The epochal innovation that distinguishes the modern economic epoch is the extended application of science to problems of economic production. (Kuznets 1966, p. 9)

Basic research provides most of the original discoveries from which all other progress flows. (United Kingdom Council for Scientific Policy 1967)

The credit for our recent success really goes to the powerful system we have generated to create new knowledge and develop it into technologies that drive our economy, guarantee our national security, and improve our health and quality of life. (President’s Council of Advisors on Science and Technology 2000, p. 1)

During the second half of the twentieth century, advanced industrial countries made unparalleled public investment in exploring what Vannevar Bush (1945) termed ‘the endless frontier’. Combined with charitable and private investment, this investment constructed a number of ‘powerful systems’ for generating new knowledge and harnessing them to invention. This book is about the evolution of these systems, our changing understanding of their composition and operation and the lessons this offers for conceiving and implementing science and technology policy.

In times of turbulence or rapid change in the past the practices and understandings seem to have been more straightforward. In recent years, many within the scientific community have longed for the consensus that governed science policy following the Second World War. Few, however, would wish to reinstate one of the principal conditions supporting this consensus, the imperative of using science to fuel military races that could be lost but never won. Even well before this imperative was fundamentally altered by the events of 1989, however, the consensus supporting public investment in science and the tenets that had been established to govern this investment had already begun to fray.

The decline of belief in three fundamental principles has been central to the unravelling of the consensus. First, it was believed that scientific knowledge is gained through processes of investigation independent of its application and, therefore, relies upon institutions with a central interest in the pursuit of knowledge without regard to its immediate practical application. The accumulation of scientific discoveries originating in corporate research laboratories, from the transistor and the identification of the background
radiation from the ‘big bang’, to the sequencing of human and other genomes, reduce the credibility of this belief. Even though it is possible to explain the mechanisms that generated these examples as exceptional, the veil of science’s independence has been torn.

Second, while it was understood that the application of scientific knowledge could lead to danger or harm, it was widely believed that the scientific enterprise itself was innocent of these misapplications and therefore did not require external governance or review. Although scientists remain among the most trusted of all groups in public opinion surveys, they have not escaped a relative loss of public sympathy resulting from the accumulation of catastrophes in the application of science and the growing perception that the threat of even larger catastrophes is a product of scientific investigation. In addition, for many the extension of research into the natural and medical sciences raises ethical concerns on which no broad consensus exists and that, therefore, are inevitably a source of controversy, leading to loss of confidence in scientists’ self-governance. While there continue to be many questions about how science should be governed and by whom, the common belief now is that science does need to be governed.

Third, it was believed that the processes governing scientific performance and reputation principally relied upon the capacities and energies of individual scientists and therefore that these processes could be relied upon to provide reliable guides to the allocation of resources. The decline in this belief is linked to the unravelling of the two previous beliefs and to the general distrust in many industrialized countries of elites and authority. Rather than consensus that scientists are pursuing a ‘higher’ interest in truth or public interest, the suspicion has grown that scientists (like almost everyone else) may be pursuing more conventional personal interests such as fame or money. For many scientists the decay of practice and belief in the principle that science pursues ‘higher goals’ is particularly troubling as it represents an attack on the cultural values that still motivate them. One measure of this is the 1969 exchange between US Senator John Pastore and Robert Wilson, the founder of Fermilab. When Pastore asked about the value of high-energy physics research in the support of national defence, Wilson replied, ‘It has nothing to do directly with defending our country, except to make it worth defending’. For some, including many scientists, Wilson’s reply is a spirited defence of the cultural value of science; for others it is an expression of the indifference of scientists to social need.

The military imperative, which had gradually faded from the rationale of first resort to a lower standing, collapsed entirely as the Berlin Wall came down. This has left only a few fundamental rationales for public science that remained safe from the declines in belief about scientific enterprise. One is the perceived centrality of science in supporting social needs such as
health care and the safeguarding of the environment. Another is the opportunity to support domestic industrial competitiveness by supporting the generation of knowledge for eventual commercialization. A third and perhaps less central rationale for the public support of scientific enterprise, is that it is an essential component of advanced scientific training, through either the renewal of the skills and knowledge of university teachers or the provision of training in research for their students. None of these rationales supports the conclusion that the scientific community alone should govern investigation. Nor do they provide much basis for the pursuit of science as a cultural ideal, as an expression of a distinct set of values or the pursuit of aims that are governed by the search for fundamental knowledge or truth.

While some may lament these developments or look for ways to reverse the tide of public belief or some of its consequences, the contributors to this book have another goal in mind. They are seeking to identify what is happening and what is likely to happen as a result of the changing rationales for funding and governing science. The means that they employ to investigate these developments and potentials all reflect the view that science may be viewed as a social system with actors, structures and incentives that are rapidly evolving. This evolution is marked by a degree of stress or pressure. The dissipation of practice and belief in the several principles has reduced the autonomy of scientific organizations and increased efforts to establish methods for assuring their accountability. Predictably, the governance models used in other contexts have been extended to science – renewals of interest in cost–benefit accounting for public investments in science, efforts to ‘commodify’ scientific output by modifications in the definition of intellectual property rights and more explicit efforts to measure the quantity and quality of scientific outputs, are all symptoms of the efforts to apply managerial methods to the governance of science. Such efforts are likely to have mischievous and unintended effects. It is in this context that we introduce the idea of rethinking the underlying rationales for funding and governance.

The dominant economic theory of science established by Nelson (1959) and Arrow (1962) is based upon, and played a significant role in buttressing, the view that science requires independent public institutions. The central feature of this theory is that the information represented by scientific outputs has the feature of a ‘public good’ – it is, in principle, available to all – and, additionally, that because it is information, its use would not suffer from congestion effects, a conspicuous feature of other public goods ranging from roads and harbours to clean air and salubrious beaches. A minor lacuna in this theory was the requirement that there be some mechanism for recovering the costs of developing potential applications from
the use of this publicly available scientific information, lest it ‘sit on the shelf’. The mechanisms of intellectual property rights, first mover advantage and commercial secrecy were, however, likely to be adequate.

Nelson (1959) and Arrow (1962) provide the answer to the question, ‘why is the market system unable to produce scientific information as it does other information outputs?’. Their answer is that it will produce such outputs, but that their amount will be smaller than is socially desirable. This is simply because any particular private actor contemplating an investment in scientific research will produce only as much as he or she is able to directly employ and capture the returns from creating – an amount that is likely to be less than is socially desirable. Unfortunately, the theory does not provide a means of assessing how much less or the problems of accountability would have been solved in the 1960s.

If private firms do not have adequate incentives to produce the appropriate amount of scientific information (and to distribute it throughout the economy), then it follows that this market failure is one in which it is proper for the government to intervene. Such intervention might range from subsidizing to commissioning the generation and distribution of scientific information. The specific assumption in Nelson’s and Arrow’s arguments, involving the universality of access to scientific information, also explains why extending the intellectual property rights to scientific information is unlikely to be a cure. While such an extension would increase private actor interest in making investments in generating scientific information, it would also raise the costs to other firms wanting to use this information far above the costs of its reproduction, again ensuring that too little science would be employed in the economy with deleterious consequences for output and productivity growth.

As with many arguments, the reliability of Arrow’s and Nelson’s conclusions depends upon the assumptions. Several of these assumptions need to be qualified in the light of intervening experience with the operation of the scientific system. The separation between scientific and technical knowledge production must be relaxed to consider the potential for complementarities between technological and scientific information. In other words, the progress of science may depend upon the advance of technology. The concept of a socially optimal amount of scientific information, therefore, cannot be separated from the decisions governing the production of technological knowledge. At first glance, this would seem to strengthen the Arrow and Nelson arguments. Greater outputs of scientific information will yield a more rapid rate of technological progress and, therefore, further strengthen scientific advance. The problem is that technological knowledge is not likely to be a public good that is freely available as an input into the production of new science. The asymmetry in access between scientific and
technological knowledge provides a motive for linking scientific and technological research efforts and institutions.

Further evidence of the motives for linking scientific and technological research projects and organizations has been provided by scholars examining scientific laboratory experience. Collins (1982) notes the difficulty of replicating results based only upon published results. The replication of scientific knowledge, particularly at the early stages of new discoveries, may require the exchange of personnel as well as publication. It is certainly possible that the linkage between technological and scientific research is as important. The participation of corporations in scientific research and networks of researchers suggests further motives for linkages, such as the need to publish in scientific journals to gain effective access to the scientific community. If knowledge transfer problems are significant, existing channels for the publication of scientific information, for example, scientific journals, cannot be viewed as the solution to the problems of improving access to knowledge – linkages between research efforts and institutions need to be fostered.

The drawing of scientific and technological research into closer interaction suggests an alternative model for the science system, one based upon a ‘network’ of distributed knowledge. Some parts of this network may function effectively by employing the traditional social norms of ‘open science’, which emphasize that open disclosure is directly linked to the competition for scientific priority, the identification of the first discoverer of new scientific results (Dasgupta and David 1994). Other parts of the network may require the negotiation of exchange between those developing knowledge, either because they have not disclosed this information or because they are unable to disclose it effectively. While both types of networks are subject to the problems of market failure described by Arrow and Nelson, the ‘negotiated access’ part of the network is also subject to further market failures resulting from failures in coordination, transaction or knowledge discovery, that is, the identification of things worth knowing. These factors may be collectively termed ‘scientific network failure’.

Analysing scientific network failure focuses attention on the scope of knowledge exchange and the possibilities of missing nodes or transfer agents that might bridge the parts of the network that do not regularly interact. It also suggests that some types of scientific knowledge may be exclusively exploited for a period of time by a limited number of participants. For example, if a particular line of scientific research, such as an investigation of the chemistry of proteins produced by the human endocrine system, is likely to have a specific applicability to the derivation of new pharmaceuticals it is conceivable that interested actors will identify each other and act either as an interest group supporting government funding
for such research or as a ‘club’ to privately finance such research. To the extent that such clubs include all of the actors that might make use of such knowledge, the social welfare losses identified by Arrow and Nelson will not appear, even though the information that they produce does not circulate generally within society. The creation of such network structures serves a similar purpose to those served by intellectual property rights in that the costs of establishing them must somehow be recouped and passed on to those consuming the goods and services produced using the knowledge that the club produces or exchanges. In the search for ways to accomplish the aim of recouping the costs of network formation or the conduct of research, all of the traditional mechanisms of cartelization – restriction of membership, control of prices and output and monitoring of behaviour – are likely to be employed.

Gibbons et al. (1994) have suggested that the network of distributed scientific knowledge is a new mode for the operation of the scientific system and that it is in the process of displacing the traditional system in which universities and government research laboratories held a favoured position. It is possible to identify the creation of new organizational forms and methods of finance for the generation and distribution of scientific results. As yet, however, there is little systematic evidence for assessing the contributions of these new organizations to the knowledge base of science or their performance relative to older organizational forms. What does appear to be clear is that corporations, particularly the growing share of those that depend upon technological advances for sustaining their competitiveness and productivity improvement, are seeking wider and more effective access to a broader range of scientific and technological knowledge. In many cases, achieving this access may require active participation in scientific networks, both to support the interaction between their scientists and scientists working in public institutions and to provide better absorptive capacity for new knowledge (Cohen and Levinthal 1990).

The coexistence of a traditional public good and the newer network structure of science is the context that the contributors to this volume address. Each part takes up one of the primary questions posed by the evolving context in which science is funded and governed. The contributions in Part I further elaborate the evolving context of the policy environment focusing on the changing role of the university (Martin, Chapter 1), the challenges to existing structures of scientific expertise by extensions in the scientific network (Callon, Chapter 2) and the specific issues posed for network organization by the growing interdisciplinarity of research (Llerena and Meyer-Krahmer, Chapter 3). Commentaries by Pavitt and Wolfe challenge the contributors and extend the scope of the discussion.

In Part II, the changing relationships among actors are examined,
principally using empirical research methods. Each of these contributions examines a piece of the larger puzzle, illustrating the scope of the new research that will be required to fully understand changes in the organization and performance of the science system. Both characterizing the changing nature of linkages between industrial and publicly funded research (Cohen, Nelson and Walsh, Chapter 4) and assessing their performance (Cesaroni and Gambardella, Chapter 7) are essential for understanding what may be expected. In addition, it is important to assess how the specificities of national context (Llerena, Matt and Schaeffer, Chapter 5) and the domain of scientific investigation (Riccaboni, Powell, Pammolli and Owen-Smith, Chapter 6) influence the evolving structure and performance of the science system. In their commentaries, Stephan and Steinmueller identify some of the key contributions and their limitations as well as identifying some of the unmet research needs in this area.

Part III develops the theory of the distributed knowledge system. The models developed in this part take up the new assumptions suggested by the network model of the science system and trace their implications for the design of collaborative alliances (David and Keely, Chapter 8) and the development of collaborative arrangements through individual initiative (Cowan and Jonard, Chapter 9). The pivotal role of new funding mechanisms is taken up for the cases of club good production (Swann, Chapter 10) and specific public programmes aimed at encouraging the formation of such clubs (Foray, Chapter 11). The commentaries of Antonelli and Hall extend the argument and identify further areas worthy of theoretical examination.

In the conclusion, we return to the overarching issues identified in this introduction and summarize some of the key findings in the chapters comprising this volume that are relevant to policy discussions, such as the emergence of the new European Research Area framework for guiding the next round of European Union funding for scientific and technological research.
REFERENCES


