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Citation for published version (APA):
Edgerton, D. (2012). Time, Money, and History. *Isis*, *103*(2), 316-327. https://doi.org/10.1086/666358

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CHICAGO JOURNALS


History of Science Society

Time, Money, and History
Author(s): David Edgerton
Reviewed work(s):
Source: *Isis*, Vol. 103, No. 2 (June 2012), pp. 316-327
Published by: The University of Chicago Press on behalf of The History of Science Society
Stable URL: http://www.jstor.org/stable/10.1086/666358
Accessed: 30/06/2012 05:41

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Time, Money, and History

*By David Edgerton**

ABSTRACT

This essay argues that taking the economy seriously in histories of science could not only extend the range of activities studied but also change—often quite radically—our understanding of well-known cases and instances in twentieth-century science. It shows how scientific intellectuals and historians of science have followed the money as a means of critique of particular forms of science and of particular conceptions of science. It suggests the need to go further, to a much broader implicit definition of what constitutes science—one that implies a criticism of much history of twentieth-century science for defining it implicitly and inappropriately in very restrictive ways.

THE *COMPANION TO THE HISTORY OF MODERN SCIENCE*, edited by R. C. Olby, G. N. Cantor, J. R. R. Christie, and M. J. S. Hodge, remains the best introduction to modern history of science. Any number of disciplines, arguments, interpretations, and topics are covered. In different guises, we find discussion of science and philosophy, literature, war, imperialism, nationalism, political ideology, society, the public, language, sociology, and so on. The economy, industry, and money are inconspicuously absent, even from the reflections on Marxism.[1] Such omissions will surprise no one and will be lamented by few. There appears to be an implicit and sometimes explicit concern that dealing with "horrid political economy"—as Cecily puts it in Oscar Wilde's *The Importance of Being Earnest*—will mean not merely tedium but imbibing methodological poison—neoliberal, Marxist, perhaps mere naive quantification. But this is to make the serious and vulgar error of conflating a vast area of human life and endeavor with particular methods of studying it.

There is a good deal to gain by taking the world of production, consumption, work, and the economy seriously in thinking about the conduct, nature, and consequences of natural science. And such studies are hardly rare. Recent history of science has much to say about

* Centre for the History of Science, Technology, and Medicine, Imperial College London, London SW7 2AZ, Great Britain.

I am grateful to Jean-Baptiste Fressoz, Santiago Lopez, William Thomas, and Abigail Woods for their incisive comments.

[1] R. C. Olby, G. N. Cantor, J. R. R. Christie, and M. J. S. Hodge, eds., *Companion to the History of Modern Science* (London/New York: Routledge, 1990). In Edward J. Hackett, Olga Amsterdamska, Michael Lynch, and Judy Wajcman, eds., *The Handbook of Science and Technology Studies*, 3rd ed. (Cambridge, Mass.: MIT Press, 2007), one chapter out of thirty-eight concerns economic relations.

Isis, 2012, 103:316–327
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0021-1753/2012/10302-0005$10.00

money, about patronage and trade; the term "technoscience" is in common use; and the idea that universities were not concerned with the economy before the 1980s is correctly criticized. Moreover, the issue of the economy is now getting attention from leading scholars in broader discussions of the policies for scientific research.[2] Yet studies tend to focus on the economic, monetary, and industrial relations of very particular kinds of scientific research, those most distant from the economic whirl—that is, academic research. Basing our picture on the full range of scientific activity in the economy, the polity, and society would transform the map of natural science that guides research and teaching in the history of modern science. I am not merely arguing for a larger scale of analysis, or a more complete one; I believe that this new picture will lead us to new perspectives on both broad issues in studies of science and society and on the traditional focus of history of science—the academy. We need to think differently upon money's relationship with science. In the twentieth century, most research in science has been quite unproblematically conducted in the search for profit, production, or military security. Yet histories tend to focus on a single site—the academy—a context where such connections were in some circumstances problematic and were believed to be so by only a minority of academics.

Furthermore, our understanding of modern science is shaped by an implicit, often simplistic and naive, understanding of the economic impact of research and of the funding of research, rather than on empirically based studies of these relations. The economy and money are not missing from studies; rather, they are present in particular, often unhelpful, forms; the focus on money on campus draws too much from varieties of what might be called the spontaneous economics of academic research scientists. Broadly speaking, this downplays the importance of filthy lucre in "science," while overestimating the economic and other impacts of academic research compared with industrial and governmental research and other forms of inventive activity. Of course professional historians of science know that accounts given by scientists of the social, economic, political, and other relations of science are not a reliable guide to reality, and they have certainly challenged the idea of academic research as pure. And yet, they are perhaps not sufficiently aware of the extent to which particular scientists' conceptions of what constitutes science have constrained inquiry. At the most trivial level, this has involved relying on academic physicists' testimony about levels of funding. All sorts of claims are made for the significance of the cancellation of the Superconducting Super Collider in 1993; yet that did not signal the end or even the decline of federal funding. There was growth in every year from 1975 to 2005 in federally funded "basic research" in universities and colleges in the United States (data before and after 1997 are not strictly comparable).[3] Worse still, historians' own often crude accounts of what some scientists believed have come to define historiographic agendas.[4] In what follows, my comments should be understood as re-

[2] Dominique Pestre, *Sciences, argent et politique: Un essai d'interprétation* (Paris: INRA, 2003); and Philip Mirowski, *Science-Mart: Privatizing American Science* (Cambridge, Mass.: Harvard Univ. Press, 2011).

[3] "National Patterns of R&D Resources: 2008 Data Update Detailed Statistical Tables," NSF 10-314, Mar. 2010, Table 6: U.S. Basic Research Expenditures, by Source of Funds and Performing Sector: 1953–2008 [Constant 2000 U.S. Dollars], http://www.nsf.gov/statistics/nsf10314/pdf/nsf10314.pdf. See also Daniel Greenberg, "Government-Funded Basic Research in the United States," in *Research Budgets in an Age of Limits: Basic Science—Health—Culture*, ed. Klaus-Dirk Henke, Hans-Liudger Dienel, and Arthur P. Molella (Baden-Baden: Nomos, 2000).

[4] This is the burden of David Edgerton, "'The Linear Model' Did Not Exist: Reflections on the History and Historiography of Science and Research in Industry in the Twentieth Century," in *The Science–Industry Nexus: History, Policy, Implications*, ed. Karl Grandin and Nina Wormbs (New York: Watson, 2005), pp. 31–57.

stricted to the history and historiography of the twentieth century, since for earlier periods my argument would necessarily be different. This essay is thus a plea not only for taking the economy seriously, but also for understanding the specificities of the relations of science and the economy in the twentieth century.

There was an important Marxist tradition in thinking about the relations of science, the economy, and society that gave rise, from the 1930s, to rich new histories of science and studies of science policy that yielded and stimulated quantitative estimates of the volume of research both in and out of the academy. This is not the place to track the well-known vicissitudes of Marxist analyses of science and its history, but it is important to note that in its late incarnations Western Marxism had shunned both vulgar economism and political economy; the left began reading the color supplements rather than the economics pages: it discovered consumption and abandoned production and politics as passé. This is not to say that the Marxism of the 1970s and 1980s did not have brilliantly productive moments, particularly in the study of labor processes—it most certainly did, and it did influence certain strands in the history of science.[5] More generally, the 1970s and 1980s saw fresh and powerful studies of corporate research.[6] Yet despite the increasing interest in technoscience, the economy and studies of nonacademic research have become less prominent.

It is significant that in the last thirty years there has been a vast expansion in the economics of innovation and also the beginnings of an economics of science. The former has been technocratic and nationalist in character and hostile to neoclassical economics. On the other hand, there has been a powerful renewal in the neoliberal political economy of science.[7] Neither, however, has had a significant influence on the historical study of science, although the assumptions of both are present, transmitted in general through scientists.

POLITICAL ECONOMY AND THE IDEOLOGY OF THE SCIENTISTS

It is a cliché that economists—indeed, many social scientists—have wanted to ape natural scientists, and there is now a rich historical literature on the relations between the two.[8] There was traffic the other way, too, from political economy to natural science, the most famous instance being Darwin's theory of evolution. There is, however, another class of relations that seem to be important—the relations of discourses about science and society and broader political economic discourse. For students of science and scientists, it may be too tempting to see scientists' more general ideas as scientism, rather than as what they more often are—versions of commonplace ideas. Victorian scientists' hostility to state funding of research was an instance of general attitudes to the state; the change in attitudes toward economic nationalism before the Great War was similarly not specifically scientific. That J. D. Bernal's *Social Function of Science* (1939) is derivative of standard Marxist analyses of monopoly capitalism, imperialism, and militarism is pretty obvious; he is trying to show scientists that the only way

[5] Les Levidow and Bob Young, eds., *Science, Technology, and the Labour Process* (Marxist Studies, 1) (London: CSE Books, 1981); and Gary Werskey, "The Marxist Critique of Capitalist Science: A History in Three Movements?" *Science as Culture*, 2007, *16*:397–461.

[6] See the review by Michael Aaron Dennis, "Accounting for Research: New Histories of Corporate Laboratories and the Social History of American Science," *Social Studies of Science*, 1987, *17*:479–518.

[7] The most brilliant work has been that of Terence Kealey, *The Economic Laws of Scientific Research* (London: Macmillan, 1996); see also Kealey, *Sex, Science, and Profits* (London: Heinemann, 2008).

[8] Philip Mirowski, *More Heat than Light: Economics as Social Physics, Physics as Nature's Economics* (Cambridge: Cambridge Univ. Press, 1989); and Margaret Schabas, *The Natural Origins of Economics* (Chicago: Univ. Chicago Press, 2005).

to free science is to abolish capitalism. Similarly, the anti-planners of the Society for Freedom in Science did not invent their own theory of free science but found one in Austrian economics.[9] Perhaps the most powerful political economy has not dared to speak its name: many scientific intellectuals reproduced standard economic nationalism, which became central to a species of economics of innovation.[10]

In each of these modes, and to various degrees, the scientific intellectuals overemphasized academic research. Bernal, for all his critique of pure science and his pioneering quantification of research funding, seriously underreported industrial research and highlighted military funding as part of his critique of capitalism (see below). The neoliberal anti-planners were concerned with pure academic research—everything else was technology and was ignored. The more nationalist of thinkers were perhaps overwhelmingly more inclusive, but the key cases remained academic ones.

That money, the economy, and business have been so integral a part of science does not mean that economists have dealt with them adequately. Thus the most famous instance of economic analysis of science—the market failure argument for its funding by the state—assumes that it is a nonappropriable public good, pure information, like the light from a lighthouse. Some scientific knowledge may be like that, but hardly all or even most of it. In any case, though the argument gives a rationale for the funding of some research by states, it does not explain why and how states actually funded research, which they did long before the argument was thought of. In any case, the analysis would suggest that particular states should *not* fund research, since the knowledge thus produced is by the principle invoked freely available to other states.[11] What implicit or explicit economic ideas about research have been in play in actual research policies of states is hardly addressed in either the economics or the history of science or science policy literature.[12]

Furthermore, economic histories (and the economics of science and technology) have too often relied on received accounts of well-known innovations rather than examining innovation afresh for themselves.[13] They have also often incorporated the seemingly

[9] David Edgerton and Kirsty Hughes, "The Poverty of Science: A Critical Analysis of Scientific and Industrial Policy under Mrs. Thatcher," *Public Administration*, 1989, *67*:419–433; and Jessica Reinisch, "The Society for Freedom in Science, 1940–1963" (M.Sc. thesis, Univ. London, 2000). See also Richard Cockett, *Thinking the Unthinkable: Think-Tanks and the Economic Counterrevolution, 1931–1983* (1994; London: Fontana, 1995); Frances Stonor Saunders, *Who Paid the Piper?* (London: Granta, 2000); Philip Mirowski, *The Effortless Economy of Science?* (Durham, N.C.: Duke Univ. Press, 2004); Mirowski, *Science-Mart* (cit. n. 2); and Adrian Johns, *Death of a Pirate: British Radio and the Making of the Information Age* (New York: Norton, 2010).

[10] The term "national systems of innovation" was coined in the 1980s by Christopher Freeman and has been much used since, though without its ideological baggage always being clear. Freeman espoused a national political economy of technology, drawing on Friedrich List, the nineteenth-century German advocate of what Roman Szporluk called "scientific nationalism." See Simon Lee, "Industrial Policy and British Decline," in Andrew Cox, Lee, and Joe Sanderson, *The Political Economy of Modern Britain* (Cheltenham: Elgar, 1997); and Lee, "British Culture and Economic Decline," *ibid.* On List see Roman Szporluk, "Thoughts about Change: Ernest Gellner and the History of Nationalism," in *The State of the Nation: Ernest Gellner and the Theory of Nationalism*, ed. John A. Hall (Cambridge: Cambridge Univ. Press, 1998), pp. 23–39.

[11] R. R. Nelson, "The Simple Economics of Basic Scientific Research," *Journal of Political Economy*, 1959, *67*:297–306; K. J. Arrow, "Economic Welfare and the Allocation of Resources for Inventions," in *The Rate and Direction of Inventive Activity: Economic and Social Factors*, ed. Nelson (Princeton, N.J.: Princeton Univ. Press for the NBER, 1962); David Hounshell, "The Cold War, RAND, and the Generation of Knowledge, 1946–1962," *Historical Studies in the Physical and Biological Sciences*, 1997, *27*:237–267; and Hounshell, "The Medium is the Message; or, How Context Matters: The RAND Corporation Builds an Economics of Innovation, 1946–1962," in *Systems, Experts, and Computers*, ed. Agatha C. Hughes and Thomas P. Hughes (Cambridge, Mass.: MIT Press, 2000), pp. 255–310.

[12] Sabine Clarke, "Pure Science with a Practical Aim: The Meanings of Fundamental Research in Britain, c. 1916–1950," *Isis*, 2010, *101*:285–311, is a notable exception.

[13] David Edgerton, "Innovation, Technology, or History: What Is the Historiography of Technology About?"

common-sense assumption of a positive correlation between national investment in research and development (expressed as a percentage of GDP) and national rates of economic growth. Thus Germany and America grew fast in the early years of the twentieth century because of rapid national innovation; Britain grew slowly because of poor or misdirected innovation.[14] Surprise is expressed at low Japanese growth in recent years, despite its huge R&D spending, which is second only to that of the United States in scale. In fact—and for very good reasons—there is if anything an inverse correlation between national rates of growth and national innovation.[15] Some economic analysis seemingly ignored what might have been another obvious fact—that as R&D expenditure increased in the 1970s, 1980s, and 1990s, rates of economic growth in the countries funding high levels of R&D fell below what they had been in earlier decades.

We also need to be very careful not to attribute undue significance to standard measures that are at the core of economic analysis. The use of comparisons of R&D intensity (R&D expenditure as a percentage of GDP, say) owes more to the fact that these one-dimensional numbers avoid all the problems of comparison of prices than to any satisfactory analysis of what the significance of the ratio might be. Counts of patents assume that patents reflect technical novelty, yet they notoriously do not. Furthermore, the financial importance of an individual patent is not a measure of its technical significance.[16]

MONEY, TIME, AND HISTORY

As historians, we chart variations in ideas and practices over time and space. But there are further axes that we can use to inform our analyses—for example, economic development. A vulgar version of this idea might suppose that a wealthy country's past is a poorer country's present: "*de te fabula narratr*"—the tale is told of you—wrote Marx to explain to his German readers the significance of his earlier British cases.[17] In the terms of later economic commentary, countries always industrialize, they urbanize, they undergo demographic transitions, they turn into service economies, and so on. One way of expressing this would be to say that development follows not time or virtue or piety but, say, income per head (measured, perhaps, as GDP per head). Of course, there are powerful objections to such a determinist model (for example, Bogota in 2000 is not like London in 1900), but leaving out the money is about as silly as leaving out the time we historians so dutifully record.

Take the case of the development of the universities of Christendom. In 1500 universities were concentrated in Western Europe, stretching to Prague and Vienna. Before going east, they spread west to Spanish colonies in the Americas. Royal and pontifical universities were founded in Lima and in Mexico in 1551; a university was founded in Córdoba (now Argentina) in 1622, predating Harvard (1636) and anything in the Russian Empire (St. Petersburg and Moscow universities were founded in 1724 and 1755). León, in Nicaragua,

Technology and Culture, 2010, *51*:680–697. For the economics of innovation see, e.g., Bronwyn H. Hall and Nathan Rosenberg, *Handbook of the Economics of Innovation*, 2 vols. (Amsterdam: North Holland, 2010).

[14] For a critique of these literatures see David Edgerton, *Science, Technology, and the British Industrial "Decline," 1870–1970* (Cambridge: Cambridge Univ. Press, 1996).

[15] For surprise at Japan's low growth see Ben Steil, David G. Victor, and Richard R. Nelson, eds., *Technological Innovation and Economic Performance* (Princeton, N.J.: Princeton Univ. Press, 2002). Regarding the inverse correlation between rates of growth and innovation see Edgerton, *Science, Technology, and the British Industrial "Decline," 1870–1970*; and Kealey, *Economic Laws of Scientific Research* (cit. n. 7).

[16] Christopher Beauchamp, "The Telephone Patents: Intellectual Property, Business, and the Law in the United States and Britain, 1876–1900" (Ph.D. diss., Univ. Cambridge, 2007).

[17] Karl Marx, preface to the first German edition of *Capital*, reproduced and translated into English in, e.g., Marx, *Capital: A New Abridgement* (Oxford: Oxford Univ. Press, 1995).

hosted a university from 1816, long before most western or southern parts of the United States and the same year as Warsaw. There was a university in Montevideo (1849) before there was one in Manchester. We might refine the picture by considering the emergence of the research university. The few research universities of the late nineteenth century were mostly new and were in Britain, the United States, and Germany. As other places achieved the levels of income per head these countries had in 1900 (very roughly speaking), they too developed research universities. Thus it is only now that Colombia is producing large numbers of Ph.D.'s and that its elite professoriate is qualified with the Ph.D.

We may note that the research-oriented international rankings (and the ranking of *scientific* research is central) of universities correlate rather better with income per head in the host nation than with age of university. The list of the highest-ranking universities is of course full of U.S. institutions, which are overwhelmingly younger than the hispanophone universities of the Americas. In a 2011 ranking, the first and only Latin American universities to appear in the top two hundred, sharing 169th place, are the Universidad Nacional Autónoma de México (the oldest university in North America, founded in 1551) and the University of Sao Paolo (the oldest in Brazil, founded in 1934). They are also outranked by many new Asian universities. The old universities of Britain and the United States are very high on the list, but even the new universities in those nations trump the great majority of medieval and early modern foundations—say, Salamanca or Bologna. Within a two-hundred-mile radius of New York, London, and central California, one can find well over half of the top-rated—say, the top twenty—universities in the world. We might note also that U.S. universities rose to world dominance long after U.S. industry and agriculture and that the growth of Asian tigers and Latin American economies was hardly due to their new or ancient universities; the latter benefited more from the former than vice versa. It was money that brought academics to California, just as it was money that brought Old Masters to the new art galleries of Philadelphia and Buenos Aires and Impressionists to the Hermitage. And, indeed, great corporations started doing research rather than becoming large and rich through research. (See Figure 1.)

FOLLOW THE MONEY: MONEY AS TOOL OF CRITIQUE

In the Watergate case, the informant Deep Throat was not willing to tell his story, only to confirm whether Bob Woodward was on the right track; his famous injunction as to how to get the story was "Follow the money!" This technique has long been used in similar circumstances by analysts of science and by historians when they have wanted to get at the story of science where the funding agencies and recipients were not frank. There has been a long-standing tradition, dating back to at least the 1930s, that pointed to the significance of what it took to be tainted industrial and military money in funding research. In a pioneering early 1930s survey of funding, the biologist Julian Huxley noted,

> If you are willing to pay for more men and more facilities in war research than in, say, medical research, you will get more results adapted to killing people and less adapted to keeping them alive. And it is when we look at the amounts of expenditure in different fields that we begin to realise what a large share of the nation's scientific brains is occupied with war. It is very difficult to obtain exact figures; but I have attempted to reach rough estimates which I think are not too far from actuality to be of service. I submit them with reserve, and as subject to an error of at least 15 to 20 per cent. For research in industry, and in the sciences mainly basic to industry, like physics and chemistry, the country spends perhaps 2¼ or 2½ millions a year. War research comes next to this, with certainly over a million pounds, perhaps a million and a half. Research in agriculture and the agricultural side of biology take somewhere around



Figure 1. *Bell Labs, Murray Hill, New Jersey, through a window of the Acoustics Laboratory (1942). Gottscho-Schleisner Collection, Library of Congress, LC-G612-42356.*

> three-quarters of a million; research in health and the physiological side of biology about half a million or probably less. And research in the specifically human sciences like psychology and sociology probably accounts for well under a hundred thousand. Money talks: and these figures tell a tale. Science is being applied on a large scale to the ends of destruction, not because science is essentially destructive or scientists particularly militarist, but because the nation, through its appointed government, is paying handsomely to secure that it shall be so applied.[18]

In *The Social Function of Science*, J. D. Bernal also highlighted the extent to which British research was funded by the military: "It would not be unfair to say that something between one-third and one-half of the money spent on scientific research in Britain is spent directly or indirectly on war research. . . . And this in peace time." He estimated that there were 842 scientists doing research for the services, spending some £1.5 million, out of a total war research and development budget of £2.8 million.[19] In the late 1940s and early 1950s, Bernal was one of the very few to point out that British research was highly militarized—again by pointing to the money. He thought this was a very bad thing, but unavoidable under capitalism.

[18] Julian Huxley, "Peace through Science," in Philip Noel-Baker *et al.*, *Challenge to Death* (London: Constable, 1934), pp. 292–293.

[19] J. D. Bernal, *The Social Function of Science* (London: Routledge, 1939), pp. 173 (quotation), 427–428. The figures are for 1937.

In the 1980s, historians writing about the 1940s and 1950s used the same technique. Paul Forman wrote of scientists' "false consciousness, which succeeded so well in what it was intended to do, to mislead others even as it blinded themselves" about the realities and scale of the links between postwar (academic) physics and the military. He thus looked to money to demonstrate the extent of the influence of the military. Forman showed just how vital defense dollars were for U.S. university research in physics after the war—so much so as to create "a physics as the military funding agencies would have wished." Academic physics was not in command, it was being used; and physicists "had lost control of their discipline." There are many other fine studies of the "patronage" of particular fields by the military. More recently, Philip Mirowski has followed the money (like Forman, he has done much else besides, of course) as part of a critique of recent science. Mirowski sees a transition from federally funded (including military) research to corporate funding that requires appropriable rather than public knowledge to be produced.[20] (see Figure 2)

FOLLOWING THE MONEY TO UNDERMINE CLICHÉS

It might be thought that as a result of such studies we have a good picture of "science and the military," as the phrase goes. Yet we do not, for the great majority of such studies are concerned with only a minor aspect of the relations of science and the military, which merely appear to exhaust the issue. What we have are studies of the impact of the military on science on the university campus, a particular story about a particular part of the relationship that stands for the whole. We need to follow all the money, not just that going to the university.[21] Rough estimates of the comparative scale of industrial, government, and academic research through the century show that the usual implicit maps of the historians systematically oversize academic research by comparison with government and industrial research.[22] Industry and the military (largely in industry) have been—nearly everywhere and nearly always—the main funders of research and development. Not only research within the academy but, indeed, those aspects of academic research least connected to industry are oversized—physics, particularly particle physics, and biology, particularly molecular biology—while chemistry, mathematics, and engineering are undersized. Similar distortions are at work for research that takes place outside the academy. The research and development part of the Manhattan Project is routinely oversized because of the tendency to picture the whole project as a research and development effort. But most of the $2 billion the whole project cost went to build two nuclear factories at Oak Ridge and Hanford, an effort undertaken by large corporations, including DuPont; the

[20] Paul Forman, "Behind Quantum Electronics: National Security as a Basis for Physical Research in the United States, 1940–1960," *Hist. Stud. Phys. Biol. Sci.*, 1987, *18*:149–229, on pp. 228, 224, 239; Ronald E. Doel, "Constituting the Postwar Earth Sciences: The Military's Influence on the Environmental Sciences in the USA after 1945," *Soc. Stud. Sci.*, 2003, *33*:635–666 (in a special issue on "Earth Sciences in the Cold War"); and Mirowski, *Science-Mart* (cit. n. 2).

[21] This is the burden of Forman, "Behind Quantum Electronics"; and Stuart W. Leslie, *The Cold War and American Science: The Military-Industrial-Academic Complex at MIT and Stanford* (New York: Columbia Univ. Press, 1993), which recognizes in the first few pages that most R&D was not academic. See also Everett Mendelsohn, Merritt Roe Smith, and Peter Weingart, eds., *Science, Technology, and the Military*, 2 vols. (Dordrecht: Kluwer, 1988); the journal *Historical Studies in the Physical and Biological Sciences*, for the 1990s in particular; and the special issue on "Science in the Cold War," *Soc. Stud. Sci.*, 2001, *31*.

[22] See David Edgerton, *England and the Aeroplane: An Essay on a Militant and Technological Nation* (London: Macmillan, 1991); Edgerton, *Science, Technology, and the British Industrial "Decline," 1870–1970* (cit. n. 14), p. 11; and Edgerton, "Science in the United Kingdom: A Case Study in the Nationalisation of Science," in *Science in the Twentieth Century*, ed. John Krige and Dominique Pestre (London: Harwood, 1997), pp. 759–776, for examples of this.



Figure 2. *A geologist, employed by a U.S. oil company, with his "rod man," looking for oil in the United States, circa 1944. Library of Congress, LC-USW4-029549.*

research and development part of the project came to a mere $70 million.[23] Assuming that each type of bomb cost $35 million to develop, this was around ten times the development cost of the DC4 aircraft of the late 1930s. Furthermore, it represented only a small fraction of overall warlike R&D expenditure in the United States: in fiscal year 1945 the Office of Scientific Research and Development spent around $100 million, while the U.S. Army and Navy spent $700 million on research and development alone.[24] Many other initiatives and policies are given undue prominence and significance in historical treatments as well.

Vannevar Bush was very clear, in his *Science, the Endless Frontier* (1945), about the funding of research in the United States. Paying attention to this will help us understand what he was proposing and avoid misunderstanding as to the scope of his proposals. He observed, "Expenditures for scientific research by industry and Government—almost entirely applied research—have more than doubled between 1930 and 1940. Whereas in 1930 they were six times as large as the research expenditures of the colleges, universities, and research institutes, by 1940 they were nearly ten times as large." The war made things worse: "We have been living on our fat. For more than 5 years many of our scientists have been fighting the war in the laboratories, in the factories and shops, and at the front. . . . They have been diverted to a greater extent than is generally appreciated from the search

[23] These figures come from the remarkable Brookings Institution study by Stephen I. Schwartz, *Atomic Audit: The Costs and Consequences of U.S. Nuclear Weapons since 1940* (Washington, D.C.: Brookings Institution Press, 1998), Table 1-1, p. 60. The research and development figure may be an underestimate, but it is worth noting that the cost given for "Los Alamos Project" is $74 million, a sum that is additional to the R&D total.

[24] Forman, "Behind Quantum Electronics" (cit. n. 20), p. 152.

for answers to the fundamental problems—from the search on which human welfare and progress depends." The key point was that "if the colleges, universities, and research institutes are to meet the rapidly increasing demands of industry and Government for new scientific knowledge, their basic research should be strengthened by use of public funds."[25] Bush was arguing for the public support of basic research in universities at a time when he thought the growth in such research had *failed* to keep up with the huge rises in *government* and *industrial* research, both of which were overwhelmingly and necessarily "applied." He did not (as many later analysts have done when thinking in terms of the "linear model") conflate policy for academic research with policy for innovation. Nor, in any case, did the Bush-inspired National Science Foundation (NSF) dominate funding even of academic basic research. Even in the early 1960s, the NSF supported less than 10 percent of all basic research and less than 15 percent of all federally funded basic research. The Department of Defense was still supporting as much as 44 percent of federally funded basic research in universities and colleges in 1958.[26]

Older studies of the patronage of British science in the twentieth century overemphasized the most visible agencies, like the National Physical Laboratory, the Department of Scientific and Industrial Research (DSIR), and the Medical Research Council. A little accounting vitiated any claim to the centrality of these organisms: the military departments of state spent more even on civil research and development; industry spent more than the state; and so on. Looking at the money and who controlled it made it obvious that there was no single research policy, nor did the supposed principles that guided such policy apply to most research funders.[27] This was a matter not just of recognizing the significance of the military and of industry, but of noting funding expended for imperial purposes and the huge sums spent for forgotten industries like whaling.[28]

Why is it important to get this right? Essentially, because there are great dangers in generalizing from often atypical cases (the academy, the NSF, the DSIR) that are taken to be of central importance. Moreover, there is a danger of misunderstanding the wider research contexts for any particular form of research. To illustrate: the suggestion that the production of knowledge was until recently characterized as, say, "Mode 1" is problematic because it should be obvious that there were many different ways in which knowledge was produced in the past. Even had it been the case that academic research could be characterized as Mode 1—which is doubtful indeed—the whole of knowledge production could not. To put it another way, the still-common suggestion that the science policies of Britain and the United States have been governed, since 1918 or 1945, by notions labeled "the Haldane principle" or "the linear model" is vitiated by the fact that if these ideas existed at all (which, again, is very doubtful) they applied to only a small proportion even of state-sponsored, much less industrially supported, research. In other words, serious category errors are easily committed.

[25] Vannevar Bush, *Science, the Endless Frontier* (1945; Washington, D.C.: National Science Foundation, 1960), p. 7.

[26] Bruce L. R. Smith, *American Science Policy since World War Two* (Washington, D.C.: Brookings Institution Press, 1990), p. 51 (NSF support of basic research); and Harvey M. Sapolsky, *Science for the Navy: A History of the Office of Naval Research* (Princeton, N.J.: Princeton Univ. Press, 1990), Table A-5, p. 137 (Department of Defense support of basic research). More generally, see Donald E. Stokes, *Pasteur's Quadrant: Basic Science and Technological Innovation* (Washington, D.C.: Brookings Institution Press, 1997).

[27] Edgerton, *Science, Technology, and the British Industrial "Decline," 1870–1970* (cit. n. 14).

[28] Sabine Clarke, "A Technocratic Imperial State? The Colonial Office and Scientific Research, 1940–1960," *Twentieth Century British History*, 2007, *18*:453–480; and D. Graham Burnett, *The Sounding of the Whale: Science and Cetaceans in the Twentieth Century* (Chicago: Univ. Chicago Press, 2012).

TURNING IT AROUND

The distancing of science and scientists from filthy lucre has relied on a successful program of identifying science as a whole with that part of it that has been outside the direct control of powerful economic agents like industry, the military, and so on. Distinguishing something called "science" from something called "technology" has thus been peculiarly important and helps explain hostility to the idea of technoscience and Mode 2 science. Academic scientists have not been the only ones involved in this task. Academic sociologists of science of the 1950s followed academic scientists in assuming that there was a major cultural gap between the ethos of the scientist (understood as a university researcher) and that of the practitioners of science in industry and government. In the 1970s this assumption was found not to hold, and yet it has continued to inform commentary on science and industry.[29] Rare have been the historians and sociologists of science who have pointed to the limitations of the academic-centered view; rarer still are those who note that the implied asymmetry is misplaced. Steven Shapin has recovered a whole history of academic commentary on industrial science and, in a study of the present, directly challenged the still flourishing assumption of a radical difference between the commercial and the academic contexts for scientific research, at least of the sort that are usually suggested. In an earlier precocious and pointed essay, Michael Aaron Dennis, analyzing new histories of industrial research in the contexts of science around 1900, made the devastating observation that research was only part of a scientist's work, whether in the academy or in industry, but that for select individuals industry provided not only a higher salary but also time and equipment to pursue research that universities would not then support.[30] We urgently need to recognize that most scientific research activity has been conducted for economic and military purposes and that pecuniary rewards—whether in the form of patents or otherwise—have been central, whether that research was conducted in industry, in government, or in universities. For most scientists a direct connection to mammon has been the norm rather than the exception.

Our knowledge of scientists pursuing standard careers in industry and in government is very limited. Yet our historical image of the scientist could usefully start with them. Our understanding of the history of invention and innovation, and the place of scientific research—whether in government, industry, or the academy—in it, should be our starting point for thinking about the sources of invention. Yet we are still mired in clichéd stage theories, where the individual inventor gives way to the corporate R&D laboratory and, in the academic case, Mode 1 is replaced by Mode 2; in notions of very dubious value, like the linear model; or in limited criticisms of these models.[31] While some important work is adumbrating these issues in a broad range of cases, from histories of corporate R&D to

[29] See Stephen F. Cotgrove and Steven Box, *Science, Industry, and Society: Studies in the Sociology of Science* (London: Allen & Unwin, 1970); and S. B. Barnes, "Making Out in Industrial Research," *Science Studies*, 1971, *1*:157–175.

[30] Steven Shapin, *The Scientific Life: A Moral History of a Late Modern Vocation* (Chicago: Univ. Chicago Press, 2008) (see also Paul Lucier, "The Professional and the Scientist in Nineteenth-Century America," *Isis*, 2009, *100*:699–732); and Dennis, "Accounting for Research" (cit. n. 6).

[31] Hermione Giffard, "The Development and Production of Turbojet Aero-Engines in Britain, Germany, and the United States, 1936–1945" (Ph.D. diss., Imperial College, 2011); Philip Scranton, "Technology-Led Innovation: The Non-Linearity of U.S. Jet Propulsion Development," *History and Technology*, 2006, *22*:337–367; and Scranton, "Mastering Failure: Technological and Organisational Challenges in British and American Military Jet Propulsion, 1943–57," *Business History*, 2011, *53*:479–504.

the rich literature on, for example, scientific knowledge, political economy, and plant breeding, there is much more to be done.[32] Similarly, we are just at the beginning of asking historical questions as to why firms and governments have funded research, how they have done so, and how they have understood what they were doing. We need not so much an economic history of science as, instead, a history of science in the economy.[33] Activists have been much more prominent than historians in addressing key questions about how inventiveness has changed over time and about the nature of what is invented and sold, as exemplified by rich recent commentary on the pharmaceutical industry.[34]

CONCLUSION

My point is not that money has not been studied but, rather, that it has been inserted into an old story. We need to follow the money to a new story, to a new map. This is not just a question of extending the range of history of science to neglected aspects of scientific research; we need to reconsider both the whole and well-known parts. We need to recognize the breadth and variety of "science" and the centrality of the economic to most of it. For all the invocation of "technoscience," of the military, and of the economy, we assume far too readily that academic research stands for science. The problem is likely to persist. "Science" is still implicitly defined in relation to academic research, and this "science" still has relations with what are taken to be external economies, publics, societies, states, and the military; it is this "science" that becomes "techno-science." Research agendas for history of science are set more by concerns about this "science" and its relations than by any richer historical conception of what we have long known about knowledge creation.[35] It is perhaps for this reason that there is so much resistance to views that challenge the centrality of the academy and associated ideas about the prevalence of linear models and the supposed primacy of science in the years after World War II.[36] A refreshed history of twentieth-century science will become possible only if it is liberated from the boundaries and emphases imposed by conceptions of science insisted on by academic scientists of the past; following the money can indicate just how significant a change that might involve.

[32] Kees Gispen, *Poems in Steel: National Socialism and the Politics of Inventing from Weimar to Bonn* (Oxford: Berghahn, 2001); Jonathan Harwood, *Technology's Dilemma: Agricultural Colleges between Science and Practice in Germany, 1860–1934* (Oxford: Lang, 2005); Harwood, "The Fate of Peasant-Friendly Plant-Breeding in Nazi Germany," *Historical Studies in the Natural Sciences*, 2010, *40*:570–604; and Paolo Palladino, "Science, Technology, and the Economy: Plant Breeding in Great Britain, 1920–1970," *Economic History Review*, 1996, *49*:116–136.

[33] Clarke, "Pure Science with a Practical Aim" (cit. n. 12); and Mirowski, *Science-Mart* (cit. n. 2), esp. Ch. 2.

[34] David Edgerton, *The Shock of the Old: Technology and Global History since 1900* (Oxford: Oxford Univ. Press, 2007); Tyler Cohen, *The Great Stagnation: How America Ate All the Low-Hanging Fruit of Modern History, Got Sick, and Will (Eventually) Feel Better* (New York: Dutton, 2011); James Le Fanu, *The Rise and Fall of Modern Medicine*, 2nd ed. (London: Abacus, 2011); Mirowski, *Science-Mart*; Marcia Angell, *The Truth about the Drug Companies: How They Deceive Us and What to Do About It* (New York: Random House, 2004); Angell, "The Illusions of Psychiatry," *New York Review of Books*, 14 July 2011; and Angell, "The Epidemic of Mental Illness: Why?" *ibid*., 23 June 2011.

[35] Edgerton, "Innovation, Technology, or History" (cit. n. 13).

[36] See Paul Forman, "The Primacy of Science in Modernity, of Technology in Postmodernity, and of Ideology in the History of Technology," *Hist. & Technol.*, 2007, *23*:1–152; and Mirowski, *Science-Mart* (cit. n. 2).