emphasis will be on what output indicators are available, since they are the best measure of current scientific leadership. A change in an input indicator like funding can signal a country's intentions, and may result in a performance change in an output indicator, but only years later.

Qualitative methods are usually studies of the international stature of research efforts. These are conducted by experts in the target discipline using a variety of data, but the best ones include lab visits in the appropriate countries. Because of travel costs and the time demands on senior researchers, such studies are expensive, and can cover only selected disciplines. However, the authors have organized over 55 such studies in the last 13 years. This paper will present findings from ten studies completed since 1996 that included study tours of the leading countries of the EU for comparison to efforts in the U.S. In addition it summarizes three qualitative studies conducted by the U. S. National Academy of Sciences

2. Quantitative Indicators

2.1. Input Indicators

The most important input indicators like total R&D investment, investment per GDP, and total number of research personnel, strongly favor the U.S. over the EU, (Shelton, 2000). It is probably this dominance of these input indicators that leads to the common impression that the U.S. lead in S&T is unassailable.

The recent EU assessment of its position (EC, 2002) contains dozens of indicators. The overall conclusion of the report is based on two composite indicators that characterize investment inputs and normalized outputs (productivity measures). These composite indicators put the U.S. far ahead of the EU, and show that the EU is not really making sufficient progress to meet its goals. However, one can easily argue with the importance of the components chosen and their weights. Indeed the EU is already leading the U.S. in some of the most important output indicators.

2.2. Output Indicators

Table I summarizes the most important output qualitative indicators, including the sources and dates of the data. Each row will be discussed in turn.

The indicator that shows the most dramatic shift from the U.S. to the EU is the number of technical publications in the world's leading journals (Row 1). As late as 1991, the U.S. led in 17 of 20 fields of science as measured by its success in placing its papers in the some 2500 of the world's leading journals in the ISI database. The EU then led only in three fields, but by 2001 their positions had reversed. The EU now leads in 12 fields, while the U.S. leads in only seven. (The Asia Pacific Region leads in one field.) Extrapolations of trends (and addition of ten more EU countries) predict that the EU will take the lead away from the U.S. in at least three more fields by 2004. An analysis of the causes of this sharp decline in the U.S. position was made in (NSB, 2001, pp 5-39), but the conclusion was, "The reasons for this development remain unknown."

On the other hand, the U.S. led the EU as a whole in relative impacts (Row 2). These normalized citation counts are a rough measure of the quality of technical papers. Compared to others, U.S. researchers have an extraordinary propensity to cite mostly papers from their own country, which may distort this measure substantially. Even so, some individual EU members led the U.S. in up to eight of 20 technical fields in the ISI database. Incidentally, non-member Switzerland has led the world in relative impacts since the early 1980s.

Inventions are mainly patented in the home country of the inventors, which provides a "home court advantage" that makes it difficult to use this key output measure to compare the position of countries. Triadic patents (Row 3) are inventions that are patented in all three locations: the U.S., EU, and Japan, thus reducing the home country bias for patenting, among these three anyway. The U.S. has only a small lead over the EU in this indicator. In recent years it has increased this lead slightly, but it would not take much for the EU to take the lead. Policies that merely encourage researchers to file more patent applications could make the difference.

While the total number of working scientists and engineers is an input resource to the R&D process, the production of new scientific personnel can be considered to be an output of the scientific establishment, particularly PhDs. In any event the EU has a clear lead in production of scientific human resources (Rows 4 and 5), and will strengthen this lead with the addition of new countries like the Czech Republic, Hungary, and Poland.

Nobel prizes are the gold standard of quality in scientific achievement in the fields where they are given. In 2001 the Japanese set a goal for increasing the number of their laureates by 30 over the next 50 years, which would require a huge R&D investment to

Table 1. S&T Output Indicators*

Indicator (Data Year)	**U.S.**	**EU**	**Japan**	**Source**
1. Quantity of Papers (2001)	250,128	273,179	70,574	(ISI, 2002)
2. Quality of Papers: Relative Impacts (2001)	1.47	1.06	0.91	(ISI, 2002)
3. Triadic Patents, Market Share (1998)	36.03%	33.33%	25.36%	(OECD, 2002)
4. S&E Ph.D. Production (1999)	25,953	39,021	6,575	(NSB, 2002)
5. S&T Graduates (1998)	169,311	225,796	25,021	(EC, 2002)
6. Nobel Prizes Physics Chemistry Medicine (1950-2002)	 64 38 74	 31 33 38	 4 4 1	(Nobel Prize Internet Archive, 2003)
7. High-Tech Market Share (2000) Percent Aerospace Electronics Office/Computers Pharmaceuticals Instruments	 33.79 23.68 23.99 13.13 27.47	 33.5 16.38 12.25 32.85 21.21	 1.58 18.94 14.68 3.23 17.24	(OECD, 2002)
8. External Trade Balance as a percent of GDP (2001)	-3.2%	1.2%	0.6%	(Eurostat, 2002)

* In some cases the data for some countries is an earlier year, the latest available. The highest metric of the three columns is underlined.

achieve. The U.S. has dominated this indicator over the last 50 years (Row 6). However, brain drain exaggerates this leadership somewhat. The career path of many Nobelists starts with a European education and early research there, but by the time the award is made, they are working in a U.S. lab or have retired in the U.S. For example if Table I counted the countries of origin instead, the U.S. totals would go down by six, and the EU total would go up by five -- in just the last three years of data. If the EU were to reverse its brain drain by encouraging a few scientific superstars to move to the south of France for their senior years, they could probably increase their count of Nobel prizes at very little cost. Braun and colleagues (2003) have recently examined various ways of tabulating the counts. For example for the whole 20th Century (1901-2001), the countries of the EU would lead the U.S., even counting nationality by residence at award time.

Selling innovative products in the international market place is one bottom line of the innovation process. High technology market share is a particularly relevant indicator of the overall success of a country's S&T policies, although there are many other factors involved. Row 7 lists the international market share in five sectors. The U.S. leads in four of them and the EU in one (pharmaceuticals). The trend curves show the EU gaining in one more sector (aerospace), but the most dramatic phenomenon is the sharp loss of Japanese market share in all five sectors. In 2002 U.S. international trade in high technology products ran a deficit ($17.5 billion) for the first time ever.

Overall international trade is often used as an indicator of a nation's business and technological prowess in competing in the marketplace. (Row 8.) By this measure the U.S. is leading the world, but in the enormous and increasing size of its trade deficit. The U.S. deficit in goods and services in 2002 was $435 billion, greater than the total GDP of all but a few nations. The EU has a positive surplus greater than that of Japan, which is thought to be an export powerhouse. It also has an $82 billion trade surplus with the U.S.

Space does not permit trend graphs of all these indicators, but a couple of the more interesting ones are included here. Fig. 1 shows the percent share of papers published in the world's leading journals as compiled by ISI (2002). The surge of the EU is quite remarkable, while the decline in U.S. "market share" of these slots in refereed journals is puzzling. Fig. 2 shows the EU well ahead of the U. S. in production of PhDs in science and engineering, and again we see the U.S. declining. Other trend graphs are posted at http://itri2.org/s/USEU/. In some cases the U.S. leads, but EU position in output indicators is strong and getting stronger.

3. Qualitative Indicators

Qualitative assessments also raise questions about whether the U.S. or EU leads in S&T. While relatively few fields have been analyzed by this comprehensive, but expensive approach, expert review of the main competitors frequently finds European centers of excellence that equal or lead the best work in the U.S. Two U.S. benchmarking activities using peer review as their main methodology are reviewed here briefly: (a) the WTEC program sponsored by several U.S. Government agencies (WTEC, 2003), and (b) the

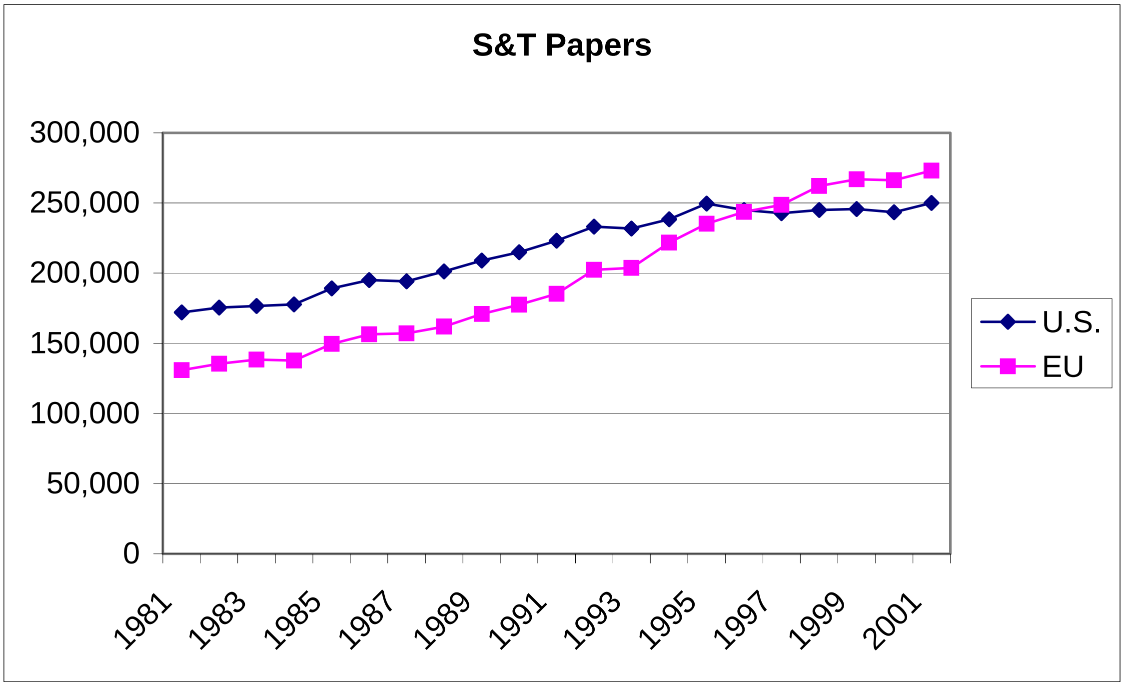

Fig. 1. Market share of papers in the 24 fields on the ISI CD.

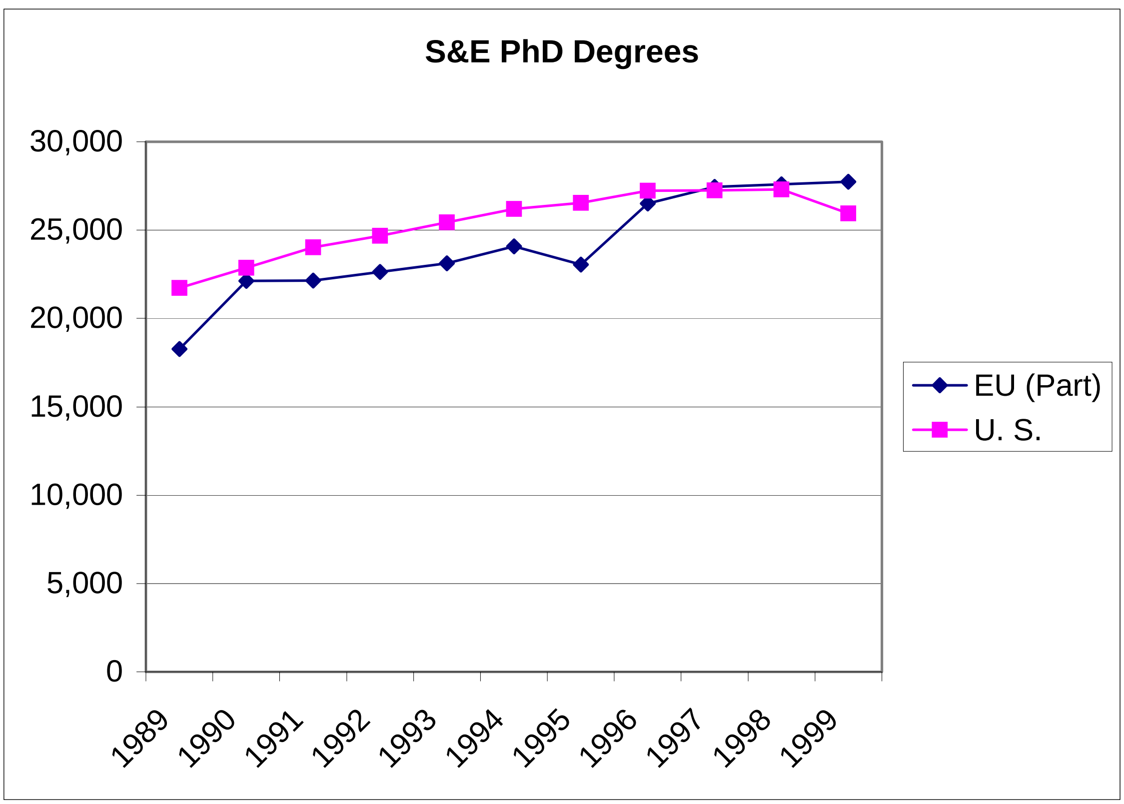

Fig. 2. PhD degree production in science and engineering (NSB, 2002). The EU (Part) curve is only for Germany, France, and the UK. The 1999 total EU figure is 39,021, so the total EU curve would be well above that of the U.S.

experimental international benchmarking program recently completed by the U. S. National Academy of Sciences (NAS 2000).

3.1 WTEC Study Findings Covering the European Union

WTEC benchmarking studies have found that many technologies are led by countries other than the United States, particularly Japan and the EU. To conduct benchmarking studies, WTEC organizes a review panel of distinguished U.S. scientists. This panel then surveys a variety of information sources, in some cases including publications, patents, and other bibliometric data, then selects leading labs to visit in person. Following these site visits, the panelists then prepare an analysis comparing the status and trends of the best R&D abroad with that in the U. S. A detailed description of the WTEC methodology is at http://wtec.org/loyola/ar9798/001_intr.htm.

Table II lists WTEC studies since 1996 that have included coverage of EU countries. EU countries were judged to be leading or equivalent to U.S. R&D activities in 52 percent of the 151 separate technical sub-topics that were rated by these ten WTEC study panels, as shown in the right hand column. The second column from the right shows both the number of subfields where Europe was rated “leading” as well as “either leading or equal” to the United States.

Even WTEC panels that have rated the U. S. as leading its international competition have often sounded warnings about future trends. A case in point is the recently completed tissue engineering (TE) study. As indicated in Table II, this panel rated the U. S. as ahead of or equal to Europe in all subfields of TE research. In particular, the panel rated the U. S. as leading the world in industrial applications of TE. However, in their verbal conclusions, the panelists stated that Europe is leading the U. S. in supporting basic research necessary for *future* industrial development of TE, hence the panel’s overall assessment of *trends* leading to future European competitiveness in this field was very favorable. Since the TE report was published last year, two leading U.S. TE firms, Advanced Tissue Sciences and Organogenesis, have declared bankruptcy. Both are in the hands of European partners. This suggests that the WTEC panel’s assessment would be different if it were revisited today. The overall picture that the WTEC study findings paint, therefore, is of a highly competitive EU R&D enterprise poised to carry out its stated goals.

3.2 NAS Experiments in International Benchmarking

While WTEC has conducted most peer review assessments of international technologies, in the late 1990s the U.S. National Academy of Sciences conducted three assessments of the international position of U.S. research in mathematics, in materials science, and in immunology. (NAS, 2000) Each drew on a variety of quantitative indicators (publications, patents, etc.) All studies also included a novel concept for assessing U.S. competitiveness, a “virtual congress.” First, the Academy appointed expert panels ranging from 12 to 14 (mostly U.S.) experts in each of these three fields.

Table 2. Recent WTEC Assessments Covering EU Countries*

Report Title	Number of EU Sites Visited	Number of Technical Subtopics Rated	Sub-topics where Europe Leading / Leading or Equal to U.S.	% of Subtopics Where Europe Rated Equal to or Ahead of U.S.
JTEC/WTEC Panel Report on Rapid Prototyping in Europe and Japan (3/97)	12	13	1 / 8	62%
WTEC Panel Report on Advanced Casting Technologies in Japan and Europe (3/97)	7	14	5 / 11	79%
WTEC Panel Report on Power Applications of Superconductivity in Japan and Germany (9/97)	5 (plus a review conference for the German program)	~15	1 / 3	20%
WTEC Panel Report on Nanostructure Science and Technology (12/98)	16 (plus workshops in Germany and Sweden covering an additional 13 sites)	6	1 / 4	67%
WTEC Panel Report on Global Satellite Communications Technology and Systems (12/98)	12 (plus a conference where other European developments were discussed)	N.A.	N.A.[1]	
WTEC/MCC Strategic Technology Tour Report on MEMS and Microsystems in Europe (1/2000)	15 (plus a workshop reviewing other European developments)	9	2 / 6	67%
WTEC Panel Report on Wireless Technologies and Information Networks (7/2000)	11	21	3 / 12	57%
WTEC Panel Report on Environmentally Benign Manufacturing (4/2001)	17	10	6 / 7	70%
WTEC Panel Report on Tissue Engineering Research (1/2002)	23 (plus a workshop covering 3 additional sites)	37	0 / 13[2]	35%
WTEC Panel Report on Applications of Molecular and Materials Modeling (1/2002)	25	26	5 / 15	58%
Total/Average		151	24 / 79	52%

*Source: (WTEC, 2003)

[1] This satellite communications panel did not produce a rating table. However, the panel's conclusions suggest that while the United States continued to lead in satellite communications markets, this lead was slipping due to inadequate funding for R&D for satellite communications systems.

[2] With 5 subtopics rated as "too early to determine."

Then the panelists were then asked to divide their fields into sub-fields and sub-subfields, and to identify a group of from 5 to 15 “respected leaders” in each sub-subfield. These leaders were then polled and asked to imagine that they were organizing an international “congress” in that sub-subfield, and to list 5 to 20 people from anywhere in the world who would be their first choices to speak at such a congress. The NAS panel members then drew on the results of these polls, as well as several more traditional quantitative indicators, in arriving at their final assessments.

Space does not permit much detail, however, the NAS conclusions rate the U.S. position highly:

- The United States is clearly pre-eminent in mathematics today
- The United States is among the world leaders in all subfields of materials science and engineering research and is the leader in some subfields, although not in the field as a whole
- The United States is the world leader in all the major subfields of immunology, but is only among the world leaders in some specific sub-subfields

One possible reason that the NAS studies tended to rate the U. S. as more highly competitive than the WTEC studies do is that, even though the panelists in both programs are mostly Americans, the NAS panels never traveled abroad as an explicit part of their assessments. Most WTEC panelists start their studies with a higher opinion of U.S. competitiveness than they do after the study tours.

4. Conclusions

So who is leading the world in S&T: the U.S. or the EU? While no single nation rivals the U.S. for the lead, it is becoming clear that the European Union as a whole is mounting a serious challenge. It has set strategic leadership goals and has committed itself to substantial funding increases to meet those goals. The 15-nation EU already leads the US in important metrics, and the EU's addition of ten more countries in 2004 will strengthen its position. As the EU becomes more tightly integrated into a European Research Area, it will be more reasonable to compare its overall performance to that of the U.S. And that performance is likely to lead that of the U.S. by any reasonable composite of measures, unless U.S. policies toward science change.

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