Assessing and Enhancing the Impact of Science R&D in the United States: Chemical Sciences

Final Report to the National Science Foundation
Prepared by

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and
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On November 16-17, 2009 a workshop—"Assessing and Enhancing the Impact of Science R&D in the United States: Chemical Sciences"—was convened at the National Science Foundation. Academic scholars and industry experts were invited to discuss the state of knowledge about the impact of science R&D in the United States, focusing on chemical sciences and related industries. The timing of the workshop was particularly important, given that science R&D is a centerpiece of the American Recovery and Reinvestment Act (ARRA) of 2009.

The workshop participants were charged to advance the scientific basis for thinking about and beginning to answer the following four questions:

1. How can we measure the broad (economic, social and scientific) impact of scientific research?
2. What is the nexus between industrial and federal investments in science R&D?
3. How can an optimal portfolio of (public and private) science R&D investments be characterized?
4. How can economics inform the accountability process related to federal R&D investments?

An intended output of this workshop was the identification of useful and important directions for relevant future scholarship.

The Agenda for the workshop is attached as Appendix A to this workshop report.

The workshop planners realized early on that a full day or more could be devoted to a discussion of each of the above questions. Given participant time constraints, all of the questions were posed at the outset of the workshop, and it was expected that the academic and industry participants would focus the day's discussion toward those issues that they believed were the most important and about which the most was known.   The residual issues might therefore be viewed as a direction for relevant future scholarship.

The remainder of this report is organized around the four questions listed above. Relevant to each of these important questions is that R&D in the chemical sciences (hereafter chemistry or chemical industry for simplicity) occurs throughout the economy, including in:

- private-sector companies in the chemical industry
- private-sector companies in industries for which advancements in technology are related to advances in chemistry
- university research laboratories, and
- national laboratories.

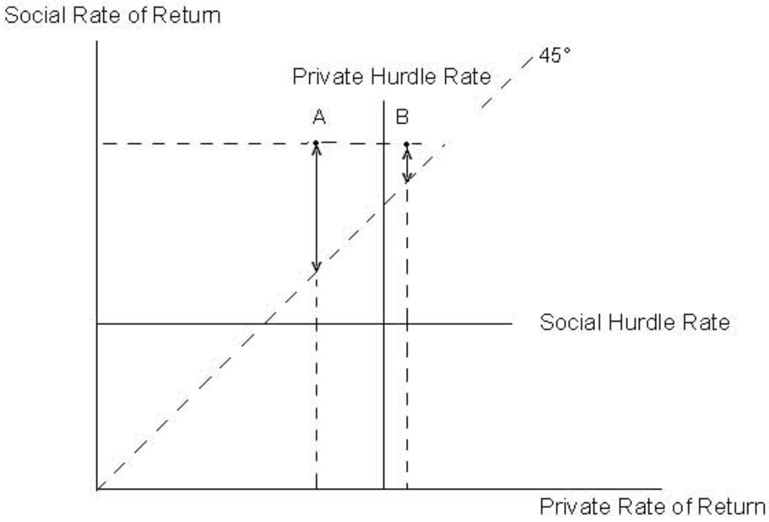
To generalize, chemistry R&D that is performed within private-sector firms is mostly applied research and development. Chemistry R&D that is performed within universities is mostly basic research and applied research. And, chemistry R&D that is performed within our national laboratories includes basic research, applied research, demonstration projects, and research leading to infrastructure technology.

With respect to each of the above questions, the remainder of this report both summarizes the discussions at the workshop relevant to each question and points out a number of important issues that were neither fully discussed nor resolved.

1. How can we measure the broad (economic, social and scientific) impact of scientific research?

Most of the discussion at the workshop was about how to measure the economic impact of chemistry R&D in chemical firms conducting the R&D. Two arguments for chemical firms underinvesting in R&D, relative to the socially-optimal level of R&D, were made. One argument was that investors systematically undervalue publicly-traded R&D companies because of deficient financial disclosure standards. This undervaluation leads to an overvaluation of the cost of capital and thus to an underinvestment in R&D. Other arguments commonly made within the economics literature for an underinvestment in R&D fall under the rubric of market failure: companies cannot fully appropriate the returns to their investments in R&D, and, there are technical and market risk barriers to socially-desirable technology development that companies cannot fully overcome.

The following diagram illustrates this underinvestment in R&D, and it provides a useful framework for discussing issues raised during the workshop.[1] The social rate of return is measured on the vertical axis and the company's private rate of return is measured on the



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[1] This diagram was not discussed at the workshop. It does, however, provide a useful framework for thinking about discussion points. It is taken from A. N. Link and J. T. Scott, *Public Goods, Public Gains: Calculating the Social Benefits of Public R&D* (Oxford University Press, forthcoming), and it is based on G. Tassey, *The Economics of R&D Policy*, Quorum Books, Westport, CN (1997), and A. B. Jaffe, "The Importance of 'Spillovers' in the Policy Mission of the ATP," *Journal of Technology Transfer*, 23: 11-19 (1998).

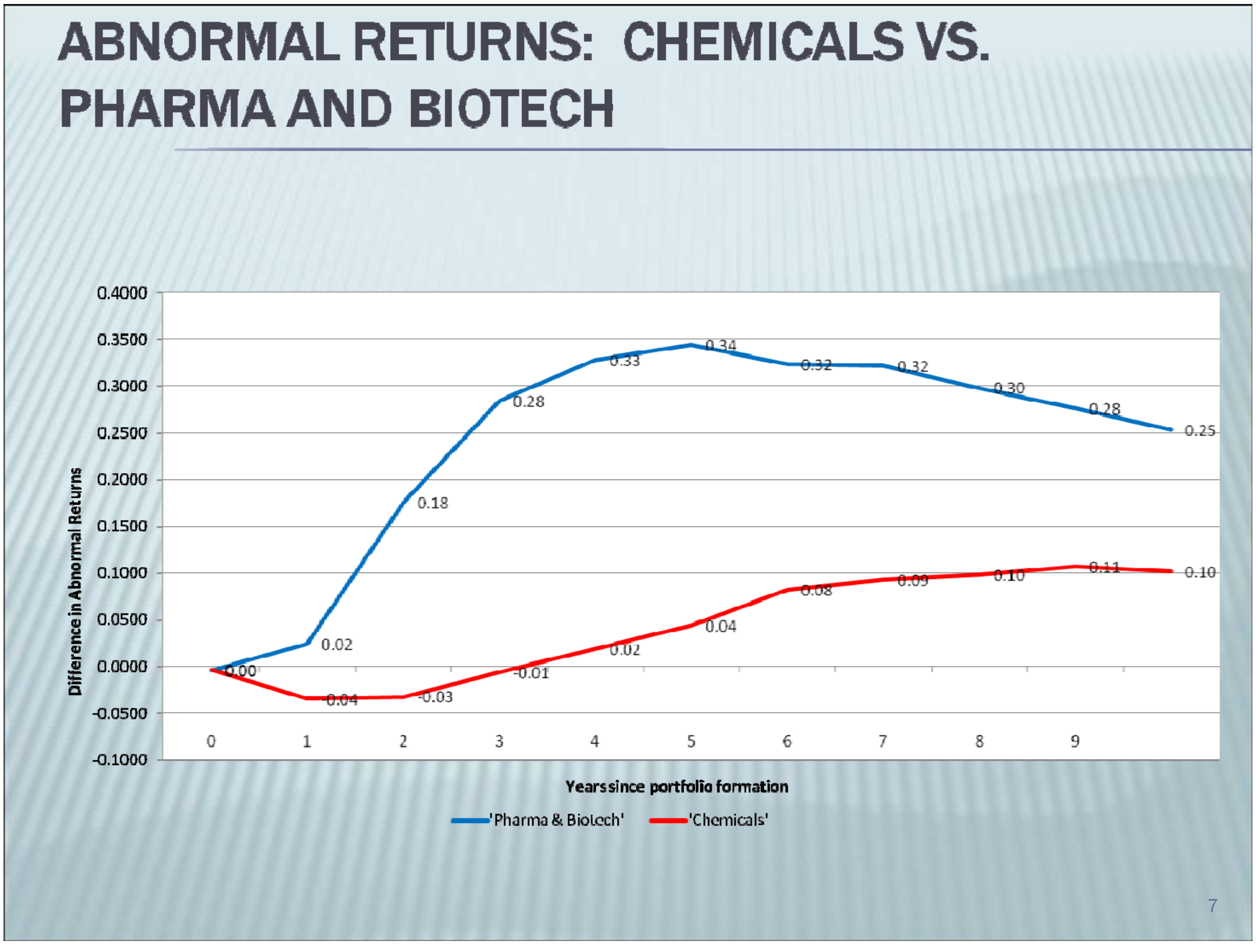
horizontal axis. Both society and the company have a hurdle rate that must be achieved, or is expected to be achieved, for a marginal dollar of R&D to be invested. The 45-degree line is imposed on the diagram under the assumption that the social rate of return from R&D will at least equal the private rate of return for the same investment.

From the diagram, the company will not invest in project A because its private rate of return is less than its hurdle rate although the social benefits associated with project A are well above society's hurdle rate (hence the classic market failure as noted above). The company will invest in project B because the private rate of return is above its hurdle rate; the company can appropriate an amount of the social return sufficient to make the investment worthwhile.

Regarding the undervaluation of R&D investments in publicly-traded companies, which can be a reason for the situation like that depicted for project A in the diagram above, key findings from academic studies are that:

- shares of R&D-intensive companies are systematically undervalued due to asymmetry of information between company stakeholders and potential investors
- share undervaluation implies the company faces an excessive cost of capital due to undervaluation of intangible assets (including knowledge capital), which leads to underinvestment in R&D, and
- standardization with regard to disclosure about innovative activities could substantially reduce information asymmetries and consequent underinvestment.

Workshop discussion suggested that for companies needing outside finance for their investments, standardization with regard to disclosure of information about companies' innovative activities would increase outside investors' perceptions of the expected returns from the investment and thereby move the private rate of return to project A in the above diagram to the right and thus make it a more desirable company investment. Moreover, inadequate accounting for R&D investments may hide their true value even from insiders at the company, and again, better accounting would increase the expected private rate of return from an investment project. Additionally, better accounting standards and disclosure of information about innovative activity could lower the private hurdle rate for the investments since the required rate of return might fall if investors better understood the riskiness of the investment. Again, the effect would be to make it less likely that there would be a market failure of underinvestment.



ABNORMAL RETURNS: CHEMICALS VS. PHARMA AND BIOTECH

Professor Lev from New York University used the diagram above to illustrate that investors in pharma and biotech companies have realized higher returns to their investments than have investors in the stocks of chemical firms. The reason for these higher realized returns to holding stock in pharma and biotech companies, according to Professor Lev, is less complete disclosure of information by those companies about their internal innovation investments. Hence, investors undervalue the stocks of the R&D-intensive pharma and biotech companies; and then subsequently, the investors earn abnormally high rates of return on their investments.

However, several subtleties associated with standardization of disclosures about innovative activity were not considered in detail at the workshop. For example:

- Why would a company, on its own, not fully and clearly disclose to investors relevant R&D information? The standard answer in the economics literature, of course, is that the "paradox of information" could make such disclosures counterproductive if outsiders acquired enough information to use the company's investment plans for their own

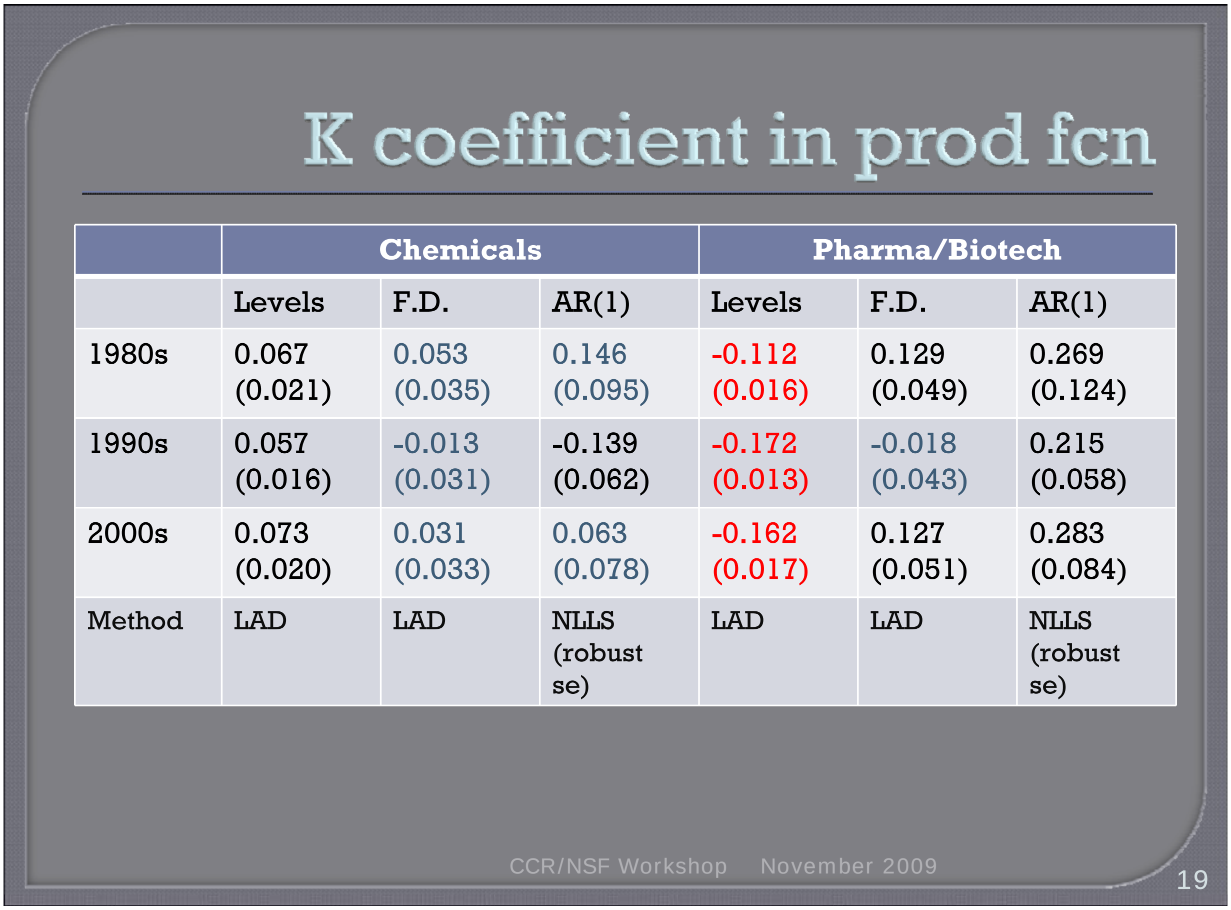
- If standardization is required, how much standardization would be needed to align project A's return with the company's hurdle rate? Or stated different, how much disclosure would be needed to protect the strategic advantage of companies yet at the same time be useful to investors? There were very few comments, much less answers, to this important question.
- What organization would be the advocate for the standardization, and how would agreement among companies be reached? Would this be a public policy issue, or would this be a voluntary industry issue? There was no consensus of opinion about this last question.

There is a long and rich literature in economics related to measuring the return to R&D (e.g., the return to project A or B in the diagram above) in total and/or by character of use and/or by source of funding (e.g., publicly-financed R&D that is performed within the company). *Ex post* cross-sectional studies have generally been based on a productivity approach in which revenue, output or profits are modeled as a function of R&D capital stock. *Ex ante* cross-sectional studies have generally been based on a market value approach in which the current financial market value of the company is modeled as a function of R&D capital stock.

Regardless of the approach, several fundamental issues were discussed specifically with regard to total private R&D. It was noted that these issues have yet to be fully resolved in the academic literature—although important research has been done especially with regard to the depreciation of R&D—and each issue has a quantitative impact on the estimation of the private returns to R&D. These issues include:

- the pricing of R&D capital (no intermediate market)
- the rate at which the R&D capital stock should be depreciated

- the relevant time period for the depreciation
- the cross-company heterogeneity of activities, and
- the composition of R&D activity (e.g., basic research vs. development vs. clinical trials).



K coefficient in prod fcn

	Chemicals			Pharma/Biotech		
	Levels	F.D.	AR(1)	Levels	F.D.	AR(1)
1980s	0.067 (0.021)	0.053 (0.035)	0.146 (0.095)	-0.112 (0.016)	0.129 (0.049)	0.269 (0.124)
1990s	0.057 (0.016)	-0.013 (0.031)	-0.139 (0.062)	-0.172 (0.013)	-0.018 (0.043)	0.215 (0.058)
2000s	0.073 (0.020)	0.031 (0.033)	0.063 (0.078)	-0.162 (0.017)	0.127 (0.051)	0.283 (0.084)
Method	LAD	LAD	NLLS (robust se)	LAD	LAD	NLLS (robust se)

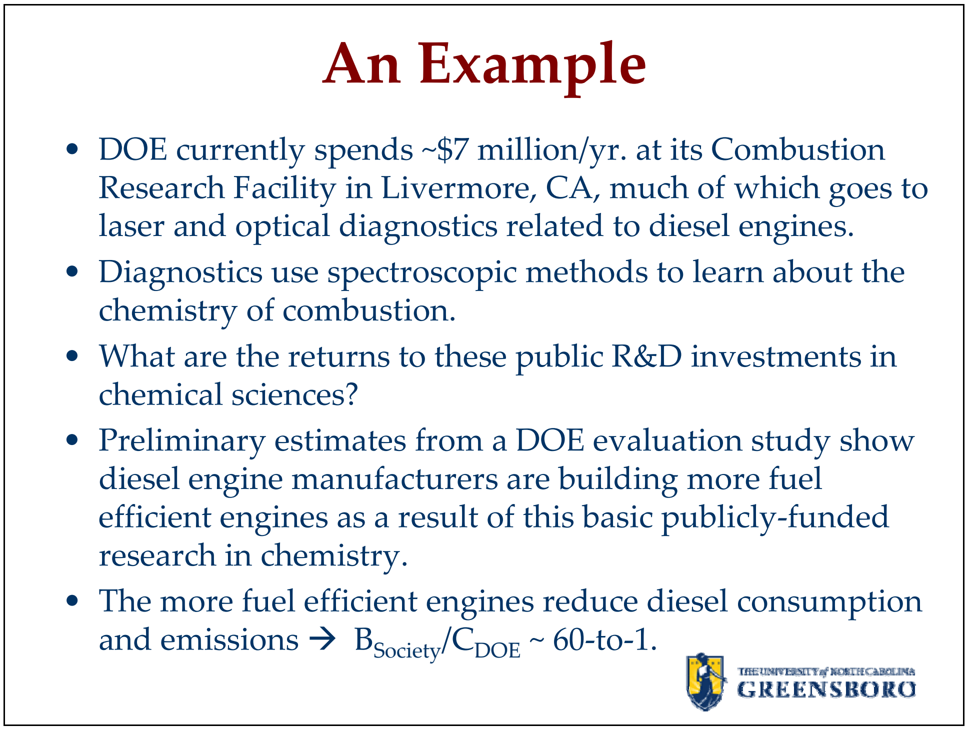
Professor Hall from the University of California at Berkeley and the University of Maastricht notes that economic models used to measure the returns to R&D (derived from the elasticity or K coefficient) find the return generally to be positive, as summarized in the table above, which is based on production function studies that use constant-dollar revenues to measure output. The elasticity of output with respect to R&D is larger in pharmaceuticals than in most other sectors. However, for statistical (e.g., determining functional forms for estimation or finding instruments for endogenous explanatory variables) and economic (e.g., assumed depreciation rates for R&D-generated knowledge capital) reasons, the results are sensitive to the method of estimation.

Discussion related to these issues led to a consensus that empirical academic research can go only so far in measuring the impact of R&D in chemical companies primarily because of a lack of available detailed company-specific data. Scholars within economics, finance, and business have proffered sophisticated models related to R&D investment behavior, but predictions based on those models is limited by the availability of relevant disaggregated data. With detailed disaggregated data empirical advances in R&D evaluation could be made. This was the first, but not the last, mention of the need for academics, as well as for funding agencies, to consider the probative value of case studies and survey-based collection efforts to gather appropriate data.

Surprisingly, during the presentations on how the impact of R&D within chemical companies is measured by academics, there was a conspicuous absence of input from those representing the chemical industry about their own company's R&D investment evaluation process, either *ex ante* or *ex post*. Such general input, albeit that specific company input might be considered confidential, could inform the direction for relevant future scholarship in two ways. One, it could provide insights for scholars to model more realistically the chemistry R&D investment process; and two, it could inform those involved in case studies or in collecting data relevant to measuring the impact of R&D.

Discussion about the social impact of R&D in chemistry was limited. But, it was noted by several speakers and workshop participants that chemistry is a foundational science for industrial R&D, and thus a focus on the impact of chemistry R&D on companies conducting the R&D might be too narrow. There are a number of examples of general purpose technologies—technologies that have broad applications and productivity-enhancing effects in numerous downstream sectors—that have resulted from basic research in chemistry conducted both within companies and within universities, and participants emphasized that there is a need to understand the social impact of such research.

Technology-specific studies were suggested as one means for evaluating the social impact of R&D in chemistry.



An Example

- DOE currently spends ~$7 million/yr. at its Combustion Research Facility in Livermore, CA, much of which goes to laser and optical diagnostics related to diesel engines.
- Diagnostics use spectroscopic methods to learn about the chemistry of combustion.
- What are the returns to these public R&D investments in chemical sciences?
- Preliminary estimates from a DOE evaluation study show diesel engine manufacturers are building more fuel efficient engines as a result of this basic publicly-funded research in chemistry.
- The more fuel efficient engines reduce diesel consumption and emissions → $B_{Society}/C_{DOE}$ ~ 60-to-1.

THE UNIVERSITY of NORTH CAROLINA
GREENSBORO

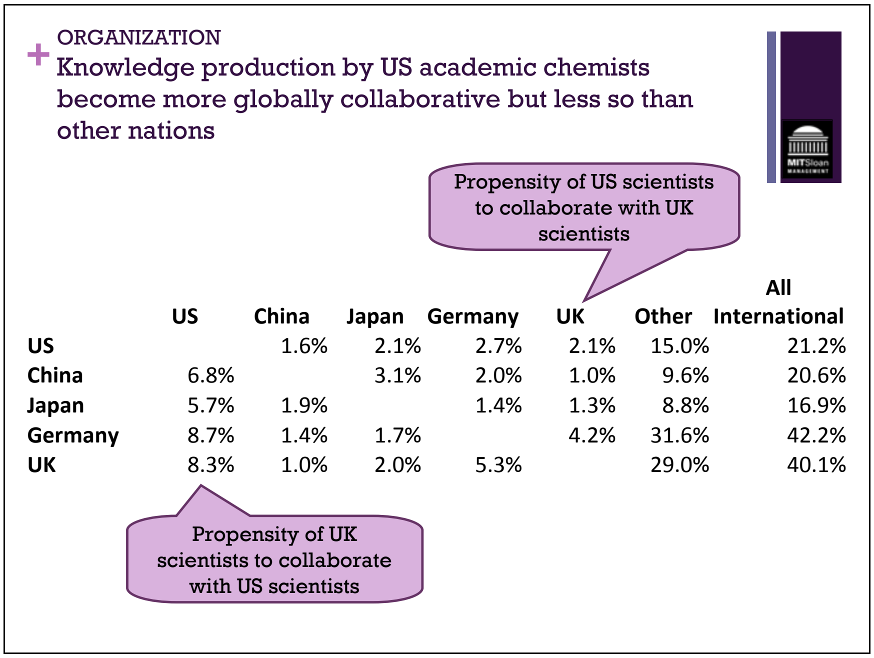
Professor Link from the University of North Carolina at Greensboro illustrated the probative value of technology-specific studies through an example of a DoE-funded research study on the chemistry of combustion in diesel engines.

The <u>scientific impact</u> of chemical research can occur through patenting and publishing, but much of the workshop discussion focused on publishing behavior of university scientists. Three important points were made:

- U.S. research universities produce over 10,000 journal chemistry articles per year compared to between 2,000 and 4,000 per year in other countries (e.g., China, Germany, Japan, and U.K.), but the annual rate of growth in publications is greater in China than in the other countries.
- Within the United States between 1995 and 2005, the share of chemistry publications authored by industrial scientists has decreased by about 13 percent and the share by academic scientists has increased by about 27 percent.
- Over time, there has been a decoupling of academic and industrial chemists; research collaboration between the two groups has declined over time relative to the growth in university-with-university research.

This last point on the non-collaborative nature of chemistry research or decoupling of academic and industrial chemists raised the obvious question:

- Why is there so little collaboration between academics and industrial scientists?



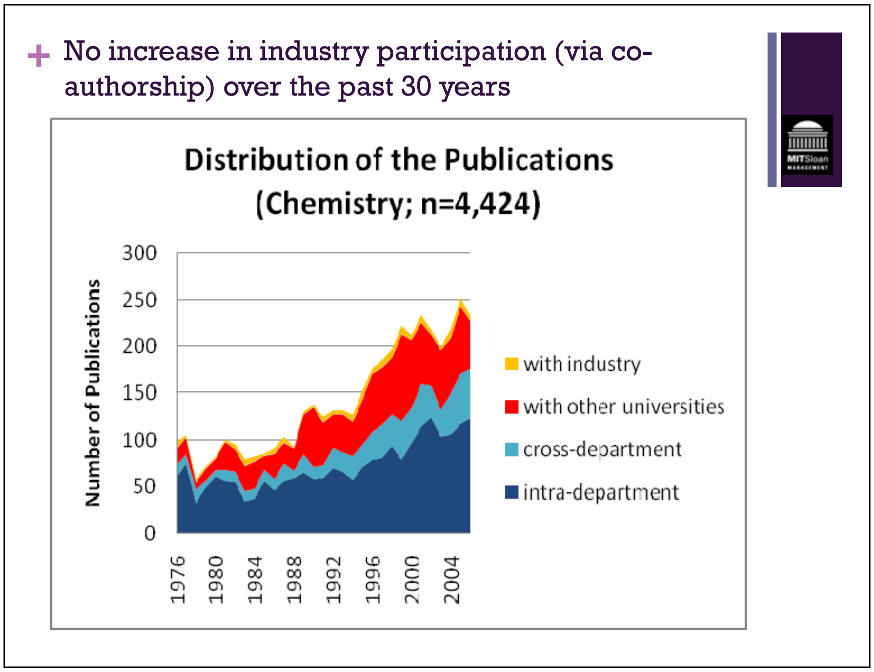
ORGANIZATION

Knowledge production by US academic chemists become more globally collaborative but less so than other nations

Propensity of US scientists to collaborate with UK scientists

	US	China	Japan	Germany	UK	Other	All International
US		1.6%	2.1%	2.7%	2.1%	15.0%	21.2%
China	6.8%		3.1%	2.0%	1.0%	9.6%	20.6%
Japan	5.7%	1.9%		1.4%	1.3%	8.8%	16.9%
Germany	8.7%	1.4%	1.7%		4.2%	31.6%	42.2%
UK	8.3%	1.0%	2.0%	5.3%		29.0%	40.1%

Propensity of UK scientists to collaborate with US scientists



No increase in industry participation (via co-authorship) over the past 30 years

Distribution of the Publications (Chemistry; n=4,424)

Professor Murray from MIT presented the table above to illustrate that knowledge production of U.S. academic chemists has become more globally collaborative. But, as the diagram below the table shows, such collaboration has not increased with industrial chemists.

Some thought that the answer to this question might be related to the foundational nature of chemistry research, but others noted that other sciences are generic in nature and all scientists want their research findings published and used widely. Others thought that the decoupling might be related to different planning horizons or time scales between academic and industry scientists—much shorter for industry because of the quarterly financial pressures on publicly-traded companies—and as a result, industry scientists might not have the luxury of engaging in longer-term research. And still others suggested that heightened intellectual property (IP) issues might be the culprit, and IP issue have long been important to industry and recently to academic scientists as a result of Bayh-Dole. Here, as with other unresolved discussion items, questions remain that perhaps could be answered through detailed case studies, through more detailed data gathering with patents as well as publications, and through more longitudinal analyses. Such questions are:

- Does collaboration increase the social value of chemistry research?
- If so, is the social value dependent on the composition of the research team?

2. What is the nexus between industrial and federal investments in science R&D?

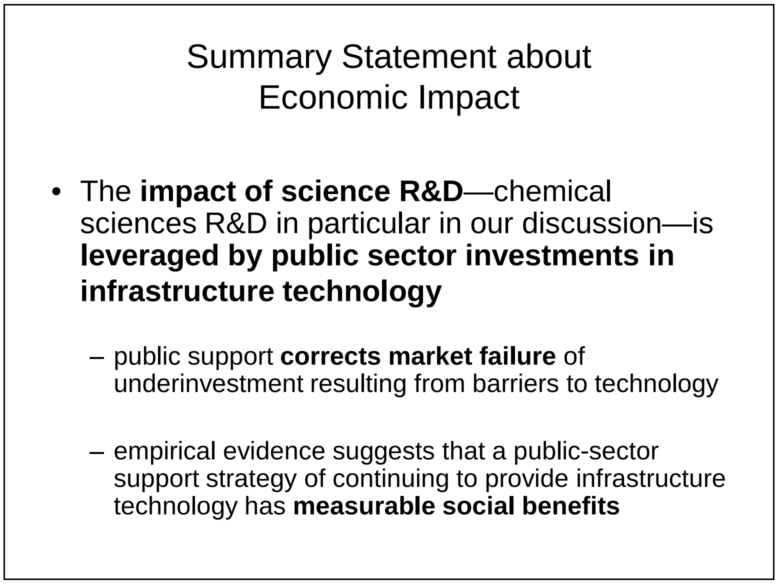
For nearly 50 years, the economics literature has addressed in one way or another the complementarity versus substitutability of private R&D and public R&D, but to date, the issue has not been addressed specifically for the chemical industry. However, another dimension of the nexus between industrial and federal investments in science R&D - the role and impact of federal investments in infrastructure technology in the context of the chemical sciences - was discussed at length.

The importance of infrastructure technology was discussed in general and with specific reference to the activities of the National Institute of Standards and Technology (NIST). Infrastructure technologies (e.g., calibrations, databases, laboratory accreditation, measurement and standards research, software, Standard Reference Materials, traceability, and weights and measures) overcome some of the barriers to technology development that bring about market failure and thus an underinvestment in private R&D.

To understand the importance of infrastructure technology, the economics of investment in R&D were simplified to be as follows:

- The profitability of R&D depends first on the technical success of the company's R&D program—achieving the technical goals of an R&D-investment's output when it is embodied in products and services.
- Given technical success, the commercial success of the R&D-embodying products and services is realized when the ensuing final products and services are successfully marketed.

The availability and use of infrastructure technologies increases the efficiency of all three major stages of the innovation process: R&D, production, and commercialization. As a result, the value of a company's R&D is not only directly enhanced, but also the market value of the technical knowledge produced is enhanced as is the marginal value of doing additional R&D.

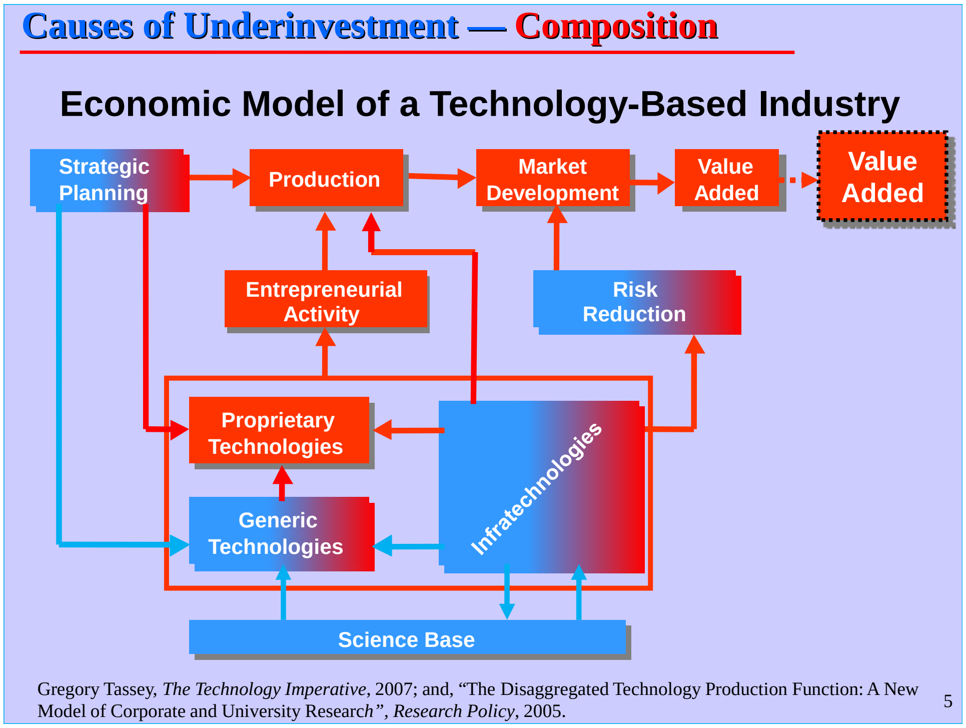


Summary Statement about
Economic Impact

- The **impact of science R&D**—chemical sciences R&D in particular in our discussion—is **leveraged by public sector investments in infrastructure technology**
  - public support **corrects market failure** of underinvestment resulting from barriers to technology
  - empirical evidence suggests that a public-sector support strategy of continuing to provide infrastructure technology has **measurable social benefits**

Professor Scott from Dartmouth College emphasized the economic leveraging role of infrastructure technology noting that it corrects for market failure and thus has a large social impact.

The private sector will not invest in such infrastructure technology because of its public good nature, meaning that private companies, even if they could absorb the cost which is doubtful, will not be able to appropriate the full benefit of the investment.



Causes of Underinvestment — Composition

Economic Model of a Technology-Based Industry

Gregory Tassey, *The Technology Imperative*, 2007; and, "The Disaggregated Technology Production Function: A New Model of Corporate and University Research", *Research Policy*, 2005.

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Red denotes private good elements and blue denotes public good elements.

> Dr. Tassey, Senior Economist at NIST, echoed the importance of infrastructure technology using the diagram above to illustrate the myriad roles of infrastructure technology—a quasi-public good—with an economic model of a technology-based industry.

A few of the academic participants noted that there is growing evidence, through case studies, that the social rate of return to the public's infrastructure research is large. One shortcoming of this research, however, is that the cause of the market failure that brought about the private sector's underinvestment in R&D is not always identified. Understanding specific barriers to private-sector investments in technology might inform public policy designed to stimulate private-sector R&D. The academic literature is clear that the causes of underinvestment by the private sector are many, including:[2]

1. High technical risk associated with the underlying R&D
2. High capital costs to undertake the underlying R&D with high market risk
3. Long-time to complete the R&D and commercialize the resulting technology
4. Underlying R&D spills over to multiple markets and is not appropriable
5. Market success of the technology depends on technologies in different industries
6. Property rights cannot be assigned to the underlying R&D
7. Resulting technology must be compatible and interoperable with other technologies
8. High risk of opportunistic behavior when sharing information about the technology

3. How can an optimal portfolio of (public and private) science R&D investments be characterized?

Theoretical or policy issues related to an optimal portfolio of public and private R&D related to the chemical sciences was not a specific discussion item at the workshop, but as the above summary suggests, it was tangential to much of the workshop's dialogue. Specifically, company investments in chemical R&D are optimal from the company's own perspective, given all of the dimensions of market failure that characterize the R&D process, but such company investments are not optimal from society's perspective.

Questions about an optimal portfolio of public and private investments in science R&D might be posed in terms of the most efficient investment strategy for the public sector to induce the company to invest in project A in the diagram above. That is, public investments in science R&D need not be direct, they could be indirect and take the form of a R&D tax credit, a change in antitrust law to encourage R&D cooperation as a means to reduce barriers to technology that bring about market failure, or increased investments in publicly-provided infrastructure technology.

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[2] This table was not discussed *per se* at the workshop although aspects of it were mentioned. It is taken from A. N. Link and J. T. Scott, *Public Goods, Public Gains*.

Very little is known about the conditions under which a particular policy action is most effective. One reason for this lack of information is that the specific causes of the market failure that brought about the underinvestment are rarely identified in the research (or policy making) process. Another reason is that within academic research related to technology development and innovation, most queries are driven by the availability of data; those researchers who have collected their own data or who have conducted technology-specific studies are few. Several academics at the workshop were vocal that extramural research support of survey data and case studies might sway the profession's opinion about the value of such a research methodology.

4. How can economics inform the accountability process related to federal R&D investments?

Issues related to public accountability were not a discussion item at the workshop except for mention of the October 7, 2009 memorandum from Peter Orszag, Director of the Office of Management and Budget, to the heads of executive departments and agencies on the subject of increased emphasis on program evaluation. Therein Orszag wrote: "Rigorous … program evaluations can be a key resource in determining whether government programs are achieving their intended outcomes … and at the lowest possible cost. Evaluations … can help the Administration determine how to spend taxpayer dollars effectively and efficiently …"

For program evaluation to effectively inform the accountability process, systematic steps should be considered for the conduct of the evaluation. Early-on steps should include the identification of the cause(s)—barriers to innovation and technology—of the market failure to which the federal R&D investments are directed and an explanation of how the federal R&D investments have reduced those barriers.

Some of the participants emphasized that related to public accountability is the existence of mechanisms and institutions, such as a central S&T policy making organization, with authority to promulgate S&T policy initiatives. Accordingly, the following are policy issues discussed during the workshop.

- The economic impact of chemistry R&D in chemical companies might increase through the company's disclosure of information about its internal innovative investments in a standardized manner. If so, then an organization should be charged with the responsibility of promulgating such standards.
- Chemical companies underinvest in R&D from a social perspective because there are technical and market risk barriers to socially-desirable technology development that the companies cannot overcome (independent of the level of disclosure). Increased public investments in infrastructure technology could correct for the market failure of underinvestment.
- A greater understanding of the social impact of chemistry R&D might come from technology-specific case studies. But, currently there are few mainstream economics or policy journals that publish such research. This editorial preference might change through increased extramural research funding; that would not only increase the supply of such research but also it would send a signal to the relevant professions about the policy importance of such research.

Appendix A

Assessing and Enhancing the Impact of Science R&D in the United States: Chemical Sciences

Workshop Agenda

November 16, 2009

6:30 pm Working Dinner

November 17, 2009

8:30 – 8:45 Opening Remarks
Arden L. Bement, Jr., Director of the NSF

8:45 – 9:00 Welcome, Purpose of the Workshop, and Overview of the Day
Kelsey D. Cook, NSF and Hratch G. Semerjian, CCR

9:00 – 10:00 "Understanding the Impact of R&D in the Context of the Chemical Sciences"
Baruch Lev, NYU
Discussant, Adam Jaffe**,** Brandeis

10:00 – 10:15 Coffee

10:15 – 11:15 "Indicators of R&D Performance in the Chemical Sciences Industry"
Fiona Murray, MIT
Discussant, Bob Cava, Princeton

11:15 – 12:15 "The Role of Public Infrastructure in the Context of the Chemical Sciences"
John Scott, Dartmouth College
Discussant, Greg Tassey, NIST

12:15 – 1:15 Lunch
"Leadership at the Intersection of Innovation and Globalization"
Katie Hunt, Dow Chemical Company

1:15 – 2:15 "Returns to Private R&D Investments in Chemical Science: Empirical Evidence"
Bronwyn Hall, UC Berkeley
Discussant, Albert Link, University of North Carolina at Greensboro

2:15 – 2:30 Coffee

2:30 – 3:30 “Lessons Learned from the Day: Academic and Industry Perspectives”
Wes Cohen, Duke

Panel Discussion, Moderator, Wes Cohen
- Robert Boege, ASTRA
- Robert Fry, DuPont
- Katie Hunt, Dow Chemical
- Matt Yates, Eli Lilly
- Robert Wikman, BASF

3:25 – 3:45 Closing Remarks and Next Steps
Kelsey Cook and Julia Lane, NSF

3:45 Adjourn