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Global Research Competition Affects Measured U.S. Academic Output

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The Changing Competitiveness of U.S. Science and the Organization of Academic Science

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Global Research Competition Affects Measured U.S. Academic Output

DIANA M. HICKS

Introduction

Between 1992 and 1999, the number of papers published by U.S. academics fell by 9 percent as reported in the National Sciences Board's *Science & Engineering Indicators–2002* (SEI). This chapter seeks to understand why this occurred. A 9 percent decline in output could be a valuable tool for advocacy for almost any constituency in U.S. academia. Advocates could report trends in particular fields over limited periods of time to support arguments about the deleterious effects of the emerging patent culture, the insidious effects of health insurers on medical research, the harm of decreasing federal support for engineering, the dangers of an aging university professorate, and so on. This chapter approaches the question differently. It argues that to understand this decline properly we must take a step back and look at trends across the U.S. research enterprise. When we do, we see that the decline is so broadly based that any explanation particular to one field of research or even to universities as a whole must be inadequate. This chapter looks for a global phenomenon that explains both the broad pattern of decline and its surprising obscurity.

The Larger Context

Open publication in peer-reviewed research journals traditionally characterizes scientific communication, and counts of countries' papers in these journals are the basic indicators of national scientific output. Increases in published output are routine, expected, and taken as indicators of a healthy scientific research system. A declining publication count, however, would be

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worrying, perhaps signaling weakness or decay in the research system, which in turn might threaten future economic growth in our science-driven, high-tech economy. SEI 2002 reported that U.S. academics published almost 8 percent fewer papers in 1999 than in 1995. Examined in the context of the past three decades, the decline is unprecedented.

Three decades of U.S. publication output as reported in SEI are displayed in Figure 11.1. Within each series, papers are counted only if they appear in journals indexed in the *Science Citation Index* (SCI) or *Social Science Citation Index* (SSCI)[1] in the first year of the series, taking into account journal administrative changes; that is, the journal set is fixed within series. Between series, the number of journals included in the counts increased resulting in the gaps between the series. The figure reveals that U.S. publication output has held steady within fixed journal sets and increased as the journal sets were updated. Only in the mid-1990s did decline set in.

The decline was broadly based, affecting more than just universities. Table 11.1 reports the percentage change in number of papers for each sector between 1992 and 1999. In aggregate, U.S. output dropped by 10 percent. Academic output dropped by 9 percent and accounted for 64 percent of the total change in output (because a large percentage of U.S. output comes

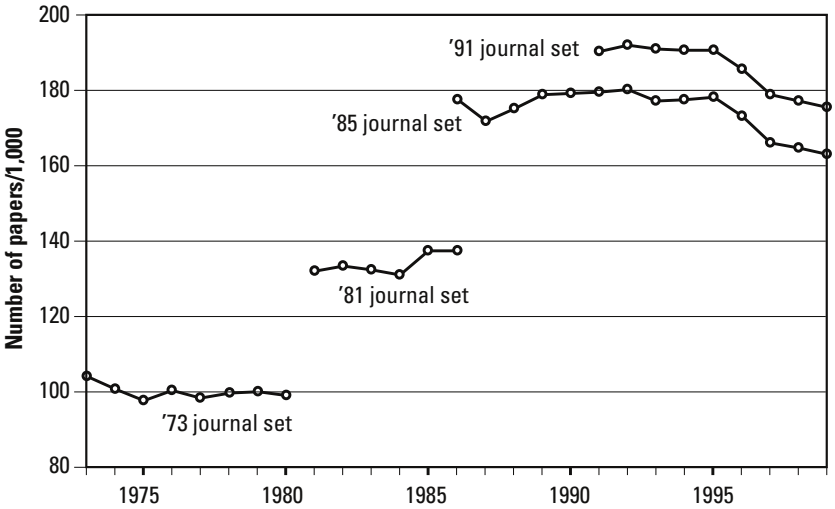

FIGURE 11.1 U.S.-authored papers fractionally counted in fixed journal sets, 1973–99.

Source: National Science Board, *Science and Engineering Indicators–2000.*

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from universities). Note that federal government and corporate laboratories saw larger declines in output, and all sectors saw some decline.

The decline was broad in a second dimension; it affected most fields. For each scientific field, Table 11.2 reports the percentage change in number of U.S. papers between 1992 and 1999. Every field except earth and space sciences exhibited an absolute decline in output. The decline was most surprising in the life sciences, particularly biomedical research and clinical medicine, since these fields enjoyed increased government support during the 1990s. Granted, the declines in these fields were smaller in percentage terms than in other areas, but there were declines. Because the life sciences accounted for such a large share of papers, even their smaller absolute declines accounted for 41 percent of the total decline in U.S. output.

That it is not just university output in a few fields that was in decline in the late 1990s, but all U.S. scientific output across all fields, is a fundamental

TABLE 11.1 Percentage change in articles by sector, 1991–99.

Sector	Percent Change
Academia	–9
Federal Government	–17
Companies	–24
Nonprofits	–1
FFRDC	–1
Other	–13
Total	**–10**

TABLE 11.2 Percentage change in articles by field, 1992–99.

Field	Percent Change
Life Sciences	–7
Clinical medicine	–5
Biomedical research	–6
Biology	–22
Chemistry	–9
Physics	–9
Earth and space sciences	13
Engineering and technology	–26
Mathematics	–10
Social and behavioral sciences	–19
All fields/total	**–10**

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point. Any explanation must act on the entire U.S. research enterprise. Already doubt has been cast on particular constituencies presenting one or two of these figures to argue their case for more resources.

Possible Explanations

The first possible explanation for the decline is that U.S. scientists are indeed publishing more and more articles in scientific journals as they always have, but SEI counts are somehow missing that and getting it wrong. After all, these publication counts are indicators, and indicators can go astray. Specifically, bibliographic databases index part of the scientific literature. No representation of the scientific literature is more complete than these databases, yet there are published scientific papers that are not indexed. Thus, publication indicators can go astray if the database is not a faithful representation of the scientific literature. Of particular relevance here, if the database grows more slowly than the literature, U.S. scientific output could appear to decline when measured in the database yet could still be expanding.

It is quite likely that the scientific literature grows differently from the literature databases because different mechanisms underlie the expansion of the literature and the expansion of databases. The literature expands as journals grow and split and new journals are founded to serve new specialist interests. This reflects the continuous expansion of research as scientists become more specialized and new specialties emerge. Perhaps most crucially, the literature grows as the result of decisions of innumerable highly motivated individuals and publishers looking for expansion. This growth may be slowed, however, if subscriptions are harder to come by—for example, if library budgets are static or journal subscription costs rise. Databases must expand or risk looking old fashioned and losing subscribers, yet expansion per se probably does not increase subscriptions, though it does increase costs. Also, databases are affected by changes in company policy, such as a decision to include more foreign literature or to add all health sciences journals (as happened in the SSCI in 1996). Database growth is controlled by skilled management who assess the costs and benefits. Thus, the literature is biased toward exuberant and uncontrolled growth, while databases are biased toward staying the same size or, if they must, growing slowly, steadily, and predictably. The SCI grows linearly at about 3 percent per year.

This disparity is not as worrying as it might seem at first because of

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what might be termed "the quality factor" in science. Simply put, not all literature that claims to be scientific is really scientific, and not all scientific literature is equally valuable. In the first category would be, for example, journals about astrology or homeopathy. In the second would be house journals, locally oriented journals, and often new journals, because researchers may be wary of submitting good work to new journals with an uncertain future and limited circulation. The boundary between the best scientific literature and the rest is subjective and shifts over time as approaches once considered obsessions of the fringe gain acceptance. However, from the policy perspective, quality counts. If U.S. output in *Science* and *Nature* declined, it would not be comforting to know that increased publishing in *Astrology Today* and *Vegetable Journal* more than made up for it.

To generalize this principle, in bibliometrics we rely on databases to draw a line somewhere and to incorporate the best scientific literature. We hope, and in general this is the case, that the database indexes the best literature and that at the bottom end of its quality spectrum questions may arise and coverage may change but that, overall, what is missed is much less important than what is indexed. This works because the impact of scientific research is not arrayed in a normal distribution (like height or intelligence). Measured by citations, impact follows a power law distribution, meaning that a very few papers earn very high citation counts and a large number earn no citations at all. Normal distributions are well described by a mean and standard deviation; power law distributions are not. Thus, database providers work not to cover a spread about a quality mean but, rather, to identify the top of the distribution. The top is very visible, given the nature of the distribution, and the nature of the distribution means that however far down the distribution databases draw their line, the literature excluded will be much less significant than the literature included.

The implications for assessing growth of U.S. scientific output are these. What we would like to count are papers in peer-reviewed, internationally oriented journals, because this is the yardstick by which a nation's science should be measured against other nations. The SEI fixed set of journals is relatively static in size when compared to the full scientific literature. Nevertheless, growth in number of U.S. papers is possible. Between the five-year periods ending 1994 and 1999, the number of papers in the SEI fixed set of journals grew by 5 percent. Although this growth rate is probably lower than would be obtained from a count of the full scientific literature, our indicators have not gone astray. If U.S. output in the world's

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top peer-reviewed, internationally oriented journals is in decline, that in itself may signify a problem. Our indicators may be more complex than we initially thought, but they raise policy-relevant questions.

Electronic Publishing

Declining numbers of journal articles would not be cause for worry if authors were shifting to newer forms of publishing such as electronic publishing or new journals. The SCI indexes high-quality, regularly published electronic journals, so for this explanation to hold, something would have to be happening that defeats their policy of indexing the best literature. In addition, the tenure system at U.S. universities is rigid in its focus on journal quality, and this has not been said to be changing. So presumably, if this explanation holds, already tenured academics are responsible. Finally, for this explanation to hold, American scientists would have to be in the vanguard of shifts to electronic publication, depressing their journal article counts relative to those of foreign scientists, even though Web preprint archives are very helpful for geographically isolated scientists (Glanz 2001).

Although electronic publishing is much discussed, perspective is important. Kling and McKim (1999) point out that we must distinguish between pure electronic journals and hybrid paper-electronic (p-e) journals, or traditional journals whose contents are available to subscribers online. In the late 1990s there were remarkably few pure electronic journals, and they published few papers. For example, in 1997 the *Internet Journal of Science: Biological Chemistry* published fewer than 10 papers (and then disappeared) while the traditional *Journal of Biological Chemistry* published about 3,500 (and survived to put its full text online at: www.jbc.org). Kling and McKim (1999) suspect that

> reports of exponential growth of e-journals really mean exponential growth of p-e journals. This is not a minor matter, because the p-e journals bring their reputations, review practices that they established in the paper world, and some of their readership to their electronic versions. In contrast, new e-journals . . . face more daunting problems in establishing their legitimacy, and risk a higher failure rate. (892)

While questions remain about the legitimacy of publishing in pure e-journals, there is no evidence that the legitimacy of a paper journal declined when it became a hybrid paper-electronic journal. While the movement

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to hybrid paper-electronic journals reshapes scientific communication, it does not affect the bibliometric data. The indexing of traditional journals in the SCI is not affected by their adding an electronic version.

Perhaps the move to electronic publishing will bypass journals. The success of Paul Ginsparg's physics e-print server suggests that circulation of unrefereed papers might replace journal publication. Ginsparg and others have argued for the inevitability of this mechanism spreading throughout the sciences due to its cost advantages and evident superiority. However, Kling and McKim (2000) argue that it is "not just a matter of time" until all fields have an e-print server. They point out that communication practices differ between fields and suggest that the electronic communication projects that thrive tend to support and enhance preexisting practices. Physics had a thriving preprint exchange culture before the e-print server, for example. Molecular biologists never had broad circulation of preprints, limiting preprint circulation to their closest colleagues, and the few e-print servers in biology do not play a significant role in the biological communication system. In contrast, biologists increasingly depend on shared electronic databases that contain genomic data and associated information such as bibliographies, directories of suppliers, and contact information for researchers (Kling and McKim 2000). These databases are symbiotic with and enhance journal publication as journals increasingly require authors to submit information to these databases as a prerequisite to publication. Even e-print servers enhance scientific communication without supplanting traditional journals; 70 percent of the submissions to the e-print server in high energy and nuclear physics end up as journal publications.[2] Note that the U.S. decline would not be explained just by establishing that U.S. authors were moving to more informal means of publication. It would also be necessary to show that foreign authors were not doing the same thing. It is quite likely that informal publication is growing in the United States and abroad, and formal publication is growing abroad. Only U.S. formal publication is in decline.

Shifts in publication habits, if they are of any significance for the scientific literature, should leave their mark on that literature. Important work published outside SCI-indexed journals should be referenced by papers in established journals. This is the case for books in the social sciences. Although books are not indexed in the SSCI, they are so frequently cited in the journal literature that their role in the social sciences is clear. The same should hold for work published in electronic venues or in new journals not yet indexed in the SCI or SSCI. SEI 2002 reported that "an analysis of

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reference patterns in a sample of 986 papers published in 1990, 1995, and 1997 found few references to Internet URLs." This must cast a certain amount of doubt on the hypothesis that important work migrated to the Internet in the 1990s.

If a large amount of important research were being published electronically, it would change the pattern of referencing from patents to the literature. In particular, we would see a decreased share of references to journal articles and an increased share of references to other types of work. This was examined by CHI Research, Inc., which classified nonpatent references into "journals," "meetings," and "other." They calculated the share of references in each of the categories by year of referencing patent. They found that, over time, the share of patent references going to journals increased, which does not support the hypothesis.[3] Finally, one research institute's publication lists were analyzed, Woods Hole Oceanographic Institute. The institute's lists of published output in 1995, 1996, and 1997 were obtained from their library. The institute's output dropped in 1997 as counted from their own publication lists. Papers in both journals and in books and conference proceedings dropped in 1997. However, the lists contained no evidence of publication on the Internet.

Electronic publishing has been much discussed and therefore becomes an obvious hypothesis to explain the decline in U.S. publication output in the late 1990s as indexed in the *Science Citation Index*. However, the evidence does not substantiate the hypothesis. We suggest that if the effect of electronic publishing is too subtle to be found in the research reported here, then it is too subtle to cause a noticeable decline in U.S. publication output.

Rise in Academic Patenting

Patenting and licensing by universities has blossomed over the past ten years, as documented and discussed in chapters 3, 4, and 5 of this book (see also Hicks et al. 2001; AUTM 2000). Universities whose academics get involved in commercial activities must face the intractable problem of competition for academics' time. If patenting absorbs time academics would otherwise spend on research, the rise in patenting might be related to the fall in publication output. Logical though this sounds, the data seem to show no relationship between rates of patenting and rates of publishing for professors or universities.

Agrawal and Henderson (2001) studied the patenting and publishing

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behavior of professors in MIT's departments of mechanical and electrical engineering. They regressed patents and papers against each other with various lags and control variables such as length of time the professor had been active. They found no significant positive or negative relationship.[4] Stephan et al. (forthcoming) find a positive relationship between publishing and patenting, suggesting that they are complementary activities.

SEI 2002 reported the same thing at the aggregate level. Since universities differ in their promotion of and success in patenting, we might expect that growth rates in patenting will differ across universities. Universities with the highest rates of growth in patenting might be those with the greatest declines in publication output, if more patenting suppressed publication output. SEI 2002 reports that "there appears to be no significant difference in overall output of articles from universities that are major patentees and those that are not. The change in output of the former between the two three-year periods ending 1995 and 1999 was -5.4 percent compared with -4.6 percent for the latter" (5–41). Growth in patenting was uncorrelated with growth or decline in publishing, which suggests an absence of a connection between increased patenting and decreased publishing in universities.

Demography

If older researchers are less productive, it might be that the aging U.S. scientific workforce is responsible for the decline in U.S. output. However, SEI 2002 reported that

> in the early 1970s, nearly half of all academic scientists and engineers were younger than age 40. Twenty years later, that figure had fallen to 28 percent, and by 1997, it had dropped to 25 percent. If age affects research productivity negatively, then this factor could provide a plausible explanation. However, the apparent decline in publications did not occur until after this demographic shift had been well under way during the previous two decades.

Trends in U.S. Research Funding

U.S. research funding patterns have shifted over the past decade in ways that might explain growth and decline in publication output. Looking back at Tables 11.1 and 11.2 and generalizing, biology and the physical sciences seem to be suffering the most and the medical and environmental sciences

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prospering the most. This aligns with common knowledge of trends in federal research funding in the 1990s. Biomedical research has been a priority, while cutbacks at the Department of Defense would hit the physical sciences particularly hard.

Unfortunately, attempting analysis in more detail quickly becomes frustrating. Matching trends in funding to trends in paper output is complicated, first because the field classification schemes used for funding and papers differ somewhat, and second, because scientists receiving money that the government classifies as "chemistry" are not required to publish in a journal classified as "chemistry." Thus, trends in chemistry funding only roughly match trends in chemistry publishing.

SEI 2002 reported that for fields in which an approximate match could be made, the findings were inconclusive (5–41). For example, the fall in articles in biology and physical sciences coincided with a fall in federal spending (in real terms) in these two fields. However, increases in funding for physics coincided with a decline in articles. Matching funding and publication by sector is more straightforward, because institutions are classified the same way. However, there appears to be no correlation between these two variables. Basic and applied research expenditures have increased in universities and the federal government, but article output has declined in these sectors. However, funding increases in the nonprofit institutions and nonprofit Federally Funded Research and Development Centers (FFRDC) have coincided with increased article output in these sectors. A more precise match between the National Institutes of Health (NIH) publication output and intramural expenditures reveals that the trend of funding and publication growth diverged in the early 1990s, with publication growth flattening as funding continued to increase.

In conclusion, publishing in medical and environment-related areas has grown, suggesting that trends in domestic research funding shape trends in output, as we would expect. However, our expectations are confounded at the sector level, where trends in research expenditure and publication output are not aligned.

An International Perspective

If U.S. authors were winning less space in the top scientific journals, then foreign authors were winning more space. This is illustrated in Figure 11.2, which reports a growth index for publication output around the world between 1991 and 1999. Declining output was not confined to North

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America. Publication counts declined more in Eastern Europe, which includes countries of the former USSR, and in sub-Saharan Africa. Everywhere else, publication output grew. Growth was quite striking in Latin America and most especially in the newly industrializing countries of East Asia: Hong Kong, Singapore, South Korea, and Taiwan. The consequences of growth in output abroad are most striking when European and American publication output are compared—Western Europe now publishes more than the United States.

That foreign scientific output grew so much is likely due to explicit national policies. Foreign science systems have strengthened in recent years as governments around the world recognized the need to build knowledge-based economies and, as part of this, have increased research funding, strengthened graduate programs, and started to evaluate their scientific output more stringently. Most fundamentally, resources have been dedicated to science and technology, especially in East Asia. SEI 2000 reported:

> Several Asian countries—most notably South Korea and China—were particularly aggressive in expanding their support for R&D and S&T-based development. (2–47)[5]
> In Latin America and the Pacific region, other non-OECD (Organisation for Economic Co-operation and Development)

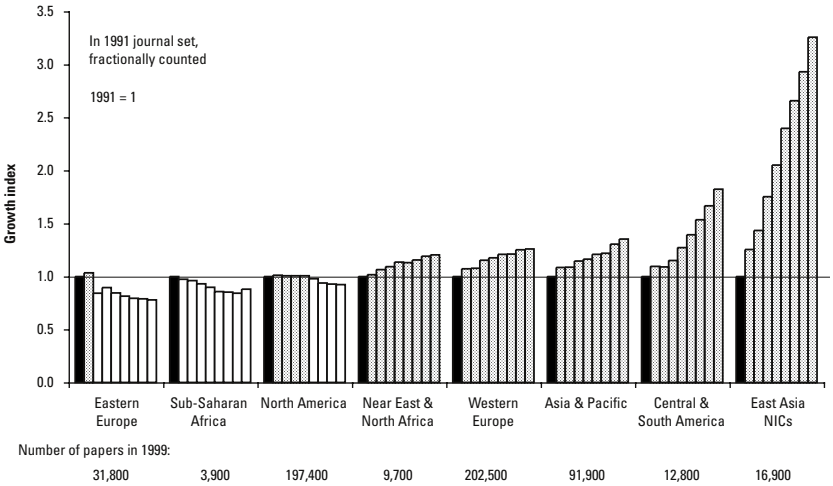

FIGURE 11.2 Growth in number of papers worldwide, 1991–99.

Source: National Science Board, *Science and Engineering Indicators–2000.*

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countries also attempted to increase R&D investments substantially. They still invest less than European countries in R&D. However, they also have substantial S&T-related government expenditures not captured in R&D statistics, especially expenditures on training and infrastructure. (2–47)

There was a worldwide slowing in R&D spending in large and small countries in the early 1990s. In fact, inflation-adjusted R&D spending fell for three consecutive years (1992, 1993, and 1994) in the United States, Japan, Germany, and Italy. R&D spending has since recovered in these countries but has remained stagnant in France and the United Kingdom. Most of the recent R&D growth results from rebounding industrial nondefense spending. (2–4)

The most notable trend among OECD countries was the relative decline in government R&D funding. (2–4)

R&D spending in the Russian Federation remained considerably below levels in place prior to the introduction of a market economy. (2–4)

Thus, it is no surprise that in the late 1990s East Asian countries topped the list of fast-growing publishers, and Latin American countries were increasing their publication output. Since government research spending should bear the most direct relation to publishing, we would not expect much growth in Western countries whose R&D growth traces to increased industrial R&D. The Russian Federation is a clear case of declining research resources and output.

Graduate programs have been strengthened as well. In 1998 the National Science Foundation held a workshop on graduate education reforms in Europe, Asia, and the Americas and on international mobility of scientists and engineers. Johnson and Coward (2000) in their overview of the discussions pointed out the following:

France undertook a reform of doctoral studies in 1988 in an effort to double the number and improve the quality of S&E doctoral degrees awarded within eight years. By 1996 they had achieved a 75 percent increase.

In Japan, doctoral reforms in 1989 called for expanding and strengthening graduate schools and for establishing a new type of

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university exclusively for graduate study. By 1994 more Japanese engineers earned doctoral degrees in university laboratories than within industry, which had been the dominant route.

China has invested heavily in graduate education with the result that in 1997 Chinese students earned more than twice as many S&E doctorates within Chinese universities as did Chinese students within U.S. universities.

Korean universities awarded almost 2,200 S&E doctoral degrees in 1997, up from 945 in 1990.

S&E doctoral degrees earned by Asian students within U.S. universities peaked in 1996 and declined in 1997. S&E doctorates earned in Asia grew by 12 percent per year on average between 1993 and 1997.

Within Latin America, Brazil greatly expanded the scale of its graduate programs in the 1980s, and Mexico, Chile, and Argentina have done so more recently. These countries are motivated by a desire to have more of their university faculty trained at the doctoral level.

Note that we know much less about the science of countries that have hitherto not made much impression in the scientific world. Many may be greatly increasing the resources they devote to research. For example, Egypt built three glass and concrete pyramids to house the Mubarak City for Scientific Research and Technological Application (MUSCAT). Institutes on everything from lasers to desert research are slated for launch (Frank 2001). If obstacles can be overcome, and expatriates attracted, ventures like this could change the scientific landscape in coming decades. We may already be seeing the first evidence of their impact on publication figures.

It may also be important to acknowledge that research funding may not fully explain the strengthening of foreign science systems. Increasingly, foreign governments tie research funding to output evaluation. When foreign governments go down this route, journals indexed in the SCI or SSCI often become the gold standard. Governments want scientists to publish in these journals; they make that clear. And scientists respond by focusing their efforts on publishing in indexed journals. This makes sense for governments that want their scientists to be working at an international standard and not lurking in the local literature, which may privately be acknowledged to be less than scholarly.

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The United Kingdom may have been one of the first countries to implement such a system. Most recently, China has been implementing such evaluations, *Science* has reported:

> As scientific activity recovered after the Cultural Revolution, much of the funding flowed from the top down, split up more or less by seniority. But competitively awarded grants now predominate, with emphasis on a good track record. . . . Although base pay still depends on rank, explains NIGP (Nanjing Institute of Geology and Paleontology) director Sha Jingeng, publications, prizes won, and research grants awarded also play a role. For each paper that appears in *Science* or *Nature,* for example, NIGP pays a researcher about $600 (Normile 2001).

Although the shake-up in China is broad based, institutes devise their own implementation plans.

> For instance, officials at a key national lab of the Institute of Zoology in Beijing began annual evaluations of staff based on the number of projects worked on, research grants obtained, international conferences and collaborations, students being advised, and papers published in Chinese and foreign journals traced by the *Science Citation Index* (SCI). The last . . . is seen as an external measure of quality. "This system can help us judge a researcher's work more objectively and fairly," says Li Dianmo, the lab's director (Yimin 2001).

Although U.S. scientists benefit from publishing in top journals, Chinese scientists who land among the top half of their colleagues ranked using measures such as those just described can earn three to four times the salaries of their coworkers. In the United Kingdom, academic departments get more money if expert committees award departments high scores based in part on limited bibliographies of their best published output. Because Australia uses a formula to distribute university funding, Australian universities can value in dollars each article faculty members publish in an indexed journal. Australian ISI-indexed output rose in response to the introduction of this formula (Butler 2002). Scientists are enticed by explicit incentives to target SCI-indexed journals for article submissions. Highly motivated foreigners targeting SCI journals will make life more difficult for U.S. researchers. U.S. scientists have always been highly competitive, so there is little scope for the kind of performance gains foreign systems appear to be achieving.

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The hypothesis that an international perspective is needed to understand the decline in U.S. output is supported by quantitative data on research resources such as funding, researchers, and students. Domestic perspectives on research resources are given in Figure 11.3, which examines trends in total U.S. R&D expenditures, numbers of scientists and engineers, and numbers of graduate students and doctoral degrees awarded.[6] In Figure 11.4, the international perspective, the U.S. resources are expressed as a share of a group of countries.

In the domestic perspective shown in Figure 11.3, there is a general pattern of growth with perhaps some leveling and a bit of decline, but nothing especially worrying. Thus, long periods of growth are interrupted in the early 1990s (except in doctoral degrees awarded, which continued to grow). There was a slight decline in R&D expenditures, a leveling of growth in scientists and engineers, and a drop-off in graduate enrollment. Note that development expenditures and personnel are included in these figures, and as military expenditure declined substantially during this period, an unknown proportion of the drop must be due to military development, which would not affect the trend in paper output much.

The most worrying decline is the drop in number of graduate students beginning in 1993, which followed four decades of increase. Historically, growth in graduate enrollment has generally echoed shifting patterns of federal R&D support, with an influx of foreign students complicating matters. Some of this decline may trace to the favorable U.S. job market after

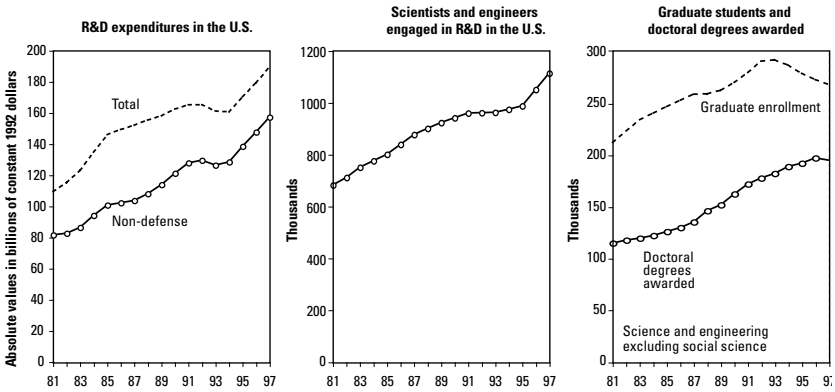

FIGURE 11.3 U.S. R&D metrics, 1981–97.

Source: National Science Board, *Science and Engineering Indicators–2000,* appendix tables 2-63, 2-64, 4-21, 4-28, 4-29.

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1992, especially since the decline is most concentrated in engineering and math and computer science. Some of the decline undoubtedly relates to increased opportunities non-U.S. students have to study outside the United States. The decline in graduate students may well be connected to the decline in university output, though the decline in graduate enrollment seems to affect the biological sciences as well as the physical sciences, which does not echo the pattern in paper output (National Science Board 2000, 4–20).

In the domestic perspective, there are hints of problems, but things really do not look too bad. In Figure 11.4, the data on U.S. research resources are expressed as a percentage of a group of countries that includes the United States.[7] This international perspective is truly worrying. The U.S. share of G7 R&D expenditure declined sharply from 1987 to 1990; the U.S. share of G7 scientists and engineers declined sharply from 1991 to 1993; and the share of U.S.-Asian doctoral degrees began declining sharply in 1993. The international perspective reveals patterns very similar to the drop in U.S. share of publications—a long-term, gentle decline in share is rudely interrupted by a slide down a much steeper slope. The declines in resources begin a couple of years before the declines in U.S. output, which makes perfect sense. Share of R&D expenditure and scientists and engineers has since turned up, offering hope that the number of U.S. publications might rise again.

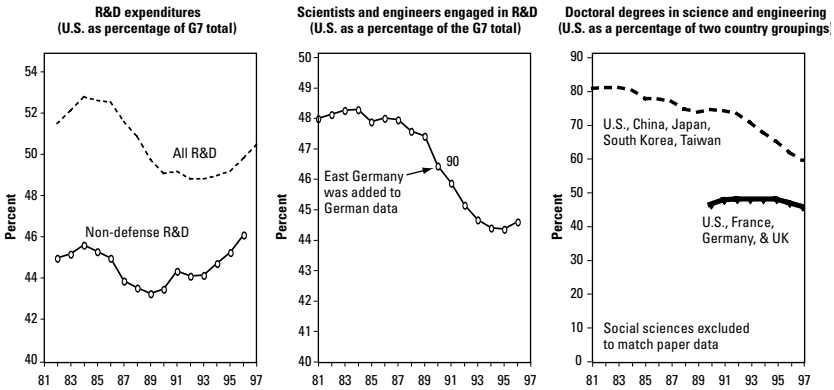

FIGURE 11.4 R&D metrics: United States as a percentage of international values, 1981–97.

Source: National Science Board, *Science and Engineering Indicators–2000,* appendix tables 2-63, 2-64, 4-21, 4-28, 4-29; figure 3-18 (U.S. data interpolated in even years).

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Discussion

Since counts have begun, the U.S. share of world publication output has declined while the number of U.S.-authored papers has increased or held steady, depending on the counting method. The late 1990s saw a new pattern, an absolute decline in number of U.S. papers in the international, peer-reviewed literature.

The late 1990s were notable for the rise of the Internet and for increased patenting by U.S. universities. Both offer plausible explanations for the decline. Perhaps publishing on the Internet is replacing traditional journal publication? However, there appears to be no evidence that in the 1990s U.S. scientific output moved to electronic venues. In any case, if U.S. output in *Science, Nature, PNAS, Cell,* and other top journals declined, would electronic preprints be an adequate substitute? Possibly, then, patenting is to blame. Do university researchers patent more by publishing less? But available data at the individual and institutional levels does not support this idea.

As it happens, the rise of the Internet and of public-sector patenting, though dramatic, are perhaps not yet as powerful an influence on scientific work as money. Recent trends in federal funding have been suggestively similar to trends in publishing in that biomedical sciences have fared much better than natural sciences in both publishing and securing federal funding. However, this is not conclusive, as federal funds are not the only source of research funding in the U.S. and the decline is very broad in scope. For example, university expenditure on research has risen annually for a decade or more, belying any close correlation between publication and funding trends. Trends in U.S. research funding provide one piece of the puzzle but not the whole story.

To understand fully the decline in U.S. publication output, an international perspective is required. Publication output is increasing across a broad range of foreign countries—newly industrializing East Asian countries, Latin America, Asian and Pacific countries, and Europe. North America, sub-Saharan Africa, and Eastern Europe exhibit declines. In the 1990s, growth in scientific publishing by other countries accelerated, forcing down the U.S. share of the top journals. U.S. and foreign authors compete in an almost zero-sum game for places in journals indexed in the SCI or SSCI. If foreigners are aggressive enough in increasing their share of publications in top journals, and if U.S. authors maintain their status quo, U.S. authors could lose share so quickly that growth in the database will not compensate for their lost share, and the number of U.S. papers will decline. This would

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produce a decline in U.S. publication output almost irrespective of domestic policy or sector-specific factors, and we do see a very broad decline.

International data on R&D expenditures, scientists and engineers, and doctoral degrees, though imperfect, tends to echo the publication data. Or rather, the pattern of gradual decline in the U.S. share interrupted by an abrupt shift to a much steeper decline is seen in the U.S. share of money, people, and students and is echoed with a convincing lag of a few years in the publication data. Moreover, the quantitative evidence is compatible with our admittedly imperfect knowledge of trends in foreign science policy. During the past decade, other countries have focused resources on research, expanded graduate programs, and sought to restructure their public-sector research institutions as part of a drive to create knowledge-driven economies.

The importance of international forces in explaining the decline in U.S. publication output accounts for two somewhat unusual aspects of the decline, namely its breadth and its invisibility. Reasoning from knowledge of trends in domestic funding, we would expect federally and commercially funded physics to be in steep decline and federally and commercially funded biomedicine to be growing buoyantly. However, federal physics laboratories are not the only ones whose output has declined; almost everybody is suffering, including pharmaceutical companies. Even NIH laboratories do not show the expected strong growth in output in recent years. Among domestic factors, only demographics could act with such breadth, but demographic trends would not exhibit the abrupt shift we see in the publication data.

The second curious aspect of the decline is that there has not already been an outcry over a crisis that has been brewing for half a decade. Admittedly limited experience suggests that the idea of an overall decline in U.S. output strikes scientists as strange. It makes sense if they think about it, but is not something that would have occurred to them. Perhaps this is because the decline manifests itself to scientists as an unexpected rejection of a paper or two. Highly competitive and competent researchers would probably blame only themselves for this. Why would they think to blame a decade of concerted effort by foreign governments to improve their scientific infrastructures?

Conclusion

We seem to be entering a new era in science policy. The United States has long accepted that its share of world scientific output will decline as

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scientific communities in other countries strengthen. This process seems to have accelerated sharply, as other governments have become convinced that their economic futures lie with knowledge-based economies in which research plays a central role. Foreign scientific communities have become much more competitive at the same time as the U.S. federal government's attention is increasingly focused on sciences closely linked to medical care.

This chapter's data would fit neatly into the Council on Competitiveness's 2001 analysis of America's relative international standing in capacity for innovation. Drawing on Porter and Stern's Innovation Index, the council argued that in the 1990s the economic landscape began to change and a number of advanced nations increased their capacity for innovation and began to converge on the United States. In addition, new groups of innovative countries and fast followers emerged. Drawing on a range of indicators, they argue that the United States' position is slipping (Porter and van Opstal 2001).

As foreign scientists note their newfound prowess (Kocher and Sutter 2001), American scientists face the challenge of the steady state. Ziman (1994) first pointed out that scientific institutions are predicated on continued expansion. For example, each faculty member trains many students who then require employment. As research advances, new specialties are created that require more resources over and above those needed to keep up with inflation as ever-more-complex equipment is needed to solve the ever-more-complex problems left behind as simpler problems are solved. Therefore, adjustment to a "steady state" or a decline in resources is extremely difficult. Although Ziman was discussing resource limitations rather than output limitations, we can predict that output declines will make life much more difficult for already stressed U.S. scientists.

Signs of strain have appeared, as Donald Kennedy's (2001) reflections on his first year as editor of *Science* attest. After listing morally dubious practices encountered in his first year, he writes:

> Since we all know that such things happen, why call attention to them now?
>
> The reason is that their frequency appears to have increased. I think I know why. The universe is larger, and in the "hot" fields like molecular biology the competition—for funds, for appointment, for tenure, and for prizes—is more intense. And the advantages that accrue to publication in a prestigious journal are correspondingly large. In some countries, governments allocate prize money and promotion directly to researchers who publish in *Science*. In the United States and Europe the rewards are more subtle, but nonetheless real.

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Under increasingly competitive circumstances outside of their control, can U.S. scientists and scientific institutions maintain the virtues so admired by the public and foreign scientific communities—fairness, openness, intellectual honesty, and rigor—virtues so necessary for swift and sure advance at the frontier of knowledge?

The institutions of modern science have in many ways been a gift from the United States to the rest of the world. The U.S. has demonstrated that the best-quality scientific research is fostered when funding is awarded competitively, when plentiful, rigorously trained Ph.D. students and postdocs are available cheaply, when substantial amounts of money are spent, when modern equipment is used, and when transfer of research to technological application is encouraged. In many ways, other countries have sought over the past decade to incorporate more of these elements into their systems. Furthermore, the U.S. has probably trained, or at some point employed, many of the scientists now doing so well back home. As a result, American universities no longer stand alone at the scientific frontier.

Notes

1. The *Science Citation Index* (SCI) and the *Social Sciences Citation Index* (SSCI) are products of Thomson Scientific (formerly know as Thomson ISI) and are the standard source for bibliometric citation analysis.

2. Seventy percent of 1999 submissions to physics e-print server in SLAC's core fields of high-energy physics and nuclear physics end up in journals. Unpublished data provided by Heath B. O'Connell, SLAC, Stanford, Calif.

3. Personal communication from Tony Breitzman, CHI Research, Inc., a scientific research firm that specialized in patent citation analysis.

4. They did, however, find a significant relationship between citations to papers and patenting. Professors whose papers had more impact produced more patents. This is consistent with Hicks et al. (2000, 310–20) who found that patents tend to preferentially cite more highly cited papers. In both cases we see a relationship between high-impact science and patenting.

5. Reported in Johnson (1993).

6. Note that social sciences have been excluded from these figures.

7. It was not possible to use a consistent group of countries across the graphs.