Chapter 5
Science and Technology as institutions

Institutions are public goods. The problem facing a society is to unearth what combination is likely to work best for it. In the rest of this book we explore how institutions interact with one another. To see what issues are involved, it will pay to begin by studying the institutions that have been created to produce a commodity that any reader of books would find interesting: *knowledge*.

Knowledge is a public good *par excellence*. It is non-rivalrous in use (when someone applies the calculus to a problem, no one else is prevented from applying the calculus to his or her problems). Unless the producer of a piece of knowledge is secretive, it is also non-excludable. Knowledge is a durable commodity, in that the same piece of knowledge can be used over and over again. If someone was to invent the wheel today, we would observe that he had merely 'reinvented the wheel'; he wouldn't contribute anything of value. Moreover, as no additional cost is involved when someone dips into a piece of knowledge, he shouldn't be charged for it.

These observations are truisms today, but they raise a problem. If knowledge is freely available to all, the only way discoverers and inventors could obtain a return on their efforts would be by being secretive or by earning profits from the head start they have with their ideas. Which means that the private incentives to produce knowledge would be low. The trick is to find more reliable ways to reward people who discover and invent.

In using the terms 'discoverers' and 'inventors', I don't mean to restrict the use of the word 'knowledge' to the products of science and technology; I want to include innovations in the arts, crafts, music, and literature. Nevertheless, in offering an account of the two overlapping institutions that have emerged in the modern era for producing knowledge, I shall rely on examples drawn from science and technology, conventionally defined. Along the way, we will discover that our analysis applies also to other forms of creative work.

By scientific and technological knowledge I mean, roughly speaking, what the classical Greeks meant by them, namely, *episteme* (speculative, theoretical, or abstract knowledge) and *techne* (art or practical knowledge), respectively. As far as I can tell, Aristotle regarded it impolite to discuss *techne*, even to enumerate achievements in that sphere. His discourses focused on *episteme*. In contrast, modern economists have attended to *techne*, which is evident from our frequent use of the term 'technological progress' when we offer reasons for continued economic growth in Becky's world (Chapter 1).

Research and development (R&D) are inputs in the production of knowledge. Publicly funded

R&D is the Wicksell-Samuelson solution (Chapter 2) to the problem of incentives in knowledge production. For reasons that will become clear presently, I shall call the institution of publicly funded R&D, *Science* (with upper case S). For concreteness, the agency that funds R&D will be taken to be the state, even though private foundations and large corporations in Becky's world augment the resources that flow into Science from the state.

So that the knowledge that is produced with public funds is freely available to all, employment contracts include the condition that discoveries and inventions are to be disclosed publicly. But knowledge often involves technical material. How is the state to prevent quacks and charlatans from muddying the enterprise? Modern societies have solved this adverse selection problem by insisting that public disclosure involves publication in peer-reviewed journals. Vetting by peers greatly reduces a problem society faces, namely, its inability to distinguish good products from bad products.

But there are further problems in Science. As a good deal of creative work is conducted in the head and success in R&D is chancy, it isn't possible to verify whether someone has complied with the agreement to work hard. How is the paymaster to know that scientists are thinking, not day-dreaming? After all, even lazy scientists could claim that they were unlucky, not lazy. Society therefore faces a moral hazard, implying that payment should not be based on time or effort. An alternative is a fixed payment for practising science, but that too has a problem. If scientists could collect the fee irrespective of whether they produced anything of interest, the incentive to work hard would be blunted; which is yet another moral hazard. If each of these hazards is to be reduced, payment has to be based in some way on performance. Such forms of payment are called *piece rate*. In the present context, 'piece rate' means payment on the basis of the quality of the product of R&D.

For reasons similar to the ones I have just enumerated, piece rates used to be a commonplace for casual labour in agricultural harvest. Today, machines set the pace, which means that human effort is verifiable. That is why piece rates have become less common even in agriculture. But performance bonuses, often in the form of stock options, are today a commonplace in large corporations, for reasons of the moral hazards facing shareholders (Chapter 6). In the knowledge sector, a special version of piece rate payment is alive and well and has played an enormously significant role in the economic transformations that have led to Becky's world.

In order to understand the version of piece rates prevalent in Science, let us recall that a piece of knowledge need not be produced more than once. If we were to interpret this literally, it would mean that those who produce a piece of knowledge after it has already been made public by someone else contribute nothing of value. That in turn implies that only the first with a discovery or invention should be rewarded. So as to encourage scientists to make fruitful discoveries, the payment schedule also needs to have the feature that, the better the discovery, the bigger is the reward. The idea therefore is to transform research into *contests*.

It can be argued that, in order to encourage entry into scientific contests, losers ought to be rewarded too. The problem is that losers could make inflated claims about their own progress once the winner discloses his or her finding. This possibility would create another moral hazard for the paymaster. The scheme that avoids each of these problems and has been adopted by Science is the *rule of priority*. Under that rule, the winner takes all that the paymaster has on offer. Science doesn't pay runners-up.

What I have just written isn't literally true of course. First, scientists are inevitably a garrulous lot, which means that colleagues usually know roughly how far behind the winner the losers were at the time the discovery was made public. Second, no two scientists follow exactly the same trail, which means that losers also produce material of interest. So, losers are rewarded too. The 'winner takes all' version of the rule of priority is simply a stylized way of saying that in Science, winners are rewarded disproportionately.

The rule of priority is ingenious, in that it elicits public disclosure of new findings by creating a private asset from the very moment a scientist relinquishes exclusive possession of the discovery. In Science, priority *is* the prize. In the words of the biologist Peter Medawar, it awards *moral* possession of discoveries to winners, even though no one obtains legal possession of them.

But there are problems with the rule of priority. It places all the risks that are inevitable in R&D firmly on the shoulders of scientists. This can't be an efficient system if scientists, like lesser mortals, are risk-averse. It would seem, after all, that in order to encourage entry into Science, scientists should be paid something whether or not they are successful in the contests they choose to enter. It is in this light that Kenneth Arrow's remark, that 'the complementarity between teaching and research is, from the point of view of the economy, something of a lucky accident', assumes its full significance. That 'complementarity' explains why so many scientists are employed in universities, and it explains why in recent centuries universities have been the place where some of the greatest advances in science have been made. Tenure in university appointments, a much debated feature of employment contracts, is a way society ties its hands not to interfere when a scientist has reasons to follow one research lead rather than another and other people have reasons to disagree with the scientist.

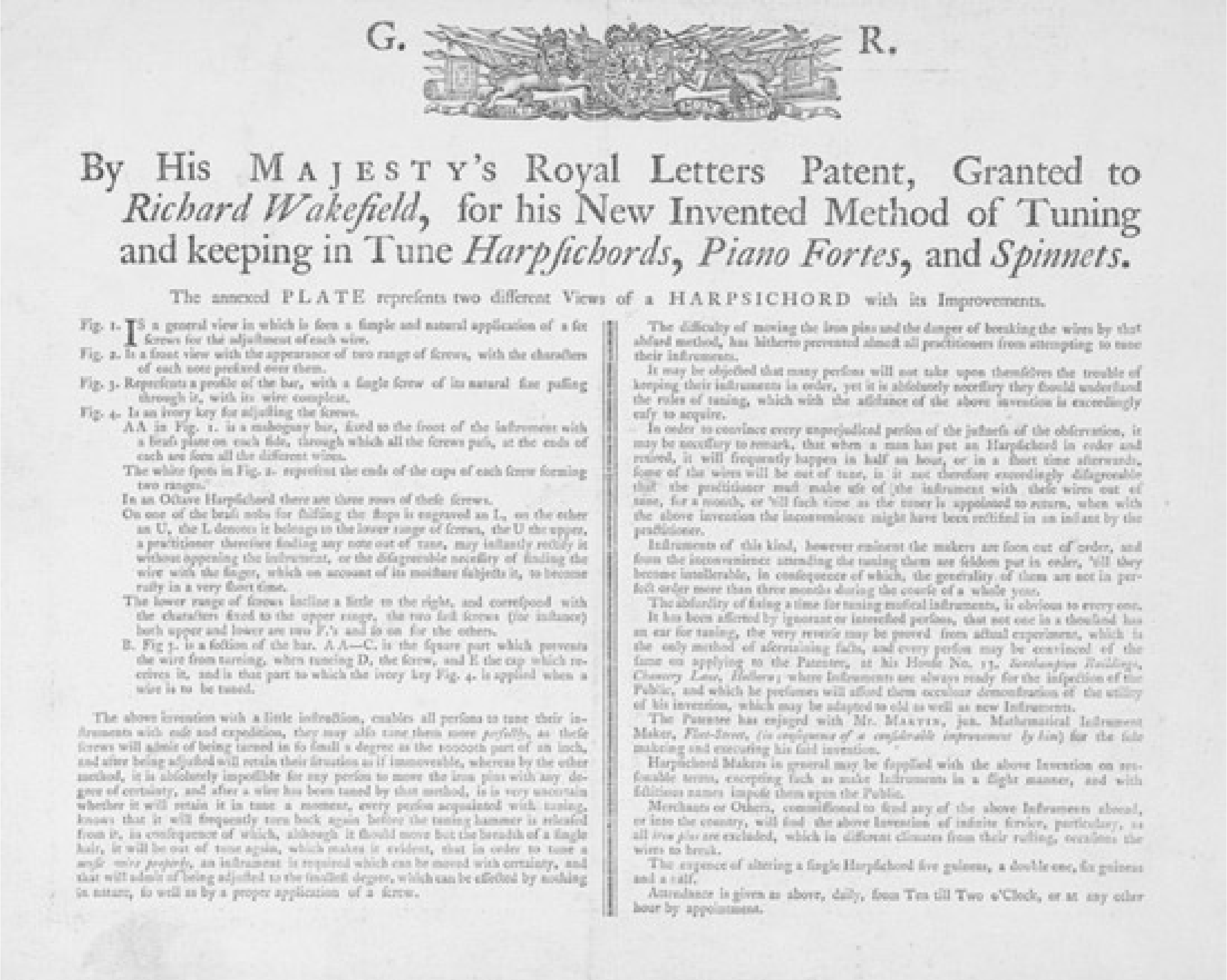
Although the reasoning I have deployed in arriving at the rule of priority draws on the language of modern economics, the rule itself became established much earlier than my discipline. (Societies are usually a lot cleverer than social thinkers.) The Royal Society of London (chartered in 1662) and similar Academies in Paris, Rome, and Berlin were established in order to facilitate the exchange of scientific knowledge and to confirm new discoveries and inventions. Those Academies also legitimized the rule of priority, administered it, and became the arena for struggles over conflicting claims to priority. The dispute between Newton and Leibnitz over moral possession of the calculus is only the most famous example.

But neither the rule of priority nor the Academies appeared in a vacuum. The economic historian Paul A. David has traced their origins to a problem rulers in the late Renaissance Italy faced increasingly: how to choose men of science who would adorn their courts. No doubt the evolution of institutions doesn't follow the dictates of analytical reasoning, but it is analytical reasoning that explains what evolutions amount to. Even the notion of moral ownership of creative works predates the Academies. For example, it was common practice among bards in medieval India to refer to themselves in their poems by name in the third person. By doing that, the poet left a signature on his creation (mostly they were men) – the better the poet, the greater his fame, the larger his audiences, and so, the greater his pecuniary benefits. Scribes, philosophers, and scholars in Eurasia had practised the open transfer of knowledge even earlier. The anthropologist, Jack Goody, has uncovered the ingenious ways in which creators even in pre-literate societies left markers on their works so as to be remembered. But those earlier practices were haphazard. What the rule of priority did was to put the stamp of an institutional imprimatur on creative works.

There are limitations to Science. An exclusive dependence on the public purse to finance R&D is problematic, because knowledge has two further properties: no one truly knows what the commodity to be produced is until it has been produced; nor does anyone really know in advance how to produce it. Of course, experts are likely to have a better idea than others of which problems are solvable, by what means. If society wants to ensure that a wide portfolio of scientific and technological problems is on the table, it ought to encourage R&D activity not only in Science, but also in a parallel institution, where discoveries and inventions are privatized. Let us call that institution, *Technology* (with an upper case T).

One way to keep knowledge from being used by others is to keep it secret. In earlier times practitioners of alchemy, witchcraft, magic, and the material crafts (glass-making, metallurgy, the manufacture of precision instruments), and experts at solving complex accounting problems for merchants and businessmen (for example, the cossists of 16th-century Germany) kept their knowledge and skills secret. In the age of maritime discoveries, maps of trade routes were carefully guarded. Holders of secrets were able to earn profits from their knowledge, which is why secrecy was practised mostly over *techne*. But secrecy isn't reliable. Reverse engineering, to use a modern term, is a danger in the crafts, as is the possibility that rivals will make the same inventions. Monopoly rights to knowledge, or *patents*, is a remedy for that problem. The patent system – and relatedly, *copyright* for images and expressions – allows people to disclose their findings without obliging them to share the profits from those findings. It is a legal means of making a piece of knowledge an excludable commodity. The system offers a private reward for disclosure and makes the award on the basis of priority of disclosure. Like the rule of priority in Science, the patent system encourages contests in Technology.

The systematic use of patents began in Venice in 1474, when the Republic promised privileges of ten years to inventors of new arts and machines. But the forerunner of present day patent laws was the English Statute of Monopolies in 1623. This enunciated the general principle that only the 'first and true' inventor of a new manufacture should be granted a monopoly patent – in the case of the 1623 statute, for a period of 14 years. Even the forerunners of modern patent laws made it impossible to patent a 'fact of nature', which is why it is customary to regard patents as belonging to the realm of *techne*. But recent litigations over patents in biotechnology have shown that it isn't always easy to agree on what is a fact of nature.



G. R.

By His MAJESTY's Royal Letters Patent, Granted to *Richard Wakefield*, for his New Invented Method of Tuning and keeping in Tune *Harpſichords*, *Piano Fortes*, and *Spinnets*.

The annexed PLATE repreſents two different Views of a HARPSICHORD with its Improvements.

Fig. 1. IS a general view in which is ſeen a ſimple and natural application of a ſet ſcrews for the adjuſtment of each wire.

Fig. 2. Is a front view with the appearance of two range of ſcrews, with the characters of each note prefixed over them.

Fig. 3. Repreſents a profile of the bar, with a ſingle ſcrew of its natural ſize paſſing through it, with its wire compleat.

Fig. 4. Is an ivory key for adjuſting the ſcrews.

11. An 18th-century patent for tuning harpsichords

Let me sum up in the language that was developed in earlier chapters: behaviour in Technology is market-driven and thus enforced by the *law*; whereas in Science, behaviour is community-ridden and thus enforced by *norms*. Both institutions produce knowledge; but in the former, it is regarded as a private good, whereas in the latter, it is viewed as a public good. The incentives in Science and Technology differ in ways that encourage scientists and technologists to regard their products in accordance with the mores of the institution to which they belong. It should then be no surprise that the character of what is produced also differs. The traditional distinction between Science and Technology, which sees the former as being concerned with basic research (whose output is an input in the production of further knowledge) and the latter with applied research (whose output is an input in the production of goods and services), interprets the two in terms of differences in their products. The viewpoint being advanced here, of regarding Science and Technology as institutions, seems to be me to be deeper. It helps to explain *why* their outputs would be expected to differ.

Today, we take it for granted that Science has in place incentives for scientists to disclose their findings. But the emergence of the social contrivances that embody those incentives was not inevitable. Nor did they emerge easily, for it required the collective efforts of scientists and their patrons. The role of Academies in subjecting claims to independent scrutiny, in adjudicating between rival claims for priority and in overseeing the quality of those who enter Science, has been substantial. Peer-group esteem, medals, and scrolls, being the currency in which scientists are rewarded, are remarkable innovations because they don't involve too many resources. In order that those social contrivances are effective, a good part of a scientist's education involves developing a taste for non-pecuniary rewards. That taste has enabled Science to produce knowledge on the cheap. Increasingly though, the taste for those social contrivances has to compete against the pecuniary rewards available in Technology. If the pecuniary rewards increase – and they have increased greatly in recent years – the taste for the mores in Science becomes more and more of a luxury to the research worker. Science embodies a set of cultural values in need of constant protection from the threat posed by its rival, Technology. That threat has proved to be so real, that in recent decades the two institutions have begun to blur into each other. Scientists increasingly behave like technologists, while technologists enjoy both the pecuniary rewards of Technology and the medals and scrolls that Science has to offer.

Despite the tensions, Science and Technology continue to progress in Becky's world. Today, expenditure on R&D amounts to 2.5% of the GDP of rich nations, while the corresponding figure in poor nations is a good deal less than 1%. Given that the GDP of rich nations is six times that of poor nations, we shouldn't be surprised that the bulk of scientific and technological advances are taking place in Becky's world, nor that Desta's world manages at best to be a limited user of those advances. And I haven't even mentioned the relative expenditures on education in the two worlds.

The institutional innovations in Science and Technology that I have just sketched, all too briefly, took place in Europe and emerged during the period historians refer to as the Age of Enlightenment. The latter term can grate if it is interpreted in an epistemological sense. And it does grate among intellectuals, because that's how the term is usually interpreted. They bristle at the suggestion that the analytic-empirical basis of knowledge – which is what both Science and Technology are built on – is a European invention. And they ask: 'what about those civilizations at earlier times, in other places, that nurtured scholars who made enduring contributions to knowledge?'

Let it be acknowledged, once and for all, that the analytic-empirical basis isn't an invention of Becky's world, and that the mystical-revelatory route to the acquisition of knowledge isn't restricted to Desta's world. Every society that I am even dimly familiar with has fielded both, often at the same time. Which may explain why people today from all parts of the globe are able to practise Science and Technology with ease when given half a chance; their 'cultural' background doesn't seem to be an intellectual bottleneck. Brandishing texts to show that scientific and technological progress was made in Desta's world at a time when Becky's was covered in darkness doesn’t advance knowledge, it merely reiterates the commonplace. What Europe achieved during the Age of Enlightenment was far more remarkable than a revolution in epistemology, in that no place had managed to do it before. It created institutions that enabled the production, dissemination, and use of knowledge – in effect, the entire knowledge industry – to be transferred from *small elites* to the *public at large*, a transfer that so sharpened the analytic-empirical mode of reasoning that it became routine. That achievement explains a good deal of the macroeconomic statistics I reported in Chapter 1