Science, technology and civilization

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One has the distinct perception that the debate on the future of science, especially regarding the acquisition of more knowledge, is hotting up. We appear to be in the midst of fast and furious change—in which the internet, new modes of funding, disseminating and applying science, and of educating future scientists, and the sheer volume of English-language scientific papers now emanating from China are all contributing. Whether the changes currently taking place are qualitatively greater than those associated with previous scientific revolutions is hard to say, but we certainly risk being overwhelmed by their quantitative hugeness, which seems unprecedented.

Perhaps the present fervour, at least in the UK, is a symptom of a nation under stress, beset on all sides by new forms of competition, much as must have been felt by Britain on the threshold of World War I, when its more or less satisfactory arrangement of recruiting troops by the individual efforts of local grandees was suddenly confronted by a Germany with a ruthlessly professional army, in which for the preceding decades the efforts of a majority of the nation's best scientists had been systematically directed towards forging industrial and military excellence.

Kealey has pointed out that the view of science leading to technology leading to military excellence can be traced back to Francis Bacon,[1] who apparently formulated the notion in another period of great stress for Britain—the Spanish Armada of 1588. Nevertheless, the Armada failed (for a variety of reasons) and Germany—ultimately—failed too.[2] These failures, and numerous other examples, should be sufficient to at least cast doubt on the so-called "linear model" of science → technology. As Moriarty points out,[3] the relationship is highly nonlinear and one can find examples of its operation in both directions. In order to investigate the matter beyond the level of anecdote, one could compile a table of as many examples as it is possible to find, and simply add up the numbers, or the associated economic value of the activities

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1 T. Kealey, Bacon's shadow. *Prospect*, October 2005, 44–47; and of course his contribution to the present debate (this issue, pp. 98–100).

2 R.V. Jones (*Most Secret War*, London: Hamish Hamilton, 1978) has given an excellent account of how in World War II too, the apparently amateurish (an epithet which should perhaps not bear the pejorative stigma with which it increasingly seems to be associated) British countermeasures to German scientific-technical aerial navigation aids were ultimately successful.

3 P. Moriarty, this issue, pp. 101–106.

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exploiting the technologies (i.e., innovations), to determine whether science *predominantly* precedes or succeeds technology. But even if this were to be done, it does not seem that new insight into the underlying reason for one direction or the other would result.

In order to find such insight, one needs to look at a picture bigger than just science and technology. Fundamentally, the economic activity of man first of all serves to satisfy the immediate needs of survival. As knowledge, and concomitantly productivity, grows, it is possible for some part of a man's life to be set aside for leisure. Science—as the disinterested pursuit of pure knowledge—is a very refined part of leisure, of which, globally, it only constitutes a minute fraction. The fact that some scientific knowledge can be used to generate new technologies is a mere epiphenomenon of the overall process.[4] And even that is not the whole story. As Cyril Smith has argued, producing such a weight of evidence so as to make the argument irrefutable, most commonly the initial motivation for technical advance is aesthetic.[5] Hence the overall picture developed so far is something along the lines of Figure 1.

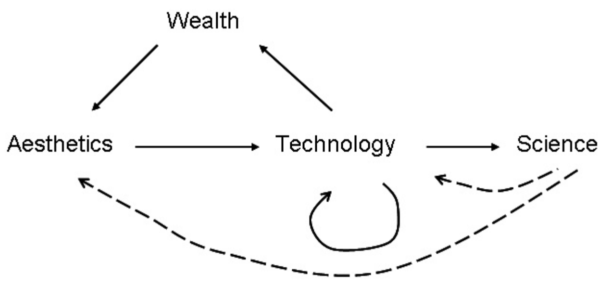

Figure 1. Putative relationships between wealth, aesthetics, technology and science. Solid arrows represent principal flows (of, fundamentally, information) and dashed arrows represent what are possibly secondary flows.

The bottom line of this is that the *sine qua non* for development is (surplus) wealth—surplus to the immediate requirements of survival. That is why, as Pethica points out,[6] the fiscal environment is so important. If there is no industry base, one of the main pillars for supporting open, exploratory science falls away. Despite some erosion in recent years, manufacturing is still very important in the USA, and this underpins open, unfettered research. In contrast, the major contributor to the UK economy nowadays is financial services. In principle it should not matter how the wealth is actually generated. In a modern economy, the surplus wealth is disposed of by government taxation and philanthropy. Its origin need not influence its destination. But it is all too understandable that a Treasury minister, looking at the relative

4 J.J. Ramsden, *The New World Order*. Moscow: Progress Publishers (1991).

5 "Over and over again, scientifically important properties of matter and technologically important ways of making and using them have been discovered or developed in an environment which suggests the dominance of the aesthetic motivation." C.S. Smith, *A Search for Structure*, p. 195. Cambridge, Mass.: MIT Press (1981). This surely even applies to efforts to formulate the most fundamental laws of nature concerned with elementary particles and their interactions: there is a strong belief in the need for the structure of these theories to be beautiful. This link is however often forgotten. For example, the booklet *Metals in the Service of Mankind* (London: The Institution of Metallurgists, 1950), issued to accompany a major exhibition, makes no mention of the aesthetic uses of metals.

6 J. Pethica, this issue, pp. 94–97.

contributions of the different sectors of the economy, might be reluctant to distribute funds to scientists whose work would appear to have little relevance to the principal wealth-generating sectors, just as the owner of a financial services enterprise is less likely to fund university research directed at (for example) the synthesis of matter at the nanoscale than the owner of a manufacturing enterprise.[7] Note that here I am not yet talking about funding directed towards a specific end, for which a definite return on the investment made is expected.

To recapitulate so far, there is a good correlation between scientific activity (as revealed, for example, by numbers of publications in scientific journals, which traditionally deal with the results of so-called pure or fundamental research, rather than applied, industrially specific work that is more likely to be documented in unpublished reports) and wealth,[4] but the latter is rather the cause, or enabler, of the former than vice versa.[8] There is however feedback, and sometimes scientific discoveries rapidly beget wealth-generating technologies.

If government involvement in science were limited to the distribution of a proportion of tax revenues along the lines suggested by Selfridge,[9] then there would be little to worry about. After all, why should government interfere in the leisure (of which, as we have seen, science is but a tiny part) of the nation's citizens? Any attempt to do so is fundamentally as futile as the promulgation of sumptuary laws.[10] Of course, these often had an apparently sound motive, such as discouraging the import of costly finery for the sake of maintaining a healthy balance of trade, as did laws of a similar nature such as those formerly prevalent in England prescribing the regular practice of archery as a pastime, which, it might plausibly be argued, would have had some tangible military benefit in case of war.

Prima facie there is no need to incorporate leisure activities into a social contract of the type promulgated in Hobbes' *Leviathan*. Yet the necessity for a nation to be militarily strong (in order to avoid domination by its neighbours) tends to blur the boundaries between work and leisure, in so far as it might justify extension of the sovereignty of government over its citizens almost without limit. Technological, rather than scientific superiority would appear to lie behind Britain's decisive victories over China in the "opium wars" of the 19th century, the first of which led to the ceding of Hong Kong. In the 20th century, however, the (scientific) discovery of nuclear fission followed by fusion suddenly placed scientists at the heart of crucial developments in weaponry. By that time there had already come into existence a specialized corps of scientists engaged exclusively and professionally in science, rather than science being

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7 Financial services do of course use nano-enabled computers, but they are not made in the UK.

8 The view that the "science base" is the enabler of wealth creation seems to be pervasive in UK government circles. See, for example, Tony Blair's speech "Science Matters" on 23 May 2002; the report *Science & Innovation Investment Framework 2004–2014* (London: HMSO, 2004); and recent pronouncements by Ian Pearson, the new minister for science. It can apparently be traced back to Harold Wilson (e.g. his speech to the Labour Party Conference on 1 October 1963), although he also spoke of the "white-hot *technological* revolution". It is doubtful whether the distinction between science and technology was clearly perceived.

9 Half-baked ideas selected by a national commission on the basis of fancy rather than obvious merit. O.G. Selfridge, A splendid national investment. In: *The Scientist Speculates* (ed. I.J. Good), p. 31. London: Heinemann (1962).

10 Astonishingly, such laws were repeatedly promulgated in Spain for over 600 years, despite their persistent failure, century after century, to significantly influence the behaviour of Spaniards.

an individual pursuit of those who could afford it, as exemplified by Henry Cavendish. Since this corps was not actually generating any wealth, it had to be supported out of the public purse, or through philanthropy. In some cases scientific work was associated with education, as in British universities for example—whose funding was then primarily philanthropic, but today primarily from the public purse, but also associated with the provision of educational services (i.e., lectures, tutorials etc.) for which fees were paid and hence could be said to be on a par with any other kind of productive labour contributing to the gross domestic product (GDP). In other cases, as in the Soviet Union (the institutes of the Academy of Sciences, for example) and France (the Centre National de la Recherche Scientifique), the scientists were employees of the state. Even in the Soviet Union, however, with its reputation for attempting to strongly control the lives of its citizens, the government realized that it was impossible to reconcile the scientific creativity necessary to do real (i.e. effective) science (with a real technological outcome, i.e. an operational nuclear bomb) without according freedom to the scientists.[11] In effect this led to a compromise that kept physics in the Soviet Union on a par with that in other leading countries, and also enabled the delivery of the atomic weapons needed to make the USSR a superpower. Of course, it was a messy, evolving process with an often uncertain outcome. Nevertheless, it is sobering to reflect that scientists under those conditions often had more freedom than is typical today (e.g. in the UK, in which most scientists are working within the framework of tightly regulated contracts with the research councils).[12]

In cases where fundamental scientific research does lead to a new potential technology, the "rule of tens" applies: the development leading to a prototype costs 10 times more than the science, and the cost of actually launching a viable commercial product is 10 times greater than the development. Let us for the moment suppose that the science has emerged from work carried out under a regime of perfect freedom. While it is perfectly true that a good deal of research council funding now goes into subsidizing what is essentially industrial research carried out at universities,[13] it seems arbitrary to object to this as a misuse of public funds, since after all much of those funds come from industry via corporation tax (and, less directly, via the income tax of salaried employees in industry). Although I would argue that actually the government thereby oversteps its side of the social contract, there is an unstated link in the strategic partnership between the Engineering and Physical Sciences Research Council (EPSRC) and Procter & Gamble,[13] namely that Procter & Gamble will provide employment, and even, through the provision of superior washing powder, a possibly more benign environment for the nation's citizens. Nevertheless, even if one were to fully concede that this is legitimate, one would have to recognize that the present government policy lacks coherence.[14] If the government *really* believed in the linear science → technology model, then it would make

[11] See, for example, D. Holloway, *Stalin and the Bomb*. New Haven: Yale University Press (1994).
[12] Cf. the remark of a young producer at this year's Budapest film festival: "Politics was spoken of more freely under communism than today" (quoted in S. Koltai, Kunst fürs Ausland oder Kommerz fürs breite Publikum? *Neue Zürcher Zeitung*, 1 March 2008) — due to the ability of the government to cut the funding of filmmakers critical of their policies.
[13] P. Moriarty, *loc. cit.*
[14] Cf. I. Gibson and S.R.P. Silva, Harnessing the full potential of nanotechnology for wealth creation (this issue, pp. 87–92).

sense to increase its expenditure on science by at least one order of magnitude, if not two. The annual expenditure of, for example, the Biotechnology and Biological Sciences Research Council (BBSRC) is somewhat less than £500 million, of which somewhat more than £300 million is disbursed in research grants. This is about a hundred times less than government expenditure on health, which is itself only about 5% of GDP (and which, it is widely conceded, is only very partially effective[15]). The real and legitimate grievance of scientists in the UK is that the government is trying to minutely control even those negligible crumbs that they receive from the public purse, thereby destroying what remains of creativity while at the same time not realistically impacting the economy.

This statement needs of course some qualification. Different scientific sectors have very different fiscal requirements. The biggest industrial interest lies in chemistry and (applied) biology. Companies operating in these sectors, which include some of the largest in the world, are more than able to fund all the research they require. It seems ludicrous to suppose that they would participate in the cumbersome bureaucracy that accompanies research council and other government support for research for anything that they felt would yield a good return within the currently accepted commercial timescales. Indeed, in those areas in which they specialize, their facilities and resources are incomparably superior to those generally found in universities. Experimental physics, however, often requires very expensive equipment, and, lacking the backing of global industries, is sometimes only affordable via consortia such as CERN. Mathematics and theoretical science, on the other hand, requires little more than a stipend for the scholar. Any vision for a new approach must take due account of these differences.

There is, in fact, no real contradiction between the views expressed in the preceding three contributions, distinctive as they are. If they may be summarized (or paraphrased) in a few words, they are: the scientist has a moral duty to better man's estate on earth as well as pursue knowledge for its own sake, but without a realistic fiscal environment one can expect very little significant new technology to emerge (Pethica); science does not inevitably lead to technology, and is therefore not a public good, at least not in a material sense (Kealey); science driven by utilitarian and commercial goals will become corrupted, and fade into mediocrity and insignificance (Moriarty).

Pethica refers to Francis Bacon as an early promoter of the view that science should lead to the relief of man's estate (presumably through technology). Indeed, the dominant motive of the great Victorian engineers was "the practical application of scientific knowledge...[they] spent their whole energy on devising and superintending the removal of physical obstacles to society's welfare and development... the thought of making man's dwelling place more commodious cast into insignificance anticipation of personal enrichment."[16] But, as Weir goes on to write, "the system assumed a new character as soon as it was made available for the

[15] This highlights another problem, namely that it is very difficult to measure the results of any policy, especially within the lifetime of a government. GDP data is so noisy that even a doubling (say) of government expenditure on research is unlikely to yield a result clearly ascribable to the doubling. On the other hand, a sudden twentyfold increase, which might be significant enough to measurably affect GDP, is likely to cause so much disruption that it might even be counterproductive.

[16] A. Weir, *The Historical Basis of Modern Europe*, pp. 393–394. London: Swan, Sonnenschein, Lowrey (1886).

general public. The elevation of society was lost sight of in a feverish desire to acquire money. Beneficial undertakings had been proved profitable; and it was now assumed that a business, so long as it was profitable, did not require to be proved beneficial." This is, perhaps, an inevitable development. Furthermore, as was pointed out long ago, purely utilitarian research tends to sink into mediocrity: "... thought loses its fine edge when it is set to cut millstones of state. It loses its fine temper in the red heat of political controversy. By turning utilitarian it ceases to be universal; and what is perhaps even worse, it ceases to be free. It tends to become a mere inventor of things which will sell at a profit; less and less the discoverer of high principles which the gods have hidden out of sight."[17] Such a tendency cannot be countered by attempts to promote excellence such as the UK's Research Assessment Exercise (RAE), which has more in common with totalitarian control than a policy to promote creative achievement in science.

Technology is today extremely complex,[18] and it is perhaps unwise to place sole trust in its ability to solve the very real problems currently besetting the world. So much technology is counterproductive. In agriculture, tremendous efforts are still being undertaken to increase crop yields, while at the same time the Common Agricultural Policy of the European Union makes strenuous efforts to encourage farmers to reduce acreage under cultivation, with the help of sophisticated geographical information systems (GIS). Since the intensive farming practices associated with high yields have such undesirable effects as carbon depletion of the soil and the pollution of groundwater, there is actually a net loss (to say nothing of losses in biodiversity and comestible quality). Regarding public health, a modern shopping mall probably contains health-promoting and health-diminishing goods and services in equal measure. The phrase "market forces" suggests knowledge as reliable as that of Newtonian forces, whereas in reality we know very little about how an economy works, and even the most ardent free marketeer would nowadays have to concede that the market appears to be unable to deliver what is expected of it. Under these circumstances, the most important contribution that the scientist can make is to uphold the ideals of "intellectual enlightenment"—scrupulous honesty and self-criticism, and keeping alive the freedom to criticize more generally. Unlike the philosopher, the scientist always has the objective arbiter of nature to fall back on, which gives a uniquely objective character to his or her efforts. One of the greatest enemies of this freedom is the stultifying bureaucracy that today tends to engulf so much academic work. Unfortunately, bureaucracy seems to be especially associated with government, and this alone constitutes an argument against government funding, however much one may agree with the idea of science as a public good, in the sense of elevating man's estate both materially and spiritually, and therefore contributing to the continuing advance of civilization.

[17] F.S. Oliver, *Ordeal by Battle*, 2nd edn. London: Macmillan (1915).

[18] J.J. Ramsden, Complex technology: a promoter of security and insecurity. In: *Complexity and Security* (eds J.J. Ramsden and P.J. Kervalishvili), pp. 249–264. Amsterdam: IOS Press (2008).