ELSEVIER

Research Policy 26 (1997) 229–255

research policy

From market magic to calypso science policy A review of Terence Kealey's *The Economic Laws of Scientific Research*

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1. Introduction

In the United Kingdom, the United States, indeed, throughout the community of industrially advanced nations, a sense of urgency now surrounds discussions and debates about the funding and conduct of R&D by government. Decision-making concerned with major public expenditure commitments in many different areas has been held in the tightening grip of fiscal stringencies, while other, more specific circumstances have combined to force a reconsideration of the proper nature and extent of the state's role in furthering scientific research. Since the ending of the Cold War, a variety of long-standing practices through which governments supported the enterprise of science, have found themselves the subjects of unanticipated critical re-examination. Their exposure has been made more severe by the stripping away of the 'national defense' rationale that frequently, and reliably had been invoked in former times; this was particularly true in the US, where Congressional susceptibilities to arguments couched in terms of national defense had wonderfully refined the art of wrapping that loose-fitting garment around the efforts of diverse coalitions seeking further support—from a wide array of public institutions and government departments—for basic as well as applied research activities, and for some connected educational and training purposes besides.

Within the past half-decade, however, the habit of linking government programs supporting basic science in academic institutions vaguely with various conceivable, long-term national defense needs, has been reduced to tatters—not by the passing of the Cold War ethos alone, but by swingeing cuts in public expenditures allocated for military and related purposes, and the consequent shifting of defense agencies' missions towards the maintenance of their near-term tactical capabilities. In the ensuing scramble to protect many R&D activities from the adverse political fallout, another candidate has been sought for the role of general-purpose rationale. 'International competitiveness', 'wealth creation', and even 'national economic security', were already acquiring greater potency as generic political slogans during the 1980s, when industrial producers in the US and Western Europe's high-income countries found

[1] The writing and re-writing of this review benefitted from my conversations and correspondence on the subject with David Edgerton, Scott Mandelbrote, John Mulvey, Keith Pavitt, Edward Steinmueller, and Paul Stoneman. I have in the process also imposed especially heavily upon the sound critical advice, patience, and good humor of Sheila Johansson, Robin Matthews, and David Vines, all of whom have done their able best on this—as on other occasions—to keep me from errors and excesses of one sort or another. None of my benefactors in this endeavor necessarily subscribe to the views expressed herein, which has made the gift of their collective assistance all the more precious.

PII S0048-7333(97)00007-3

themselves confronting new and effective competition in international product markets. Justifications for governmental support of a wide range of scientific and technological research (and even some social and behavioral science studies), accordingly, have now been re-cast by references to those even more vaguely defined national *economic* priorities.

As a consequence of this conjunction of circumstances, a new host of new questions have been raised, and some older sources of skepticism have been renewed. These concern the effects of publicly funded civilian scientific research upon the current and future pace of technological innovation, industrial productivity growth, and the resulting abilities of nations to compete in the international economic arena. How closely tied is commercially successful innovation in the high-tech sector to fundamental scientific breakthroughs? What is the best mix of basic and applied R&D expenditures for the economy to maintain over the long-run, and do the recent cutbacks of basic research funding by large corporations call for compensatory adjustments in the level and distribution of public R&D support? How much of the nation's investment in research should be left to be financed by industry, and how effective are broad instruments such as R&D tax-credits in inducing extra private sector expenditures for this purpose? How large a share of the national product should we be spending for R&D, and can one determine what are the right levels of funding for the country to maintain across the variety of contending science and engineering fields? Do subsidies for research on 'critical technologies', and government programs of collaborative research with industry merely pay for R&D that firms would do anyway—but shift funding away from basic, exploratory projects that need to be underwritten completely by government grants? Does it matter whether publicly funded non-military research is conducted in universities, rather than by private non-profit institutions or government laboratories?

Government ministries, departments, and agencies having responsibilities for the initiation and administration of research programs in many countries are being urged now to grapple with such questions; to rethink and re-evaluate their own performances so as to better direct scarce resources towards new, and rather more explicitly specified societal goals. Thus, it is entirely conceivable that such reassessments of the purposes, the funding criteria, and the organizational modes for the pursuit of scientific knowledge, will amount to more than merely another fraught, but transient episode in the increasingly turbulent lives of modern government bureaucracies. For many of the advanced industrial nations the R&D policies and performance indicators now being shaped may well turn out to constitute a significant departure from the main lines of the approach that became established in the West after the Second World War. From that refreshed policy watershed would flow a stream of governmental and industrial decisions affecting the course of scientific and technological developments well into the twenty-first century—for better or for worse. Where is one to turn for information and insights to guide thinking about these complex and critical matters?

Here, then, is Terence Kealey, a researcher and lecturer in clinical biochemistry at the University of Cambridge, deftly summing up the spirit and contents offered to debates on these questions by his timely book, *The Economic Laws of Scientific Research*:

> [R]elax. Economic, technical and scientific growths are free lunches. Under *laissez-faire* they just emerge, like grass after the rain, through the efforts of individual entrepreneurs and philanthropists.... Dr. Pangloss was right, this is the best of all possible worlds —or rather, it would be if only politicians left it alone.... The Market Place does not worship false Idols, it makes empirically correct judgements. It is the government funding of science that is an Idol of the Tribe. (Kealey, 1996, pp. 344–345)

That's right—the central message is: 'don't worry'... get rid of government and 'be happy'. Dr Kealey's rendition of this calypso-style science and technology policy tells us just to end all public support for civilian science (and university education, while we are at it) and everything will be not only well, but better! The policy thrust of this book certainly can claim to possess the virtues of simplicity, clarity, and conviction. Those, however, are not qualities that can be said to characterize the reasoning that its author advances to support his recommendations. Indeed, the passage just quoted—in which the efforts of entrepreneurs and the capital

outlays of philanthropic foundations are made to add up, somehow, to a 'free lunch' for society—is emblematic of the muddled analysis and rhetorical excesses that sustains Dr Kealey's faith in the magical powers of 'the market' to deliver the best of all possible worlds, in these affairs as in all others.

The Preface to this passionate and prolonged polemic reveals that the project of writing it was conceived well more than a decade ago, in 1984 to be precise, when (according to its author) Denis Noble, FRS, and other scientists at Oxford 'helped orchestrate' rejection of the proposal to award an honorary degree to the Prime Minister:

> The Oxford academics claimed that Mrs. Thatcher was destroying British science, but as I had been asked to leave Oxford in 1982 because of a shortage of space, I knew their claims were false (our department's labs were only three years old, yet money was so prolific they were already crowded. Newcastle University, my next home, had even newer labs, even more crowded.... (p. xi)

While there were some observers at the time who took the view that inasmuch as scientists require proper space and equipment for their work, the nub of the problem—particularly in the then rapidly expanding fields of molecular biology and biotechnology—was the persisting inadequacy of laboratory facilities in Britain's university research centers. Not so Dr Kealey, who to this day can see only a *surplus* of academic researchers (whether in Oxford, or Newcastle), a painful condition he blames upon the foolishness of excessive State funding. The career difficulties occasioned for the author by the intense competition among 'too many' scientists for limited laboratory space along Oxford's South Parks Road are thus produced as testimony to the supposed mis-use of Britain's resources on a far grander scale —all of which can be laid at the door of the 'nationalization' of science under preceding Labour governments [2] (pp. 187–192).

These highly personal revelations fired a commendably ambitious undertaking to delve into the economics and the history of science, technology and their connection with the wealth of nations. The resulting inquiries, as evinced by this book, unfortunately, were unable to carry Dr Kealey's understanding of these key issues in science and technology policy much beyond the level of the insights he reports having extracted 14 years ago, in the unhappy circumstances of his displacement from the Oxford science scene. That may account for the fact that the work in question, although it is devoted to a most topical subject, has a curiously dated quality: students of the British science and technology policy scene will search its 12 chapters in vain for some notice of recent debates, such as those over the desirability of the 1992 White Paper's commitment to public research planning exercises like Project Foresight, or the impact of sharp cutbacks in British-government funding for university research equipment budgets, or the wisdom of an institutional and administrative structure that places the Research Councils (whose responsibility it is to allocate funds for basic science) inside the Department of Trade and Industry. Such omissions could be forgiven on the grounds that these are merely the ephemera of contemporary science and technology policy. But this work has even less to offer in the way of generic and enduring principles for the practical guidance of those charged with responsibilities for allocating R&D resources between programs, projects, and competing organizations, whether in the private or the public sectors. Operational decision-making there repeatedly confronts questions involving the nature of the criteria and terms on which research programs and projects are to be funded, the locus of control over research agendas, and the disposition of the resulting research findings. These are intricate matters of balance and degree, and their elucidation calls for careful attention to the facts and even greater caution in interpretation, not dogmatic choices between the ideological extremes of laissez-faire or planning. The author of *The Economic Laws of Scientific Research*, however, displays little interest in the former, and is much preoccupied by questions of the latter variety.

This is a pity, particularly because he has not stinted in the efforts devoted to researching and

[2] There is a touch of irony in this. When Dr Kealey is arguing the positive side of his case for laissez-faire in all matters of civilian R&D, the universally beneficial nature of competition as a mechanism for resource allocation is taken to be axiomatic and unqualified.

presenting his brief. The book's first six chapters evince Dr Kealey's devotion to reading widely in the secondary historical sources on economic development, science, and technology, starting in classical antiquity and proceeding through the Industrial Revolution. Chapters 7 and 8 follow the story into modern times, displaying the author's familiarity with the main outlines of British and US government policies affecting science and technology, and university education, since World War II. In Chapters 9 and 10, entitled "The economics of research", and "The real economics of research", respectively, Dr Kealey shows he has acquainted himself with some standard items in the analytical economics literature relating to R&D investment, and goes to the lengths of essaying some econometric analyses of OECD comparative international statistics pertaining to R&D funding during the 1980s. The latter constitute the core of the book's positive empirical arguments, specifically those claiming that the effects of eliminating all public funding for non-military R&D would be beneficial even to the enterprise of science, as well as for national economic growth. Chapter 11 continues in the quantitative mode by mobilizing an assortment of bibliometric indicators (rates of publication of scientific papers, and citations) to uphold the negative part of the author's argument—an attack upon the claims made on various occasions during the past 25 years that actual or contemplated cutbacks in government support of basic research would bring about the 'decline' of science in Britain, or in the US, as the case might be. Although the presentation is somewhat discursive, rather than systematic, and the argument at times becomes rather repetitive, Dr Kealey marshals all this material, and advances his interpretations with a verve that imparts to the text a quality that is undeniably engaging.

But, and it is a very big 'but', indeed, the evidence, analysis, and interpretations put forth in this volume are so deeply flawed that the easy readability of its glib text is not so much a virtue of exposition as it is a trap set for the unwary. It would be unwise, therefore, to silently put the book aside on the ground that the portions which are novel contain little that merits notice as a contribution to reasoned discussions of contemporary science and technology policy. The appeal of its text lies elsewhere. If the recent welcome extended to the book by *The Economist* and other, still more glowing reviews in Britain's Tory press are thought to carry any reliable signals in such matters, [3] there is more than a little danger of Dr Kealey's opus being taken seriously in some influential circles—indeed, possibly even beyond the orbits of those politically and ideologically predisposed to be swayed by the rhythms of a calypso science policy.

2. A case to answer?

A sad truth about the present state of affairs regarding government funding of science in the UK, the US, and elsewhere, is that a store of resentments has been built up by past displays of collective and individual arrogance on the part of 'the academic science establishment'. On too many past occasions its representatives have felt secure in the public's approbation of their work, and therefore free to ignore (or deride) the usefulness of social scientists, especially those specializing in matters touching the funding and management of research. [4] Whether for that reason or others, the immediate commercial applicability of basic science has in recent years been much oversold by the science lobby; and, in the urgency of rallying 'round the troops to combat both skepticism and outright hostility towards their claims, only woefully inadequate efforts have been made to understand and present the proper, more subtle economic grounds that do exist for continuing substantial public patronage of open, academic science. Better understanding on the part of leading scientific researchers of the analysis and evidence produced by students of the economics and sociology of science

[3] See *The Economist* (London edition, 14 September 1996). *The Daily Telegraph*'s (3 July 1996) iconoclastic columnist, Matt Ridley, reviewing Dr Kealey's book under the headline "Help science—don't give it any more money", described it in these words: "This is one of the most intelligent, trend-changing and courageous books I have ever read. If only his publisher had made more of an effort—the book is littered with typing errors, saddled with a deadly title and gives no clue to the excitement of its contents—it would be an instant best-seller".

[4] Dr Kealey will be seen (below) to display these same attitudes, both in his treatment of economic arguments and in his total neglect of the entire literature on the sociology of science.

might have opened the door for dispassionate examination of some less desirable allocative consequences that stem from the workings of the academic science reward system and peer review; it could yield useful approaches to reducing the inefficiencies, and scope for defects in social accountability, that tend to emerge in systems of devolved responsibilities and extreme specialization. [5]

These were missed opportunities, which had appeared to be scarcely more than pointless distractions when funding was flush and scientists were widely held in high repute. Thus, latterly, in less propitious times, academic scientists occupied with fighting their respective disciplinary corners, or in speaking on behalf of the larger, collective enterprise threatened by budget cuts, often erred politically as well as intellectually—by offering weak arguments that left an impression of being considerably more self-serving than persuasive. Without the assistance that members of the science establishment thereby provided, however unwittingly, it would have been considerably more difficult for Dr Kealey to suppose there was a need, and a receptive audience for a book such as the one he has written. Yet, clearly, such an audience exists. Even within university circles in Britain one can hear voices among those on the side of the humanities raised to welcome an assault upon the legitimacy of public funding for research the natural sciences and engineering; even while acknowledging that the case brought might be too extreme, and too ideologically motivated, the point is urged that it is a salutary thing for the natural science lobby to be given 'a case to answer'. [6] The question remains whether Dr Kealey's book has brought the right case to answer.

3. The argument

The point of departure is reasonable enough: Dr Kealey's first chapter takes a skeptical stance in regard to the proposition that public subsidies for scientific and technological research are automatically conducive to faster economic growth. Rather than setting out the possible grounds for such a view, however, he proceeds immediately to dispute those who appear to take an affirmative position—without distinguishing among the variety of views that can be lumped together on that side of the question, some unqualified, some qualified, some naively simplistic, and others more subtle. His opening line of criticism aims at the most vulnerable target, which is a crude 'science supply–push' strategy for innovation. The latter is a bastardization of the far more justifiable view that continuing advances in fundamental scientific knowledge have been secured during the past half-century through prior 'investments' in exploratory research; that these were a major determinant of the potential for sustained innovations and productivity advances in the industrial economies; that, further, there is no reason not to expect that, were support for such research to be continued at equivalent levels in those economies, such would continue to be the case in the decades ahead. That should be seen to be quite different from the claim that every government research grant will yield direct and immediate economic payoffs, or should be expected to do so. Unfortunately, the formulaic rationale that government agencies in the post Cold War era have offered for supporting collaborative industrial R&D projects often is couched in just such terms, fostering the impression that tight, highly predictable connections exist between scientific research performed today and innovations, profits, and jobs that will become available tomorrow. What is conjured up is a tidy, linear sequence that proceeds from R&D expenditures, to scientific discoveries, to ideas for applying the latter, to the development of concrete new products and processes, and thence to the commercial introduction of those innovations, their diffusion into widespread acceptance among consumers or industrial users; readily identifiable productivity improvements, enhanced international 'competitiveness', and economic welfare gains then are pictured as flowing automatically from every R&D program, as the day follows night.

One of the more useful tasks performed by social scientists who have been writing on the economics of science and technology during the past two decades has been to try to disabuse people of this particular conceptualization of the dynamics of technological

[5] See, e.g., Dasgupta and David (1994) and other contributions recently surveyed in Stephan (1996). On the central contentions of Dr Kealey's book, one may consult the literature survey by Martin and Salter (1996).

[6] See the review of *The Economic Laws of Scientific Research* by Palfreyman (1997).

progress, by continuing to point out the many logical and factual deficiencies in the picture conjured up by the so-called 'linear model'. Science supply–push doctrine would have us focus attention and policy action exclusively upon the first link in the sequence envisaged by the linear model. Yet, it is not hard to see that this rests on an implicit assignment of 'strategic importance' that is quite arbitrary. Inasmuch as research activity requires scarce resource inputs—whether those invested from the capital and retained earnings of private firms or expended by the state out of its tax revenues—the last stage in the sequence portrayed by the linear model, in which more economic output is delivered for the given direct input of resources used in production, could be just as easily depicted to be temporally antecedent to the (ensuing) round of research outlays. In other words, what we are really dealing with should at very least be conceptualized as a recurring, circular process—strictly, a recursive dynamic system. To cut into the supposed uni-directional flow around this circle at any arbitrary linkage-point can serve to elevate one, or another of the activities (fundamental exploratory research, development, commercial innovation, marketing, etc.) into the star role as 'the initiator' of the sequence. That, plainly, is a rhetorical device that can be, and has been deployed effectively on behalf of the special interests identified with the activity thus selected. But it is not a sound basis for economic policies designed to increase the pace of technological advance and productivity growth. For economic analysts to dispose of what may be termed the 'vulgar science-push theory of economic prosperity' it has been quite sufficient simply to re-emphasize a piece of common-sense wisdom: if one is dependent upon a chain of activities, it will pay to attend to the soundness of all of its links, especially to the weakest among them, rather than looking only to the one that has been assigned the initiating position within the sequential arrangement. For this, and other compelling reasons, the 'simple linear model' has in recent years come to be the favored straw-man among economists and others writing on science and technology policy. [7] As is to be expected, it comes in for a proper thrashing from Dr Kealey.

But, instead of discarding the linear model as too simplistic, or reformulating it into a more complicated dynamic structure with counter-flows and feedback loops of the sort that have been suggested in the literature, the opening chapter of *The Economic Laws of Scientific Research* presages its author's conclusions by proceeding to stand the whole construct on its head. Adam Smith's authority is invoked to argue that all causal influence flows from the market, via the inducement of innovation, and thence, via the exploitation of specialization and division of labor, to invention and the discovery of new scientific principles. This is not just an illustration that expectations can make it possible for the direction of influence to flow backwards, counter to the direction assumed natural in expositions of the linear model. Dr Kealey's book asserts that historical experience and modern day observation can be used to demonstrate the unique validity of his upside-down construct, thereby proving that public sponsorship of basic scientific research is redundant because "advances in science flow from the technological advances made by industrialists" (p. 8). The latter has been shown to have been the case in many instances, but attempting to present it as the singular form of the nexus between scientific and technological progress does not qualify as an advance in thinking. It is nothing but the substitution of a different, equally naive linear model: the 'free market demand–pull' theory of economic growth via induced technological progress. To this Dr Kealey would append the optimistic faith that if government does not intervene, the signalling of commercial demands for new technologies by the price system automatically will inspire and direct the discovery of whatever scientific knowledge business firms might need to render feasible and profitable the further elaboration and exploitation of those technologies.

What, then, is the substance of the argument supporting the faith announced by this book? Actually, there is remarkably little discussion of what decentralized market systems do and how they do it, and a lot about how the State invariably gets it wrong. According to Dr Kealey's simplified version of economics, finance and production are one and the same thing when undertaken by government;

[7] For a now classic critique of the 'linear model', see Kline and Rosenberg (1986); further discussion appears in David (1993).

there is no need, therefore, to distinguish between the consequences of public funding of R&D in universities, and the performance of state management of scientific research in government laboratories and institutes. Further, since it is clear to him that government made a shambles of British Rail before it could be rescued by privatization (p. 247), readers also are expected to accept that government funding of university-based civilian research (and education) at the taxpayers' expense, similarly, must be equivalently inefficient. Business-funded R&D is always efficiently conducted, he says, especially when it is carried on in corporate laboratories under conditions of secrecy. This logic strikes Dr Kealey as so compellingly self-evident as to require no further substantiation for his conclusion that state patronage of academic science (in the UK, at least) is just another instance of the foolishness of 'nationalizing' activities that would be far better run by private enterprise.

The real task of his book, therefore, is the marshalling of evidence combed from economic history and the history of science, along with contemporary quantitative evidence and economic analysis, in order to establish three more original and radical empirical propositions that would argue for the remedial 'privatizing' of all civilian research. These are ultimately codified (in Chapter 10) as the foundational 'economic laws' supporting Dr Kealey's calypso science and technology policy recommendations:

1. Under capitalism private business incentives to innovate, and the philanthropy engendered by the vast accumulation of private wealth in few hands, increase automatically with rising per capita real income, bringing increased funding for R&D. History shows that this process has provided society with all the scientific and technology that it requires, save that which the State might have to procure to fulfil its naturally delimited purposes such as the maintenance of public order and military defense. Such is the burden of the First of the three 'Economic Laws of civil R&D funding' from which the book's title derives.
2. Not only is government funding in this sphere unnecessary, it is positively detrimental, because increased public R&D displaces the other, private sources of funding. That is the substance of 'Kealey's Second Law'.
3. Indeed, according to the 'Third Law', the displacement effect is so strong that government spending for civilian R&D expenditures (not for military R&D, mind you) causes total civilian R&D funding to shrink in relation to the country's aggregate level of output.

Surely it is a notable achievement of some kind to have plowed through so much economic history and OECD data, and all those economics journal articles, and yet managed to emerge with so erroneous and misleading a collection of generalizations. How, then, has Dr Kealey been able to do it?

4. History and the hunt for 'Kealey's First Law'

General conditions of material well-being, and the extent of human technological mastery and reliable understanding of the natural and artificial environment, may be said to have advanced together over the long sweep of history—surveyed, from the Paleolithic Period onwards, in the first half of Dr Kealey's book. This banality, however, amounts to nothing but the observation of a very broad *temporal correlation*. It cannot be taken to have held within every society and historical era. Nor can it be properly adduced as a ground for regarding the advance of socially useful knowledge to have been the *passive partner* in the affair, always responding swiftly and automatically to market incentives and charitable benefactions—which the author takes to be the inevitable accompaniments of material progress. Yet, the message that greater scientific understanding follows inevitably in the wake of improved technological practices, rather than preceding and forming a foundation for them, is the central motif of the author's selective survey of history of human civilizations up to the mid-nineteenth century. One dimension of the selectivity of this curious exercise is its allocation of one paragraph apiece to the civilizations of China and India, and the omission of Persia altogether. The less said here the better in regard to the book's breezy rendition of the cultural and technological developments of classical antiquity and the medieval West; for, it is fairer to acknowledge that the author is more seriously concerned with the

lessons for the present that might be drawn from the subsequent European experience of industrialization and the beginnings of sustained economic growth.

4.1. Misunderstanding the different roles of science in two industrial revolutions

Under that heading, Dr Kealey quite correctly reports (pp. 60–89) that among British economic historians there is a long-standing consensus that the Industrial Revolution of the late eighteenth century was not propelled by any significant investment of the country's resources in organized scientific and engineering research, and that the accelerated pace of technological innovation drew only slightly upon *contemporaneous* advances in scientific knowledge. His treatment, however, ignores the existence of long lags in the application and consequent economic impacts of advances in scientific knowledge: Chapter 6's discussion of the Industrial Revolution completely glosses over the point made by a number of economic historians and historians of science that, whereas *current* science was of limited commercial relevance, the industrial invention and engineering applications of the second half of the eighteenth century were grounded firmly upon the prior codification of the principles of mechanics that had occurred, and had become especially widely diffused in Britain during the preceding century.

For the benefit of those who might doubt that Dr Kealey's conclusions about the eighteenth century apply equally to the dynamics of science, technology, and economic growth in the twentieth century, the same message is further elaborated by his treatment of "Economic history since 1870" (Chapter 7). There it assumes the form of two, equally easy generalizations. First, the pace of long-run economic development tends to be swifter among nations who start from comparatively low levels of average income, enabling them to catch up with the higher per capita income countries (pp. 96–98). Second, rising levels of per capita income will lead to increased funding for R&D, both in absolute and proportional terms. Both parts of this argument contain half-truths, but these do not add up to the truth of the proposition as a whole. The need to amend his initial statements pertaining to the first part of the argument is acknowledged, subsequently, when Dr Kealey (pp. 104–105) says this only becomes applicable when a poor country has "made the cultural leap into capitalism". That is not entirely true either, but, it suffices here to accept the generalization that among the OECD countries there has been an historical tendency toward upwards convergence of the levels of real per capita output (and labor productivity), and that such convergence has been especially pronounced during the second half of the twentieth century.

The element of truth contained in the argument's second part is that in the modern era there is some positive correlation between national levels of economic development, and the proportion of aggregate national income or product that is spent for organized research. A broad quantitative association of this sort is implicit in the history of the West surveyed by Dr Kealey, and it also may be observed more concretely from contemporary cross-country statistical comparisons. Even within the restricted compass of the OECD statistics, it may be seen that in the low-income countries an almost vanishingly small fraction of the gross domestic product is devoted to the organized performance of civilian R&D. [8] Moreover, the economies of modern day Turkey and Portugal, which in 1985 stood at the bottom-most rungs of the per capita GDP ladder along which the OECD countries were ranked, were approximately at the average real income levels attained back in 1870 by the then richest nations in the world. On a rough reckoning for the latter date, the level of per capita GDP (evaluated in US prices of 1985) in Britain and the US, respectively, lay close to the upper and the lower ends of the range from $1500 to $1150. Viewed from this perspective, the state of economic (and technological) development that prevailed more uni-

[8] In 1985, for example, the low-income countries' gross domestic output (GDP) per capita, evaluated in US prices of that year, were still well below the $2500 mark ($2032 in Portugal, and $1057 in Turkey, according to the *OECD Economic Survey* data reported by Table 10.1 of Kealey, 1996, pp. 254–255). The corresponding estimates for the civilian R&D as a fraction of GDP lay in the range from 0.003 to 0.002. In Greece, where the level of GDP per capita was closer to the $3300 mark, and thus 50% higher than Portugal's, the fraction spent in performing civilian R&D was the same, at 0.003.

versally in the preceding historical epoch—the one from which Dr Kealey would have us draw many lessons for current economic policy—is one that at could be said at very best to have approached that of the world's poorer nations today.

To be sure, science in those former times was pursued as a comparatively novel and newly valued cultural activity, one that competed for resources along with religion, literature, music, and the plastic arts. The small scale of expenditures upon research inquiries into the natural and the 'made' worlds well might be expected to have grown somewhat faster than the level of aggregate production and income, as is generally found to be the case with 'luxuries'. But this tendency would be realized only when and where the average level of income and its distribution within the society put sufficient resources into the hands of those with the tastes and interests to indulge in these diverting, and sometimes useful activities—whether through private initiatives or under the aegis of State patronage.

Dr Kealey's book sketches the general outlines of that historical phase plainly enough. What persistently eludes notice in his text is the very different story of science in the epoch that followed, the very one for which his 'laissez-faire science' policies are being prescribed. It has been during the era of the Second Industrial Revolution that scientific analysis and experimental methods were applied regularly in company-run laboratories, government research institutes, and found a secure place within the elite universities. There they began to draw sustained support on a scale that, in the course of the twentieth century, has transformed organized R&D into a reliable source of technological innovation, medical advances, and enhanced productivity—over the long run. The relationship between economic development and the pursuit of scientific research that obtained in Britain, the US, and France in the mid-nineteenth century, and even that which might be thought to obtain still in the low income countries of the world, is thus a far cry from the complex interdependencies between investment in scientific research and economic growth that presently characterizes the situation of the industrially advanced societies. Moreover, it is precisely the latter group of countries that are funding and performing most of the world's R&D.

Despite this, only one thing seems to strike the author forcibly when he contemplates the differences between the two epochs—or, for that matter, when comparing the situation of Portugal or Turkey with that of Switzerland or the US. What his book takes to be crucial is simply the existence very large associated differences between the levels of per capita real output. In both contexts the magnitude of the gap in real gross domestic product (GDP) per capita is huge indeed: for example, by 1985, per capita income (in 1985 US prices) had risen to about $15 000 in both Switzerland and the US, about six to seven times the contemporaneous levels in Turkey and Portugal, and it is striking that the former pair of countries at the time were spending a correspondingly higher proportion (upwards of 1.7%) of their GDP on civilian research.

What significance should be read into such correlated contrasts? According to the tenets of calypso science policy, the governments of Turkey and Portugal are not to worry about their science and technology infrastructures; Kealey's First Law assures that everything will be attended to automatically, indeed, magically—because 'capitalism' causes economic growth, so they can expect to catch up with the leaders. Moreover, providing only that the politicians do nothing whatsoever, scientists in those countries will get their hands on the proper share of the resulting 'wealth'. [9]

Drawing any causal inferences—let alone general policy recommendations—from cross-country comparisons made across such disparate circumstances, is likely to be terribly misleading. That is so, especially, when the comparisons in question have turned up the simpler sort of macroeconomic 'empirical regularity' that often seems to carry special appeal for people who have trained in the natural sciences.

[9] Throughout the book the terms 'income' and 'wealth' are used interchangeably, as has become fashionable among British economic journalists. Academic economists will find it disconcerting, for, they are wont to drill it into the heads of undergraduates that income is a flow-concept, whereas wealth is a stock-concept, and that much confusion may arise when these two are mixed up. Dr Kealey, evidently, is writing for an audience untroubled by such conceptual niceties, and teachers tempted to assign the book to undergraduates should be wary of this.

Here the case in point is the broad correlation that Dr Kealey has taken for 'a general law', and described in the following seductively straightforward way (p. 106): "Rich countries spend a higher percentage of their GDP on civil R&D than do poor ones". This wording suggests it is self-evident which of the two variables is the cause, and which the effect. Nevertheless, the author lays hold of some statistical tools in an effort to nail down 'Kealey's First Law'—which would assure us that higher and higher R&D expenditure will emerge under complete laissez-faire, as an automatic consequence of rising levels of per capita real income. He begins with a simple scatter-diagram (Fig. 7.13, p. 107): along the horizontal axis of which (where it is conventional to locate the supposed causal, or 'explanatory' variable), Dr Kealey has plotted the 1985 OECD statistics for each of the 21 member countries' respective levels of per capita GDP (also measured in 1985 US prices); and along vertical axis (the conventional placement of the 'dependent' variable) are plotted the corresponding national percentage shares of civilian R&D in GDP.

The existence of a positive association between the two variables is evident, just from the orientation of the resulting scatter of points—which rises upwards and to the right (see Fig. 1). Thus encouraged, Dr Kealey underscores the positive correlation by showing the upward-sloping straight line that he has 'fitted' to this data (using the statistical technique of least-squares regression), and accompanying notes to the figure reports the bivariate relationship to be statistically significant.

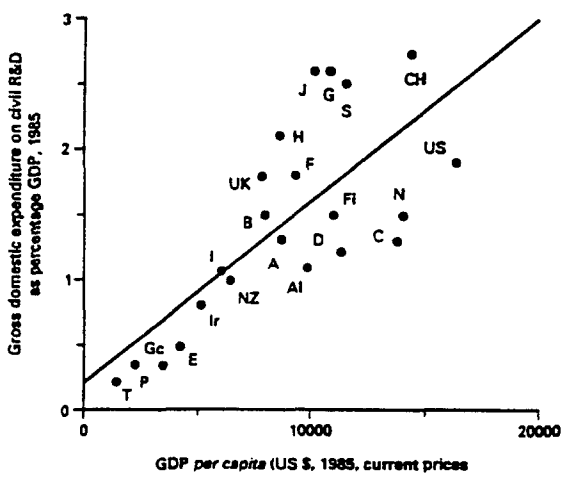

Fig. 1.

Now, even those who have not passed an 'A-level' course in statistics might get a hint that something about this is awry. The ('best-fit') line that has been put through the points in Fig. 1 (Dr Kealey's Fig. 7.13) plainly predicts a positive R&D share (near 0.25 percentage points) for countries in which the level of income per capita essentially is *zero*. Does this reveal that academic scientists around the world are now so greedy that they will successfully lobby government for at least some of your very last pennies? Or should Dr Kealey's econometric results be read as showing that some level of research effort must be reached before it is possible to produce any income at all? The correct conclusion, of course, is: "None of the above, thank you". Readers who are not so intimidated or otherwise impressed by this econometric apparatus that they fail to study the scatter-diagram, will be able to see that the straight line supposedly confirming Dr Kealey's First Law, actually, does not describe the 1985 international cross-section data at all well. For one thing, it 'explains' less than half of the variation present in the data points. [10] Secondly, the thing that is seriously wrong with the statistical version of 'Kealey's First Law' will become utterly obvious upon examining the scatter-diagram a little more closely. Among the group formed by the seven OECD countries whose per capita incomes range *downwards from $7500*, and whose civilian R&D shares of GDP range downwards from 1.0 percentage points, there is, indeed a very tight, upward-sloping linear relationship between the two variables. Yet, as soon as one moves into the portion of the diagram that lies above and to the right of that region—where the observations for all the industrially advanced countries are

[10] The coefficient of correlation reported by the notes accompanying Fig. 7.13 (see Fig. 1) is $r = 0.7$, which implies that the proportion of the sample variance accounted for is $r^2 = 0.49$.

ble for the level per capita real income to double within a span of 60 years—just *through long-term increases in TFP brought about by advances in technological knowledge alone.* One can correct the mistaken impressions conveyed in Dr Kealey's book, by comparing the latter achievement with that of the era of the Industrial Revolution: then, at the prevailing slow pace of growth in TFP (between 0.3 and 0.5% per annum, even when measured generously), it would have been necessary to wait, on average, about 200 years for a doubling of living standards attributable to the advance of technological knowledge alone. Gauged in scale of individual human experience, that is approximately the inter-generational span that would have intervened between the birth of a baby girl and the birth of her great-granddaughter—supposing, improbably, that she, and the two intervening girls all would have been lucky enough to survive the high mortality rates of the era of the Industrial Revolution and give birth to a first daughter upon reaching age 25!

Although *The Economic Laws* at other points shows its author's awareness of the magnifying power of growth at compound interest, the text's casual suppression of seemingly minor quantitative details (such as differences in growth rates) invites casual readers to ignore the potentially disastrous consequences awaiting the modern industrial society that fully embraced the author's viewpoint and implemented his recommendations. It would have been difficult, before encountering this book, even to have imagined that anyone would seriously advocate a program of economic growth for Britain in the coming century that applied strict laissez-faire principles in regard to all civilian science and education; harder still, indeed, to believe that this could be attempted by pointing to the circumstances of Britain's triumph in the First Industrial Revolution, and assuring skeptical readers (p. 82) that a public policy prescription good enough for the late-eighteenth century would be found to serve no less well in attending to the nation's present and future condition.

4.2. Why stop with misuse of history, when you can misuse economic historians too?

Dr Kealey's appeal to history is by no means restricted to the quantitative macroeconomic bits. He manages also to find ample grist for his mill in the economic history literature devoted to the underlying, microeconomic processes. In too many of these instances, however, a closer look at the specific studies that are cited will disclose (as the text does not) that their authors' conclusions are diametrically opposite to the assertions that they are being used to corroborate. As these are matters in which the devil dwells in the details, only two illustrations of this technique in action will have to suffice on the present occasion. The first of these arises in connection with Dr Kealey's novel suggestion that the major long-term benefits of free trade are to be seen not in the statistics of international trade, but, instead, in the movements of the data on patenting activity. In support of his contention (pp. 128, 212) that the threat of import competition will "encourage a company to innovate [out of] the fear that the competition will steal a market with an improved product", the author appreciatively cites a 1988 *Journal of Economic History* article by an American economic historian, Kenneth Sokoloff (Sokoloff, 1988). The reader is told that this is a fascinating study that has exploded "the protectionist myth" and "demonstrated empirically [that] imports (even subsidized imports) stimulate domestic invention", by showing that in the US during the early nineteenth century, the number of patent filings per capita increased in counties that were reached by a navigable river or canal.

All but the very last bit of this will be news to Professor Sokoloff, who, if we are to believe Dr Kealey, has utterly missed the significance his own research. Presumably, it was the opportunity to correct that 'oversight' that encouraged Dr Kealey to ignore the extensive arguments and collateral evidence that the paper's author had marshalled to support quite another set of propositions about the effect of trade on inventive activity. Professor Sokoloff's article says that it was the prospective access to wider (export) markets, and to bulky, raw materials—both of which were opened by cheap waterborne transportation—that induced manufacturers to locate production in those inland counties, and thus drew footloose inventors to congregate in close proximity to the enterprises that might make use of their patentable ideas. The issue in this is not the validity of Dr Kealey's notions about the effects of

free trade in commodities upon business investments in R&D, but, his cavalierly misleading invocation of Professor Sokoloff's 'authority' in support of those speculations. The abuse in this is all the more 'patent', one might say, because the main thrust of the cited article was to show the role of *expected demand* in stimulating inventive activity. Indeed, so far was the thesis argued by Professor Sokoloff from Dr Kealey's free reinterpretation, that his journal article explicitly identified the major factor responsible for stimulating the sharp rise in the level of US patenting activity after 1815 as none other than *the protection of American manufacturers from the competition of British imports* during the preceding period! [15]

A second illustrative example of Dr Kealey's misuse of the work of quantitative economic and social historians appears at the very end of this book, where readers are offered a "Postscript on education and the free market" (pp. 347–353). This displays the author's complete mastery of a variation on the basic technique—plucking out a particular historical nugget to produce as evidence for a view that blatantly ignores other facts and conclusions reached in the source from whence it has been drawn. "The history of education", writes Dr Kealey,

> parallels to a remarkable degree the history of science funding, and that history disproves the suggestion that government need be involved. One of the first countries to boast a fully literate population was Britain, which by 1891 enjoyed 100 per cent literacy amongst its school-leavers.... Yet, up to 1891, education in Britain was largely *laissez faire*. (p. 347)

A bit further on, the text remarks that "church and private-school attendance reached 99 percent" during the 1860s, a condition that is said to have permitted the passage through the House of Lords of the Education Act of 1870—because the bishops sitting there no longer felt any need "to block state competition with the church schools" (p. 349). An otherwise uninformed reader would have to be forgiven for surmising from this that the introduction of state-schooling in Britain had been an entirely redundant gesture. [16]

Now, immediately following his statement about the illiteracy rate among Britain's school-leavers in 1891, Dr Kealey has supplied a supporting scholarly reference to an article by the Cambridge historical demographer Roger Schofield: "The dimensions of illiteracy, 1750–1850". [17] Although Dr Schofield's study was focused on a somewhat earlier period in the history of illiteracy, it does contain a chart displaying the annual statistics compiled by the Registrar General of England and Wales for the percentage of males and females unable to sign their name at the time of marriage. From that information (and Dr Schofield's estimate that in this period the mean interval between school-leaving and entry into marriage was approximately 15 years), one may confirm the rough accuracy of rounding down to zero a 1–2% illiteracy rate for the cohorts who left school c. 1891. [18] But, something more can be inferred from the same chart, about which Dr Kealey's text remains mute. Only a few decades earlier, which is to say, prior to the Education Act of 1870, the situation prevailing among English and Welsh children of school-leaving age had been very different: 15 years after 1860 the proportions of brides and bridegrooms unable to sign their name to the wed-

[15] This protection was a consequence of Jefferson's Embargo Act of 1807, and the ensuing legislative measures restricting trans-Atlantic commerce, culminating in the further disruption of trade with Britain during the War of 1812. The era of deliberately protectionist tariff legislation in the US commenced later, with the Tariff of 1824, but the movements in the patenting statistics thereafter do not conform with the collapse of inventive activity that Dr Kealey's theory would seem to predict.

[16] That impression is soon reinforced by the author's flat rebuttal of the statements made by Barnet (1986) in *The Audit of War*, that "In the 1860s there were still fewer children in grant-aided elementary schools of efficient standard than there were children receiving no form of education whatsoever". Such statements, says Dr Kealey, "are deeply misleading, and they flow from an appalling deception of the House of Commons" practiced by advocates of "the monstrous Elementary Education Bill" introduced in 1870 (p. 251).

[17] In Dr Kealey's citation, however, the dates have been omitted.

[18] See Schofield (1973, p. 442). The chart shows that illiteracy lay in the 1–2% range for the men and women who arrived at the altar in 1905–1906, so it may be surmised that this reflected their illiteracy rate on leaving school 15 years earlier. Dr Kealey says it was nil, but, in this case, there is no point to quibbling over a difference of percentage point or two.

plotted—the scatter of points suddenly balloons outwards. [11]

Thus, in 1985 Belgium and the Netherlands both spent about 1.55 of their GDP on civilian R&D; per capita income was around $8500 in the former, whereas it stood close to $14 000 in the latter country. In Australia, as in Japan, the level of per capita income at the time was close to $10 000, yet, Japan spent more that 2.5% of its GDP for civilian R&D, whereas the corresponding share in Australia was little above 1%. The shape formed by the points in Fig. 7.13 can be visualized most readily as that of a *dandelion, leaning to the right.* Such validity as there is in Dr Kealey's First Law, therefore, refers to what goes on in the *stem* of this dandelion, and *not in its flower*. Moreover, to continue in the same metaphor, the author's entire extended discussion of the relationship between scientific research and economic development before and during the First Industrial Revolution, amounts to searching *at the lower-most end of that dandelion's stem* to find evidence supporting the laissez-faire science policy prescriptions he favors. Although this reviewer has never been one to turn scientists of any sort (natural or social) away from the serious study of historical experience, it would seem considerably more sensible in the present case to have paid closer attention to the dynamics of the processes that have brought that dandelion into flower.

This book's treatment of the evidence of macroeconomic history has thus been seriously distorted by the omission of notice of the body of recent work in which economic historians have shown 'modern, sustained economic growth' to be a process that has undergone some striking transformations during the past 200 years—in both its quantitative dimensions and proximate sources. Sensible historical research intended to inform contemporary policy decisions cannot approach the study of capitalist growth dynamics as though it has remained essentially all of one piece; it is a badly mistaken optimism that would prescribe for the present and future so simplistically, by pointing to institutions and policies that appear to have worked well enough for an earlier age. Yet, that is just the approach embraced by Dr Kealey. The record of long-term economic growth in Britain since 1700 is presented (pp. 94–95) as conforming to a pattern which "in capitalist countries is characteristic". Looking at the Angus Madison (1982) compilation of the estimates of per capita real output, Dr Kealey sees Britain's long eighteenth century as "a preliminary period [when] a country emerges from late-feudalism [*sic*] into capitalism, during which growth rates slowly accelerate, followed by a sustained period of constant growth rates"—continuing up to the present era. Putting aside Dr Kealey's possibly inadvertent, but nonetheless oddly Marxian fantasy of the English Civil War having been a "late-feudal" conflict, we may acknowledge the part of this generalization which is true enough: during the past 100 years the levels of real output in the leading industrialized nations have been rising at average growth rates in the neighborhood of 1.6–1.9% per year. [12] But, *pace* Dr Kealey, this was not the standard of economic performance achieved during the era of the Industrial Revolution; in Britain and the US during the canonical period 1780–1860, the average pace at which output per capita was rising has been estimated at less than 1.0% per annum.

[11] As a result, the variation of the actual points above and below those 'predicted' by the regression line that Dr Kealey has fitted is very much larger, absolutely and proportionally at the high-income end than it is at the low-income end. This condition is described by statisticians as one of 'heteroskedasticity', which, in addition to being hard to pronounce, constitutes a violation of the assumptions of the method of least squares regression, and signifies that the linear equation estimated by the author contains a serious specification error. Were that not enough, the notes accompanying Fig. 7.13 contain a mathematical formula—supposedly corresponding to the regression line—that is, on its face a complete nonsense. Although harmless for being so self-evidently erroneous to anyone who would be interested enough to read it, this reporting error seems hard to account for merely in terms of the vagaries arising from poor typesetting and inattentive proofreading. Similar reporting errors appear in the book's Figs. 7.9, 7.11, 7.12, and 7.14; and everything that is wrong with Fig. 7.13, including the mathematical misstatement, also is wrong with Fig. 10.3.

[12] The experience of the UK during what sometimes is referred to as The Second Thirty Years' War (1914–1945) pulled its average long-term trend growth rate for the whole century down, closer to 1.3% per annum. But, in the 1870–1913 and 1950–1973 intervals, the British economy attained the 'characteristic' modern growth rates cited in the text.

Why quibble here over a difference of something considerably smaller than a percentage point in the growth rates, between the period of the First Industrial Revolution and the more recent epoch beginning towards the close of the nineteenth century, which has been dubbed that of the 'Second Industrial Revolution'? Well, in the case Britain, the difference between the modern average growth rate of per capita real output of 1.5% per annum and a rate that averaged 0.5% per year (during 1770–1841), or 0.9% per year (during 1815–1841), translates into a difference between doubling average living standards within 46 years, instead of over spans as long as 133 or 77 or years. Similarly, the acceleration of the US average annual growth rate from 0.9 over the period 1800–1855 to the neighborhood of the 1.8% per annum rate (maintained from the late nineteenth century onwards), in effect, shortened the doubling time of average living standards from 77 years to 38 years—allowing the latter improvement to be enjoyed twice within the modern expected life-span. [13]

A second, even more striking historical transformation involving the growth of productivity, has been glossed over completely in this part of the book. The author takes considerable pains (pp. 85–86, 100–103) to point out that the long-term rise in per capita real income in the twentieth century has come through increasing labor productivity, and that the rise of labor productivity has derived mainly from "technical change in the widest sense". Further, he explains how economists and economic historians try to gauge the latter, by measuring the rising productivity of all the productive inputs combined, which they label *total factor productivity* (TFP). Yet, the general reader who will benefit from this exposition will be misled by the lack of notice given to the changing quantitative dimensions of the growth of TFP in the leading industrial countries of the West since the closing decades of the nineteenth century. In earlier times, the other principal paths to faster per capita income growth—saving more in order to speed up the accumulation of tangible capital goods, and getting more work out of the population—had played far bigger roles in the drama of economic development than they do today in the industrially advanced economies. Thus, the most carefully conservative estimates of trends in TFP for the US private domestic economy show its long-term rate of increase was approximately 1.5 percentage points per year over the period stretching from the 1889 to 1969. Inasmuch as that was precisely the era during which the US became world's industrial leader, that rate may be taken as indicative of the pace at which the advancing frontiers of knowledge were being translated into "technical change in the widest sense".

These economy-wide productivity estimates reflect the dramatic acceleration in the pace of technological progress that already was under way as the nineteenth century drew to a close, and the Second Industrial Revolution began to gather momentum—signalled qualitatively by the emergence of a succession of radically new products and industrial processes based on applications of electricity, organic chemistry, bacteriology, internal combustion engineering, aerodynamics and avionics, and the use of the electromagnetic spectrum for (wireless) communications. Indeed, the rate of growth of TFP in the technologically leading countries during most of the century following the early 1880s has been three to five times faster than the pace of advance achieved in Britain and the US during the period 1780–1860. [14]

Undoubtedly, the dominant developments in that profound transformation are the direct and indirect consequences of the great expansion of public and private 'investments' supporting science and the pursuit of science-based technological knowledge in the West. Gathering momentum since the closing decades of the nineteenth century, these have made it possi-

[13] For recent estimates of British growth during the Industrial Revolution, see Harley (1982, Crafts (1985), and Crafts and Harley (1992). For estimates of pertaining to growth in the US during 1790–1860, see Abramovitz and David (1973), Abramovitz (1993), and David (1996).

[14] Recent estimates by economic historians (see Abramovitz and David, 1973, Crafts and Harley, 1992) have established the definitive range from 0.3 to 0.5% per annum for the growth of TFP during the period 1780–1860, in the case of Britain, and 1800–1855 in the case of the US. Most of these findings have appeared in the decade-and-a-half following the publication of the undergraduate textbook that Dr Kealey consulted on this issue. See the reference (p. 87, Table 6.1) to McCloskey (1981).

ding register had stood at 17 and 23%, respectively; and, proceeding on the same basis one can see that at the end of that decade, on the eve of the Education Act, illiteracy rates among those of school-leaving age in England and Wales still must have been running at close to 12–13%. That figure, of course, must greatly understate the degree of illiteracy among the working age population at the time. [19]

From the Education Act of 1870 onwards, however, government provision of schooling drove illiteracy precipitously downwards, while raising the general standards of schooling (attendance, length of school year, scope of the curriculum, qualifications of teachers). More than one economic and social historian of Britain has argued that this new departure had come not a moment too soon, and Dr Schofield might well be counted among them. The very article that Dr Kealey has cited concludes with the observation that by the time state schooling was initiated, Britain already had passed beyond the era (1750–1850) in which the decline of illiteracy could be considered "more as a cultural change brought about by economic growth"; economy and society in Britain were entering the present epoch, in which the direction of former causal relationships were reversed; the furtherance of universal education was emerging (in parallel with intangible investments in organized scientific research) as a new and increasingly potent force for the continuation of modern economic growth. There is indeed a striking parallelism to be read in the histories of public support for science and for education, but, in Dr Kealey's book the similarities in timing and significance are achieved by a parallel distortion of both stories.

5. 'Kealey's Second and Third Laws'

It is understandable, perhaps, that after delving so uncritically into the economic and social history of eighteenth and nineteenth century Britain, one might come away (as Dr Kealey has done from his researches for Chapters 2–7), quite unable to perceive any vital role for growth-oriented programs involving major commitments of government funding in the spheres of science and education. [20] Something further, however, has made it possible to sustain that conviction when studying the world we have gained, rather than the worlds left behind. This further ingredient is the consistent disregard which Dr Kealey displays for the use of 'controls' when seeking to extract conclusions from statistical data, as well as a proclivity to misconstrue the import of theoretical analyses that turn on quantitative propositions. The core of this performance (in Chapters 9 and 10) truly is most remarkable—especially so from an author professionally trained in the methods of the natural and life sciences. His production and application of the Second and Third Laws, in particular, relies upon a special gift (intimated in Chapter 7) for demonstrating almost all the ways in which the statistical method of bivariate regression analysis can be misused, misinterpreted, and misreported (pp. 107–108, 241–243).

To learn whether or not the funding of public and private R&D behaved as *substitutes* (the growth of one displacing the other), one would have thought that a quite straightforward approach would be to examine those variables' joint movements—while holding constant ('controlling') as many other background conditions as was feasible. A very simple way to do this is to look at a number of national economies that perform substantial amounts of R&D and see if it is true that within some given time interval those countries in which government fund-

[19] Consider: among the boys and girls who had left school some 30 years earlier in the century (i.e. c. 1840) rates of illiteracy in England and Wales had ranged as high as 30% and 40%, respectively. Statistics of the same kind for Scotland show that at this time the rates of illiteracy among cohorts of school-leaving age were as low as 11% and 23%, respectively. See, e.g., Cipolla (1969). One can only wonder how Dr Kealey would propose to explain such different outcomes from these two educational regimes, inasmuch as the distinctions between them are obscured by his categorization of "education in Britain" as having been "*largely laissez faire*".

[20] Students of US economic history, however, will have some trouble with Dr Kealey's misapprehensions concerning the role of government in the economic development of that nation. For one thing, the only 'government' he can see is federal, which leaves the significant impact of state and municipal governments—in areas ranging from education to transportation—entirely out of his picture.

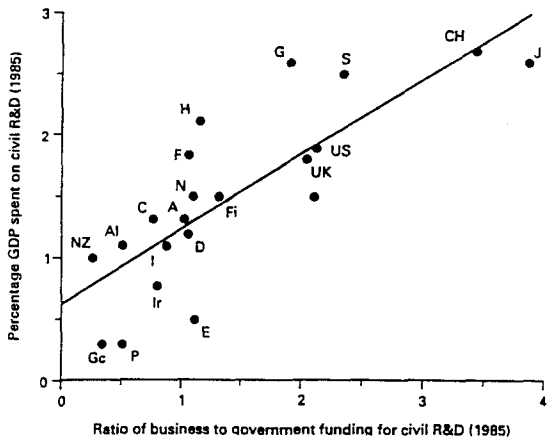

Fig. 2.

ing of civilian R&D increased faster, also were the ones in which privately funded R&D was growing more slowly. If there was a 'super-displacement' of private R&D by government civilian R&D, in conformity with the so-called Third Law, it would be seen that growth rates of total civilian R&D spending (adjusted for price changes) were higher in those economies where the public funding had increased most slowly. Dr Kealey apparently omitted to try a test of this sort.

Instead, he has arrayed international cross-section data for the OECD countries in 1985 in the following graphical way (Fig. 10.1, p. 241): the percentage of its gross domestic product (GDP) spent on civilian R&D each nation is plotted along the vertical axis of the graph, and along the horizontal he plots the country's ratio of business R&D spending to its governmental funding of civilian R&D. Some positive association appears in the resulting scatter-diagram (see Fig. 2). For example, in two nations, (Japan and Switzerland) civilian R&D's share in GDP is very high, over 2.5 percentage point, and the contribution made by the business R&D component is 3.5–4 times as large as that coming from the public sector; at the other extreme, there are countries (such as Turkey and Portugal) where civilian R&D expenditures amount to only a bit more than 0.25% of GDP, and the business component is only approximately half that provided by the government. In some 15 other countries, this pair variables take on values intermediate between the extremes just described.

On this occasion, the text (p. 241) pauses properly to acknowledge that the mere presence of a statistically significant positive correlation in this set of cross-section observations is not quite sufficient to prove the claims of 'Kealey's Second and Third Laws'; something further is needed to be able to say that where the ratio of government to business funding is high (e.g. Turkey and Portugal), this is *causing* total civilian R&D funding to remain very small in proportion to GDP. Why is the opposite interpretation not the more plausible? Even a low level of governmental R&D expenditures could appear relatively large in these low-income economies, and might be undertaken *because* private R&D investment there had remained so small. Indeed, when one looks carefully at the points plotted in this graph, it is evident that they do not even suggest that the these two variables are causally linked by some simple, linear relationship. For example, the R&D share in GDP in Sweden and Germany is essentially the same as that observed in Switzerland and Japan, whereas the ratios of business to government funding in the former pair are much lower, around 2; on the other hand, among the nine countries whose private and public sources of R&D funding are approximately in balance (the business–government funding ratio varying only narrowly between 0.75 and 1.25), the shares of total civilian R&D in GDP range as widely as from 0.5 percentages points to approximately 2.1 percentage points. Anything so simple as the hypothesis of a linear dependence of the share on the ratio appears to be an erroneous specification (again) of the structural relationships that underlie the international cross-section observations.

Nevertheless, Dr Kealey pronounces the upward-sloping straight line ('fitted' by the method of least-squares regression) in Fig. 10.1, to be a satisfactory representation of the data, and then sets forth a theoretical case for interpreting it to reflect the hypothesized 'super-displacement' effects of government R&D funding. Had the statistical methodology of multiple regression analysis been used as a way to control for the concurrent influences of other differences among these countries, such as their differences with respect to levels of real GDP per capita, readers might have been spared at least the ensuing

passages of ingeniously misleading argumentation (pp. 242–250). [21]

Indeed, had Dr Kealey but performed the simplest 'test' that is proposed above, and looked at the OECD statistics for just the G-7 countries (those responsible for most of the capitalist world's R&D) in the period 1981–1993, the dubious character of the so-called Second and Third Laws would have been exposed plainly. Within this sample of high per capita income countries, the cross-country variations in the proportionate growth rate of total civilian R&D turn out to be associated *positively* with the proportionate growth of government funding for non-military research. In actuality, Britain turned out to be singular among the major industrial powers in the West in sustaining a decline in the ratio of real aggregate R&D expenditures to real gross domestic product during the decade of the 1980s. [22] Whereas that ratio rose in Germany from 2.4% to 2.8%, in France from 2.0% to 2.4%, in the whole of the EU excluding the UK from 1.6% to 1.9%, in Britain it slid from 2.3 to 2.1%. In Japan the ratio surged upwards from 2.3% to 2.8%, whereas in the US the share of total R&D was held steady (at 2.6%) by heavy military R&D in connection with President Reagan's 'Star Wars' program, raising worries about the relative 'crowding out' of industrially more relevant civilian R&D. What happened in the UK was more dramatic, because the real level of government funding for civilian R&D was cut in absolute terms, by about 20% over the period 1981–1993, and a relatively slow expansion of R&D expenditures from all other (private) sources turned out to be inadequate to prevent total civilian R&D from growing at more than the comparatively sluggish pace of 1.5% per year. The latter thus fell far below the 3.2% per annum rate maintained by Germany and the US during this period—they being the next most *sluggish* members of the G-7 pack in this regard. One should view the behavior of the public and private components of civilian R&D as *complements and not substitutes*. [23] This certainly offers no support at all for the contention that government support for research over-displaces private R&D investment.

Yet, Dr Kealey proceeds to claim the experience of Britain during the 1980s as a "beautiful demonstration" of his dubious Third Law. Pointing out that increased funding of university research from industry and the medical charities softened the blow dealt by government cutbacks (pp. 285–286), he takes that as sufficient grounds upon which to dismiss (as "simplistic" and lacking any proper empirical substantiation) the concerns expressed over the reduction of government R&D funding at the time, notably by Ben Martin and John Irvine, of the University of Sussex's Science Policy Research Unit

[21] Readers also would have been spared a further piece of bad econometrics (pp. 242–243 and Fig. 10.2). There an attempt is made to show that it is the cross-country variations of the business–government funding ratio that are causing the statistical forecast errors which arise when using Kealey's First Law to 'predict' the cross-section share of total civilian R&D simply from the corresponding 1985 level of per capita GDP. These 'errors', which should be normally distributed around the regression line, are measured as the vertical distance between the actual observations and the corresponding points on the (mis-specified) regression line in Dr Kealey's Fig. 7.13 (see Fig. 1, above). Unfortunately, the statistical procedure that Dr Kealey follows in this exercise contains another classic flaw: in effect, it 'controls' for the influence of per capita income variations only upon the (supposed) dependent variable, the civilian R&D share, but omits to control also for that variable's 'effect' upon the business–government R&D funding ratios in the OECD cross-section data. As one might suspect, however, there is positive covariation between the latter pair of variables; science-based manufacturing industries and, hence, company-financed R&D tends to be relatively less important among countries that fall at the lower end of the per capita income range. No very sophisticated statistical methods would have been needed for Dr Kealey to have confirmed this, even from the data that appear in his Figs. 7.13 and 10.1 (reproduced here as Fig. 1 and Fig. 2). Consider, simply, that among the seven countries ranking highest in terms of the business–government funding ratio, their average rank in the 1985 distribution of per capita incomes was seven, and the median among this group position was held by Sweden, which stood fifth in per capita income among all the countries in the OECD sample. At the opposite pole, among the seven countries for which the business–government ratio was lowest (excluding Turkey, for which this data is not available), the average of country rankings in by per capita income was 14; the median position among the bottom seven was held by New Zealand, which came 16th in the per capita income distribution.

[22] The following figures are based on the data in European Commission's *The European Report on Science and Technology Indicators, 1994* (Report EUR 15874 EN), Table 1.3, 1.7A.

[23] There are a number of very good reasons why this should be the case, as will be noted a bit further on.

(SPRU). With specific regard to the support of university research, the reality of events in Britain simply does not correspond to the impression conveyed by Dr Kealey's insistence (pp. 283–286) that university science was not adversely affected by government cuts during this period, because "stagnation in government grants to the University Grants Committee (UGC) and academic science prompted a resurgence of private funding". There are two points at issue here, one concerning what happened to the aggregate level of university research funding, and the other having to do with the underlying causes and the consequent alternations in the allocation of support among fields. During the 1980s the great expansion of university research funding from the medical charities was an essentially fortuitous offsetting factor, and there is no basis for Dr Kealey's suggestion that the rise in private sector support for academic research was an induced response, supposedly from industry relieved of the burdens of government taxation. Available statistics from the Higher Education Statistical Office show that government finance for research via Exchequer grants and Research Council awards to the 'old universities' (excluding the former polytechnics and colleges) dropped by 23% in real terms over the period 1989/90 to 1992/93. Instead of finance from industry coming to the rescue, the real value of research funds received by these universities from that source contracted by 5.3% during the same interval. [24] So much for the empirical foundations of Dr Kealey's recommendations on the funding of science and technology research.

Were the 'over-displacement effect' hypothesis advanced by Dr Kealey empirically valid as a macroeconomic proposition, one still would have to consider carefully the implications for the composition of research activity of his contention that withdrawal of government support for academic science would have a net stimulating impact. The cuts in government funding over the course of the 1980s and the rise in both the absolute and relative importance of the dependence upon British science for private funds from the medical charities and industry, have had a perceptible impact on the rate and direction of scientific publication activity in the country. But these effects are ignored by Dr Kealey. Instead of examining what did happen following the public sector cutbacks in the early 1980s, his discussion of the issue (pp. 276–280) is devoted to finding fault with the arguments produced by those who warned about the likely effects. In this he makes the valid point that opponents of Mrs Thatcher's policy who presented Britain's shrinking share of the world's scientific publications during the 1970s as a harbinger of 'scientific decline' had overlooked the fact that those statistics were reflecting an upsurge of English language publications in the sciences emanating from Japan and other rising industrial economies. It is equally correct, if somewhat besides the point, for Dr Kealey to fault the critics for failing to emphasize that in 1982 Britain's scientific productivity, gauged by the absolute level of its scientific publications was still robust, and that by this measure British scientists collectively stood second only to the US in each of the major fields of science and engineering.

Of course, it is merely setting up a straw man to construe the talk of an impending 'decline of British' science literally, as a prediction of the imminent collapse in the absolute number of scientific publications by the country's research community. What was of concern at the time was the prospective alteration in the position of British scientific activities vis-a-vis those being conducted by researchers in the other, industrially mature economies. Were those concerns utterly foolish, as Dr Kealey still insists? Far from it. Although his text remains strangely silent about the trends in Britain's comparative scientific publications rates that emerged over the period 1981–1993, these might well be thought to have amply borne out the worries voiced by leading scientists and science policy analysts when the policy of the Conservative government began to take shape. Between 1981/1983 and 1991, Britain's volume of scientific papers *declined markedly in comparison with the rest of the European Union,* as well in comparison with the world at large. More significantly, the fall in Britain's share of European scientific papers occurred across the board, in every major

[24] Some part of the latter contraction is probably attributable to the impact of the recession in 1991/92–1992/93, but there was no rise in industry funding for university research when the government cuts were sustained. The underlying data is discussed in Geuna (1997).

area of the natural and life sciences, mathematics, and engineering. This was the case even in clinical medicine, a field that have been a particular beneficiary of the rise in funding from the pharmaceutical industry as well as from the medical charities, and the sole research area in which Britain maintained its initially high share of the world's scientific output. Thus, by the beginning of the 1990s, in more than half of the major scientific fields Britain no long held its former position as runner-up to the US in the volume of scientific publications. [25] These shifts, and what they might portend for the future scientific base of knowledge and domestic scientific know-how for sectors of the British economy other than those directly involved in health services and veterinary medicine, would seem to justify further careful examination, rather than silence, and the continuing derisory dismissal in this book of those who have worried that, below the continuing growth of the aggregate mass of the nation's scientific publications, all might not be well with the state of the scientific enterprise in Britain.

6. Dr Kealey and the conquest of economic theory

The foundations for the author's thesis that have been provided at the level of microeconomic analysis turn out to be even less substantial—if that really is possible. Dr Kealey's book has confronted the economics of R&D head on, and has defeated it. Economists have worked out cogent reasons why the price system and competitive markets should not be expected to do a good job producing, or distributing knowledge and information—certainly not by comparison with their performance in similarly allocating resources in the case of more conventional, tangible commodities such as fish or chips (of both the computer and the potato varieties). This conclusion rests upon the fundamental insight that ideas—especially ideas tested and reduced to codified scientific and technological information—have some important attributes found in 'public goods', and appreciation of the well-known problems that arise were one to rely upon the competitive market mechanism to provide for pure public goods, such as a smog-free environment, or defense against nuclear missile attack. Rather than systematically examining the factual premises and logic of this line of analysis, the author simply waves away the conclusions, explaining (in a footnote aside) that economists try to reveal "the market's imperfections" in order "to further their own professional importance" (p. 215).

Acknowledging the peculiar character of information as an economic commodity is central to the modern economic analysis of R&D. An idea is a thing of remarkable expansibility, being capable of spreading rapidly from mind to mind without lessening its meaning and significance for those into whose possession it comes. In that quality, ideas are more akin to fire than to coal. Jefferson remarked upon this attribute, which permits the same knowledge to be jointly used by many individuals at once: "He who receives an idea from me, receives instruction himself without lessening mine; as he who lights his taper at mine receives light without darkening me...." [26] Economists, therefore, have pointed out that the potential value of an idea to any individual buyer generally would not match its value to the social multitude. The latter, however, is not readily expressed in a willingness to pay on the part of all who would gain from the illuminating idea; once a new bit of knowledge is revealed by its discoverer(s), some benefits instantly will 'spill over' to others who are therefore able to share in its possession. How, then, could ideas be traded in markets the kind envisaged by disciples of Adam Smith—except by having aspects of their nature and significance disclosed before the transactions were consummated? Rational buyers of ideas, no less than of coal, and fish and chips, first would want to know something

[25] Based on calculations from underlying data from Science Citation Index, in the European Commission's *European Report on Science and Technology Indicators, 1994*, Tables 1.11A through 1.11I. The average contraction in the British share of EU papers was 4.1 percentage points in the 'weak decline fields' (clinical medicine, biomedicine, chemistry, and physics), whereas in the 'strong decline' fields (biology, earth sciences, and space, engineering, and mathematics) the average share dropped by 9.25 percentage points.

[26] Koch and Peden (1972). The excerpt quoted in the text appears in a letter written to a Baltimore inventor in 1814. The entire passage has been reproduced and discussed in David (1993).

about what it is that they will be getting for their money. Even if the deal fell through, it is to be expected that the *potential* purchaser would enjoy (without paying for) some benefits from what economists refer to as 'transactional spill-overs'. These occur because there may be significant commercial advantages from the acquisition of even rather general information about the nature of a discovery, or an invention—especially one that a reputable seller has thought it worthwhile to bring to the attention of people engaged in a particular line of business. This leads to the conclusion that the findings of scientific research, being new knowledge, would be seriously undervalued were they sold directly through perfectly competitive markets; some degree of exclusivity of possession of *the economic benefits derived from ideas* is necessary, therefore, if the creators of new knowledge are to derive any profit from their activities under a capitalist market system. Intellectual property rights, in the form of patent and copyright monopolies serve this end. But, imposing restrictions on the uses to which ideas may be put also saddles society with the inefficiencies that arise when monopolies are tolerated, a point harped upon by economists ever since Adam Smith.

As quite general considerations of the foregoing sort are not presented in this book, it will not come as a surprise to find that the author has also omitted to notice the failure of competitive markets to rise to the special challenges posed by a special category of knowledge products sometimes described as 'technical standards'. These acquire economic value for their possessors *only* as a consequence of being publicly disclosed and jointly utilized, and actually grow in utility for the individual user in proportion to the degree of universality in their adoption. Many technological and engineering 'reference standards', such as those for the thread-sizes of nuts and bolts, or the diameter of optical fiber (to permit splicing without degrading the light signal that is propagated through the inner core), benefit buyers and vendors by reducing transactions costs and permitting economies of scale in production, especially when they are widely adopted. Firms that know of, and wish to use such standards would have every incentive to freely share that information, in order to encourage others to follow suit. Hence, an adequate supply of reference standards and kindred 'infratechnologies' may not be forthcoming through individual private enterprise, as it may not be worthwhile for any single firm to undertake the cost of designing a reference standard that would be most useful for the industry as a whole. [27]

6.1. A scientist in praise of secrecy?

In addition to impugning the motives of those who reason in such terms, Dr Kealey pronounces their entire line of analysis to be devoid of any practical economic relevance. In the course of a deeply confused critique of a technically difficult article by the economist Paul Romer (pp. 230–232), the author comes up with what he believes to be the crushing rejoinder to those who think that new scientific information tends to be undervalued by competitive markets. A given technological idea, he rather triumphantly points out "cannot be 'used in as many different activities as desired' without the intervention of people" (p. 231); like any other human cognitive ability it has no meaning or utility outside a human head. So, new ideas residing in the heads of scientists and inventors, manifestly, cannot be 'public goods' because those people do not possess the characteristics of public goods.

Of course this completely misses the point that the same idea may be socially useful in many heads, even those which did not first conceive of it. Instead, it emphasizes a favorite theme of Dr Kealey's—the value of exclusive possession of technological information: researchers surely are able to prevent others from gaining access to their services, and a person

[27] Governmental support for the collaborative development of reference standards, or direct funding of agencies that undertake such work, such as national standards institutes, constitutes a mechanism for rectifying the effects of this particular form of competitive market failure. The alternative of granting monopoly privileges (under intellectual property rights provisions) to the private developer of a standard has a perverse effect in this particular case: in tending to restrict the extent of the standard's use, it would deprive even those who did pay the monopolist's charges from enjoying the fuller benefits of an enlarged user community. This is a general problem with standards for systems in which there are what economists refer to as 'network externalities'—such as the telephone system, whose value to individual subscribers is enhanced by being able to call, and be called by a larger number of subscribers.

can only do one thing at a time, so, if one firm is employing them at any moment of time, other firms cannot so do. "Good industrial research", according to Dr Kealey, is conducted under conditions of "confidentiality" and "seclusion" (pp. 250–251). Thus, one may supposedly rely upon market forces to make the whole problem go away: universal industrial secrecy is sufficient to rule out the difficulties that otherwise might be caused by some firms 'free-riding' on the R&D investments of others, and to render irrelevant any worries that incomplete private appropriation of the benefits of research would dilute the private business incentives to push R&D as far, and in as many directions as would be socially. QED!

At this point in his theoretical exposition, quantitative empirical issues no longer engage Dr Kealey's attention. He does not pause to consider what costs a strategy of secrecy imposes upon private enterprise; whether such practices can be totally effective in the face of the mobility of technical personnel and reverse engineering; what potential would be created for even greater collective wastage of R&D resources (not to mention injury to consumers), were the developers of new products and processes actually able to maintain indefinite secrecy about their research results. [28] So sure is Dr Kealey of the benefits of industrial secrecy, that his book nowhere discusses the economic logic of extending the protection of the State to intellectual property in science and technology. [29] Modern economic analysis has come to view the granting of patent and copyright monopolies as a sacrifice of the short-run interests of consumers that may be justified by the far greater gains that are expected to result over the long run—from giving creators of new, useful knowledge more secure pecuniary incentives to reveal it rapidly to the public at large. Either this understanding is alien to Dr Kealey, or he does not like it. The only economic function of patents acknowledged in his book is that of generating income which the patentor might use to fund further research (pp. 136–137).

Amazingly, Dr Kealey also seems not to have grasped the still more central point that the progress of scientific and technological knowledge is a cumulative process, one that depends in the long-run on the disclosure of new findings, so that they may be speedily discarded if unreliable, or confirmed and brought into fruitful conjunction with other bodies of reliable knowledge. In this way open science promotes the rapid generation of further discoveries and inventions, as well as wider practical exploitation of additions to the stock of knowledge. The economic case for public funding of basic research rests on that insight; and upon the observation that business firms are bound to be put off in some considerable measure by the greater uncertainties surrounding investment that entails entering into fundamental, exploratory inquiries (compared with commercially targeted R&D), as well as by the difficulties of forecasting when and how such outlays will generate a satisfactory rate of return. In reply to this, Dr Kealey offers only the following reductio ad absurdum: If economists the likes of Kenneth Arrow and Richard Nelson were correct in advancing this now-classic argument (over thirty years ago), profit-seeking companies today would not undertake any R&D of the basic, exploratory sort. But, as some firms do spend money performing basic research, the economists' argument is palpably false (p. 225). That rebuttal just will not do. The proposition at issue here is quantitative, not qualitative; one cannot adequately answer the question "Will there be enough?" merely by saying "There will be some". Economists do not claim that without public patronage (or intellectual property protection), basic research would cease entirely. Rather, their analysis holds that there will not be *enough* basic research—not *as much* as would be carried out were individual businesses (like society

[28] One might think of the tobacco companies' research on the carcinogenic properties of coal tar, and the addictive effects of nicotine, but, there are more benign social costs in keeping knowledge secret. Bell (1937), concluded that for all that Gauss had achieved by the time of his death in 1853, the progress of nineteenth century mathematics was held back by as much as 50 years due to Gauss's commitment of much more to his secret, private notebook. In this scientific diary (not examined until 1898), Gauss indulged his penchant for suppressing key pieces of the apparatus that he had developed on the path to his results, so that even after it existence became known, some time elapsed before mathematicians were able to grasp its full import.

[29] In itself this is quite surprising, given the author's claims (printed on the book's back cover) to have first-hand expertise in research supported by Glaxo, Roche, and other major companies —in the pharmaceutical industry—where patents really do matter!

as a whole) able to anticipate capturing all the benefits of this form of investment. [30]

Several recent economic studies point out that R&D-intensive companies fund some basic research in order to monitor progress at the frontiers of science, to pick up ideas there for potential lines of innovation that may be emerging from the research of others, and also to better penetrate the secrets of their rivals' technological practices. This is the situation as it now exists. In calling it to his readers' attention, Dr Kealey does not stop to ask what will happen in the brave new world that he advocates, where all the business firms really were keeping their R&D results completely secret, and governments stopped all funding of open, academic science? [31]

6.2. *Missing the complementarity between exploratory and applications-driven research*

The gravest deficiency of this book's treatment of the economic analysis of scientific research stems from the author's obsessive attention to the competition for R&D funding that pits applied commercially oriented projects against academic, open science research—a failing forgivable enough in a research scientist living through these times, but less so in one who claims to understand the interrelationship among the various components of the national science and technological innovation system. Resources are limited, to be sure, and in that sense research conducted in one field, and in one organizational mode is being performed at the expense of other kinds of R&D. But what is missed by attending exclusively to the competition forced by budget constraints, is an appreciation of the ways in which basic science and academic research activities *support* commercially oriented and mission-directed research that generates new production technologies and products.

First among the sources of this *complementary* relationship, is the intellectual assistance that fundamental scientific knowledge (even that deriving from contributions made long ago) provides to applied researchers—whether in the public or in the private sector. From the expanding knowledge-base it is possible to derive time- and cost-saving guidance as to how best to proceed in searching for ways to achieve some pre-specified technical objectives. This raises the expected rates of return, and reduces the riskiness of investing in applied R&D. Harvard's physicist and historian of science, Gerald Holton [32] has remarked recently that if intellectual property laws required all photoelectric devices to display a label describing their origins, "it would list prominently: 'Einstein, *Annalen der Physik* 17 (1905), pp. 132–148'". Such credits to Einstein also would have to be placed on many other practical devices, including all lasers. Many important advances in instrumentation, and generic techniques such as the use of restriction enzymes in 'gene-splicing' also should be mentioned. These by-products of the exploratory, open-ended quest for fundamental scientific understanding also might be viewed as contributing to the 'knowledge infrastructure' required for efficient R&D aimed at commercially exploitable innovations. Occasionally they are immediately profitable and

[30] It should be noted that corporate directors are likely to be less patient in evaluating the expected future returns than is society as a whole, in the sense of being more prone to discount the economic benefits that would be received in the future, indeed, even by future generations.

[31] Just conceivably (the text, however, does not say as much), the author might have had in mind the possibility of a spontaneous emergence of one of those happy situations, in which businessmen hire curiosity-driven research scientists in a mis-guided effort to uncover the basis of each others' innovations, not realizing that those rival firms' secrets have been well and truly hidden. *Hey presto*, out pops the magical result that everyone ends up satisfied to have learned about the new, fundamental discoveries that occurred in everybody else's basic research laboratories, as by-products of their fruitless efforts to probe for information about their business rivals' applied R&D results! (In economists' jargon this could be described as a 'calypso-Nash equilibrium'.) Wonderful things like that can happen. Yet, much more powerful magic would be needed to show how such an equilibrium outcome could emerge automatically from a very different state of affairs, and be sustained when the firms noticed that they were not actually uncovering their rivals' secrets. Moreover, the important point to emphasize here is that there is absolutely nothing in the workings of a competitive market that assures that this particular conjectured equilibrium—a fragile coincidence of mutually supporting actions premised upon unfulfilled expectations—would generate the right kinds, and amounts of basic research funding needed to address the opportunities and challenges facing modern society.

[32] See Holton (1996).

yield major economic payoffs for both producers and users alike. Even though coming few and far between, such 'hits' have been potent enough to raise less than comprehensive estimates of the average social rate of return on so-called 'basic' academic research, pushing the latter well above the corresponding private rates of return earned on applied, industrial R&D investments. [33] The experience of the twentieth century also testifies to the many contributions of practical value that trace their origins to large, government funded research projects which were focused upon the development of new enabling technologies for public-mission agencies. Consider just a few recent examples from the enormous and diverse range that could be instanced in this connection: airline reservation systems, packet switching for high-speed telephone traffic, the Internet communication protocols, the Global Positioning System, and computer simulation methods for visualization of molecular structures—which has been transforming the business of designing new pharmaceutical products, and much else besides.

Yet, tracing the intellectual lineage of commercially successful innovations back to their origins in exploratory and fundamental theoretical inquiries is misleading, in neglecting the practical importance of establishing what does not work, and is not remotely possible. Sometimes the subsequent utility of exploratory sciences takes the form of providing reasonably reliable guidance as to where to look first in applications-driven R&D, but, much of the time the knowledge-base provides vital instructions as to where it will be *useless* to look. The value of this is harder to quantify, but one might ask what it is worth to a venture capitalist to know that it is not a mistake to refuse to spend time talking with that persuasive inventor who wants to tell her about a wonderful new idea for perpetual motion machines? Creative geniuses are often hard to distinguish from lunatics in such situations—except by knowing the science.

The central point that is obscured by *The Economic Laws of Scientific Research*, and therefore must be re-emphasized here, is that over the long-run the fundamental knowledge and practical techniques developed in the pursuit of basic science serves to keep applied R&D as profitable an investment for the firms in many industries as it has proved to be, especially, during the past half-century. In this role, modern science continues in the tradition of the precious, even if sometimes imprecise maps that guided parties of exploration in earlier eras of discovery, and that of the geological surveys that were of such value to prospectors searching for buried mineral wealth.

That is not the end of the matter. There is a second, and no less important source of the *complementary* relationship between basic and applied research which has been totally ignored by Dr Kealey's book. This is the nexus between university research and the training of researchers, on the one hand, and the linkage of the profitability of corporate R&D to the quality and the knowledge of the people who are available to perform it, on the other hand. Seen from this angle, government funding of basic science conducted in the universities today is providing vital subsidies to the R&D performed by the private business sector, not taxing it, as Dr Kealey contends (e.g. pp. 247–248). Properly equipped research universities have turned out to be the sites of choice for training the most creative and most competent young scientists and engineers, as many a corporate director of research well knows. This is why graduates and postdoctoral students in those fields are sent, or find their own way to university labs in the US, and still to some in the UK. It explains why businesses participate (and sponsor) 'industrial affiliates' programs at research universities; it is part of the reason for US industrial research corporations' broadly protective stance in regard to the federal budget for basic science—which has escaped the most severe

[33] Confusions about such comparisons are rife, but the matter is not difficult to understand. The existence of a gap between the average social and the average private rate of return on R&D does not necessarily signify that there is under-investment in research. The latter conclusion is warranted when there is a gap between the social and the private *marginal* rate of return (i.e. the returns calculated on the last R&D project undertaken by the private sector. Dr Kealey has omitted notice of studies that document very large gaps between the social rate of return on publicly funded research and the social rates of return calculated on company financed R&D. One recent study, which he selects for discussions, is first cited approvingly to show that basic academic research rarely generates advances that immediately translate into commercially profitable innovations; but later is criticized extensively, in order to cast doubt upon its conclusion that the social rate of return on academic research as a whole is nonetheless high, and exceeds the opportunity cost rate of return available from company-funded R&D (pp. 216, 233–235, 304).

onslaughts by the Representatives of Congress. Acknowledgment of it has had a great deal to with the recent announcement by the Japanese government of a dramatic reversal of its former policies, and the initiation of a vast program of support for *university-based* basic and applied R&D. [34]

The academic science sector not only trains the next generation of researchers with the support of public monies; the universities also devise and supervise the variety of ways in which their students' competence and displays of originality can be assessed and signaled—free of charge to potential employers in private business sector, and, indeed, to prospective users of research talent everywhere. Moreover, in sending those students out into the world, the universities actively transfer the latest techniques and findings of research that resist easy codification for publication in the open scientific journals. Think of the expense to private firms, and the consequent effects on their calculated rates of return on R&D projects, were they obliged to furnish all that overhead support for themselves!

7. A matter of style

Something has to be said, after all else, about the author's style. The pre-publication blurbs describe this book as "entertaining" and "powerful". So it is, but, distressingly, for all the wrong reasons. The ambivalent wording of those blurbs, however, should be taken as a warning: a good read, and a ripping yarn are what we look for from spy thrillers and murder mysteries, rather than in serious works on complex and fraught issues like the design of science and technology policy. In the latter we are certain to read about what may be seen on the one hand, and on the other hand—but not of gore on either of the proverbial economist's two hands. Dr Kealey delivers, however—with a passionate prose style that is unhesitating, unambiguous, and unnuanced. The reader is carried along by the author's tone, which conveys total confidence that the over-simplifications and facile glosses that stud the text really have settled the issues which were made to seem so difficult by confused and inconclusive academic historians and social scientists (p. 334).

In the book's extensive and lively narrative passages, assorted worthies are trooped before the author's reviewing stand to receive his praise or blame. Successful entrepreneurs, both past and present, not unexpectedly, are lauded without reservation. Individual scientists and engineers of distinction also receive nodding approval, as a rule, but sometimes for rather surprisingly idiosyncratic reasons. For example, the nineteenth century British metallurgist, Robert Mushet, gets repeated favorable notices as an exemplar of "good industrial research"—because of the paranoid extremes to which he went in guarding the secrecy of his alloy steel experiments (pp. 76–77, 250–251). Albert Einstein also puts in a cameo appearance, being paraded along with Charles Darwin as a splendid example of "another academic failure [who] was one of the greatest of hobby scientists" (p. 89). 'Hobbyist' status appears to have been conferred in Einstein's case by virtue of his employment as a clerk in the Zurich Patent Office, whilst engaged in the researches leading to the special theory of relativity. [35]

[34] As reported in the *International Herald Tribune* (25 June 1996, p. 1): "The Council for Science and Technology, which is headed by the prime minister, called for the national government to spend 17 trillion yen, or about $155 billion, on science and technology over the next five years...an increase of about 50 percent over...the last five years...." The new plan's "overall thrust is to revitalize research in universities and national research laboratories."

[35] One pertinent detail has been omitted in Dr Kealey's explanation of his quixotic co-optation of Einstein into the company of those to whom he awards the coyly patronizing title "hobby scientist"—including Darwin, Cavendish, and Peter Mitchell (the Nobel Laureate in biochemistry). That Zurich Patent Office post had been accepted by Einstein only out of sheer financial desperation, following the failure of his father's business enterprise, and the many fruitless efforts by Einstein and his friends to find him a more suitable, academic research appointment. Those circumstances were therefore quite unlike those of this book's author, who might properly be described as a research scientist whose professional employments, academic and otherwise, have allowed him time to engage in "hobby science policy". In the Preface (p. xi), Dr Kealey graciously thanks "colleagues in the group at the lab [at Cambridge] for the beautiful research they have continued to produce while I have been distracted by this book"; he adds that "without the support of my colleagues in the lab at Cambridge, and also in Unilever, it would have been impossible to have pursued both my science and this book".

But, in this process of sorting out the sheep and the goats of history, there is no want of subjects in whom the author can find only fault, and who therefore come in for derision or censure. Thus, Jean-Baptiste Colbert was a *dirigiste* Minister of State who died in 1683 "universally loathed" for impoverishing the French people by excessive taxation and bureaucracy (p. 71); Charles Babbage is "summed up" as "an incompetent" who squandered government money, "a man who poured intense energy into bombastic conflict against trifles" (pp. 80–81). Thomas Edison "was a horrible man", caricatured as "a barely literate, uneducated artisan" who learned on the job "[l]ike most of the great American engineering pioneers" (p. 138). Vannevar Bush, the war-time director of the US Office of Scientific Research and Development, whose report to President Roosevelt in 1945 successfully advocated a peace-time program of expanded federal support for research universities as the keystone of American science and technology policy, appears as a power-seeking administrative careerist: Bush "of course, had always wanted a federally funded national research foundation through which he could initiate, fund and coordinate a vast peacetime empire of pure science..." (p. 149). Joseph Needham is depicted in a passing vignette as a "Marxist (of the Maoist persuasion) [who] dedicated his life to proving that Chinese science had long been better than that of the West...[without] actually emigrating to China" (p. 177). [36] Lord Robbins "was in fact trying to destroy the British tradition" of higher education, and so "has proved to be the greatest purveyor of anomie in British intellectual history" (p. 199).

Whatever virtues are discernable in the individual scientists and engineers sketched by Dr Kealey's pen, none can be perceived in his collective portraits. Britain's distinguished scientists fare especially badly when hauled up before him in groups: Fellows of the Royal Society, for their politicking in pursuit of honors, and their indolence thereafter, are chastised with the translation of FRS as "Friends of the Right Sort", and "Further Research Suspended" (pp. 334–335). Past directors of the Medical Research Council are chided for choosing to "depend on government handouts", rather saving British taxpayers' money by patenting penicillin and monoclonal antibodies (pp. 136–137)—as if to say that their policy stance against patenting such research findings stemmed from sheer fiscal irresponsibility, or some absurd fetish.

The author's penchant for mass indictments, verdicts, and sentencings, however, is not confined to victims close to home. It ranges far and wide: Renaissance artists, indeed, all artists, and literary and theatrical types, too, are "egomaniacal, promiscuous, downright silly"—the odd individual among them "can be tolerable, but as a group they are frightful" (p. 309). Intellectuals in general "are very Rouseausque. Like him, they feel superior to other people... wallow in self-pity... are egotistical, selfish and mean". [37] Economists specifically are let off with only a comparatively mild scourging, as has been noticed: in Dr Kealey's experience their concern is "to further their own professional importance" by finding fault with the free market (p. 215). These summary judgements are dispensed no less readily in the case of institutions, particularly the University of Wales: "the Welsh colleges have always been the weakest institutions of higher education"; into their sorry condition, somehow made manifest by the financial bankruptcy of University College Cardiff in the 1980s, readers are told they will find "horrific insight" by consulting none other than the account of Swansea in Kingsley Amis's *Lucky Jim* (1954). But, Dr Kealey should not be thought biased in such matters, for, his disparagements are distributed quite even-handedly and totally without regard to national associations. The dismissal of the Welsh colleges is as nothing compared with the moral condemnation reserved for the rest of British higher education (pp. 197–198): having been,

[36] No mention is made in this passage of Needham's extensive travels China during his 1942–1945 posting as Scientific Counselor at the British Embassy in Chunking. As is the case throughout the whole of his book, including the historical survey chapters, Dr Kealey omits any reference to the 15 volumes of Needham's *Science and Civilization in China*.

[37] At this point the text (p. 331) relents, but only momentarily: "Obviously, there are individual exceptions to those generalisations, but no organisation fosters jealousy, bitterness and envy like a modern university".

during the late 1960s and 1970s "in thrall to violence, promiscuity and Marxist *chic*... caused by the Robbins expansion", the legacy of the chaos spawned in these institutions has been awful; Dr Kealey thus finds (pp. 197–198)

every reason to believe that the universities have not only failed to transmit 'a common culture and common standards of citizenship' but that they have helped brutalize their own society. The intolerance, violence and drug abuse of the students' unions will have legitimized, for many a young thug, direct action and brutality.

One does not have to read very far into this book before recognizing that in such proceedings it bears some aspects reminiscent of the works of Thomas Babbington Macaulay—save for the sweep and grandeur of Macaulay's narrative style. An early clue to this is provided by the opening chapter, wherein the author retails selected bits from Macaulay's infamous essay in defamation of the character of Francis Bacon, and describes that source in a postscript simply as "hilarious" (p. 13). It would have been bad enough had Dr Kealey contented himself with presenting Bacon's philosophy in a distorted form calculated to contrast it unfavorably with that of Adam Smith. Why seek to further dim the brilliance and originality of Bacon's ideas concerning science and technology by repeating the gross slanders perpetrated in the Macaulay (1837) *Essay on Bacon*? Nothing in that particular "tissue of fraud and lies" [38] has the slightest logical bearing on the substance (or in substance) of either Bacon's, or Dr Kealey's views regarding the role of the State in the pursuit of science. But, in this book logic does not rule, and the author's rhetorical method does not balk at parroting past malignings of Bacon; they too can be enlisted in the campaign to discredit all proponents of the (thoroughly Baconian) position that the public funding for the collaborative pursuit of scientific understanding of both the natural and the 'made' world will serve to further the material well-being of humanity, as well as to elevate the human spirit.

Thomas Spedding, the patient and scrupulous nineteenth-century biographer of Bacon, described Macaulay's "faculty of conveying the greatest amount of false effect with the smallest amount of definite misstatement" as "an unconscious facility in him, more like genius than any other faculty he possesses". [39] Alas, one cannot be so charitable even as to offer Dr Kealey the same accolade. For, it has been seen that in the parts of his book that treat historical matters, as well as in the application of econometric methods and economic theory, there are all too many 'definite misstatements'.

It has been acknowledged that the economic arguments for public patronage of scientific research often are poorly put, and that the political case for government funding of increasingly costly science has to be grounded, ultimately, on satisfactorily answering skeptics question about getting future economic value for money spent in pursuit of such knowledge, rather than other worthy purposes. But, this does not warrant mistaking a demagogic assault for a constructive criticism; an informatively challenging analysis does not consist in responding to the past explanatory failings on the part of the academic science community by shouting "Off with their heads!". Whatever the reviewers and blurb-writers may have said, it cannot be a "courageous" or truly "brave" book that systematically panders to the common human weakness of smiling, and tolerating the telling of stories that blatantly disregard the evidence—because the author has been divertingly cheeky in denigrating commonly esteemed persons and institutions. Nor does Dr Kealey really deserve anyone's tacit thanks for offering to the non-scientist academics among his readership the exquisite satisfactions of *Schadenfreude*.

8. One man's warning

In the end I must be quite blunt: this is a thoroughly bad book, and the real worry of it is that

[38] The quoted phrase is Churchill's, used exposing Macaulay's maligning of Malborough (Churchill, 1934). Nieves Mathews (1996) provides a thoroughly persuasive demonstration that these words apply with equal justice to the *Essay on Bacon*—another production from the same untrustworthy pen.

[39] Quoted by Mathews (1996, p. 2).

critical reviews, even ones more elaborate that this space affords, will not succeed in consigning it to a well-deserved oblivion. After all, in 1881, Thomas Spedding devoted 1000 pages to righting the injustices done to the reputation of Francis Bacon by Macaulay's brief essay; and still, it has remained necessary in 1996 for Nieves Mathews to give us another 560 pages, meticulously examining the origins and the continuing legacy of that eminently readable piece of character assassination.

An old saying is too apposite here: "A fool may throw a cow down a well, and yet six wise men are not enough to get it out". The cow in question—in the shape of Dr Kealey's large and lively book—is now a fait accompli, stuck firmly into the well of public debate, where its utterances may reach and soon be echoed by others. As a source, then, even if not as an 'authority', it is almost certain to find use by other polemicists of a radical laissez-faire and mildly anti-academic disposition. In such circumstances, the one course of action that can best preserve the health of public policy discussion is to put up as many warnings as possible around the site of *The Economic Laws of Scientific Research*. Space for these will be limited, so, my proposal for a suitably brief (mental) health notice has to be this:

DANGER. ROTTING COW IN THE WELL.
Check Historical Statements Carefully
and Discard the Econometrics.
Watch Out for Flawed Economic Logic.
Boil Other Contents Thoroughly
Before Swallowing.

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