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FROM KEEPING 'NATURE'S SECRETS' TO THE INSTITUTIONALIZATION OF 'OPEN SCIENCE'

PAUL A. DAVID

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FROM KEEPING 'NATURE'S SECRETS' TO THE INSTITUTIONALIZATION OF 'OPEN SCIENCE'

PAUL A. DAVID

All Souls College, Oxford and Stanford University

ABSTRACT

This essay examines the economics of patronage and the roles of asymmetric information and reputation in the early modern reorganization of scientific activities, specifically their influence upon the historical formation of key elements in the ethos and organizational structure of *publicly funded open* science. The emergence during the late 16th and early 17th centuries of the idea and practice of 'open science' represented a break from the previously dominant ethos of secrecy in the pursuit of 'Nature's Secrets.' It was a distinctive and vital organizational aspect of the Scientific Revolution, from which crystallized a new set of norms, incentives, and organizational structures that reinforced scientific researchers' commitments to rapid disclosure of new knowledge. The rise of 'cooperative rivalries' in the revelation of new knowledge, is seen as a functional response to heightened asymmetric information problems posed for the Renaissance system of court-patronage of the arts and sciences; pre-existing informational asymmetries had been exacerbated by increased importance of mathematics and the greater reliance upon sophisticated mathematical techniques in a variety of practical contexts of application. Analysis of the court patronage system of late Renaissance Europe, within which the new natural philosophers found their support, points to the significance of the feudal legacy of fragmented political authority in creating conditions of 'common agency contracting *in substitutes*.' These conditions are shown to have been conducive to more favorable contract terms (especially with regard to autonomy and financial support) for the agent-client members of western Europe's nascent scientific communities.

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From Keeping 'Nature's Secrets' to the Institutionalization of 'Open Science'

Introduction

In the United States, indeed, throughout the community of industrially advanced nations, a sense of urgency has surrounded discussions and debates about the organization and funding of R&D by governments. Surely it is not entirely coincidental that such issues were broached for serious discussion in the US during the late 1990s against the backdrop of unprecedentedly large contractions in the projected levels of real federal expenditures for both defense-related and civilian R&D during 1997–2002.[1] Lively debates concerning science policy have erupted in the US on many previous occasions, but the most recent episode would seem to have been the first sustained that has seen a fundamental questioning of some of the infrastructure institutions and organizational commitments that have framed the nation's science and technology system—at least since the major restructuring initiated by the 1945 report of Vannevar Bush.[2]

Even when the federal funding picture seemed to improve for basic research, opinion-leaders in the areas of science and education have continued to ask whether American universities should continue to be supported as the primary sites for conducting basic research in an 'open' fashion which facilitates its close integration with teaching. Some are questioning whether the emphasis on research is healthy for undergraduate teaching. Others wonder whether an 'academic research' environment is compatible with concurrent efforts to expand the sphere of collaborative R&D with industry, pro-active forms of 'technology transfer,' and to make more extensive use of intellectual property and other means of establishing a proprietary interest in the research activities of faculty, staff and students? Might it not be better to hive off both basic and applied research into specialized institutes, thus resolving conflicts that arise between the universities' conduct of their traditional functions and the drive on the part of other organizations and agencies (both private and governmental) to control information flows in order to better exploit new findings? Issues similar to those concerning the future role of the university in the 'national innovation system' also have arisen in discussions of moves towards 'privatizing' other

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1 See Boesman 1997, Koizumi, 1997, and Mowery 1997.

2 On the Bush Report, the recurring issues in US science policy debates, and the prelude to the recent discussions, see, e.g., David 1996, Boesman 1997 and references therein.

publicly funded research institutions such as the National Laboratories, and re-orienting national research institutes towards commercial application of their research output [3]

At a time, when the reorganization of national science and technology systems are under active consideration and the fitness of recent experiments with innovations in institutional arrangements are undergoing re-assessment, it may be especially useful to look backwards to the historical circumstances in which some of the basic institutions of science first emerged; and, equally, and to the economic, social and political forces that have shaped their subsequent evolution. Economists quite rightly will wish to continue to probe for deeper understanding of the insides of the 'black box' of technology (Rosenberg 1982). But, by comparison with what has been learned already concerning institutional arrangements and business strategies affecting corporate R&D investments, and the mechanisms enabling private appropriation of research benefits, it remains surprising that so much less is known about the economics origins and effects of the corresponding institutional infrastructures shaping the world of 'academic' science, and about the organization of publicly supported R&D more generally.

The desirability of closing this particular lacuna in the economics and economic history literatures has been just as evident to those who have noticed it within a broader framework of concern with the economic analysis of institutions, as to those who have begun to approach that task by bringing the perspectives and methods of industrial organization economics to bear in the area of science and technology studies.[4] Even before the 'new economics of science' had begun to direct attention to such a program, Douglass North (1990:75) saw a significant challenge and an promising opportunity in explicit exploration of 'the connecting links between institutional structures...and incentives to acquire pure knowledge.'

A variety of historical inquiries may be seen as responses to that challenge, by examining key episodes in the institutional evolution of 'public science' and its complex and changing relationship with the other organizational spheres of contemporaneous scientific activity.[5] The latter include, of course, both those in

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[3] For entry points to the vast literature, see e.g., David, Mowery and Steinmueller (1994) on university-industry R&D collaborations; Guston and Keniston (1994) on university relations with the federal government; Branscomb (1994), Cohen and Noll (1994) on the National Labs.

[4] Within the past decade the situation has begun to change. See Dasgupta and David (1987, 1988, 1994), David (1994), and the more recent surveys by Diamond (1996), Stephan (1996), and David, Foray and Steinmueller (1997).

[5] See, for a recent effort to bring this historical experience to the attention of economists, the special session in the American Economic Association *Proceedings* on 'Clio and the

which industrial research was conducted for private commercial gain under 'proprietary rules,' and the 'defence-related' pursuit of scientific and engineering knowledge under conditions of restricted access to information about basic findings and their actual and potential applications. Much fascination is imparted to the study of institutional evolution in that sphere by the complexity of the organizational details, and the high stakes attached to issues arising from the immediate entanglement of R&D programs and project with matters of national security; or, alternatively by the strategies and fortunes of business corporations that turn on the capabilities of their research organizations. Nevertheless, the historical emergence of the other, academic sphere of research poses a number of questions to which the answers seem less intuitively obvious and straightforward, and yet critically important as a guide in the formation of constructive science and technology policies.

Although the conceptualization of science as the pursuit of 'public knowledge' and an object of public-minded patronage today seems a natural, even a 'primitive' notion, it is in reality a complex social contrivance. Moreover, 'open science' is a social innovation of comparatively recent historical origin. This has afforded historians of scientific institutions the archival material to examine the evolution of its outward forms of support in considerable detail. But the circumstances and interests that gave rise to this innovation, and their relationship to the economic forces that have sustained and shaped its subsequent development have not received the attention that the importance of the subject in the modern world would seem to warrant.

Within university-based research communities, especially, there are recognized norms and conventions that constitute a well-delineated professional ethos to which scientists generally are disposed to publicly subscribe, whether or not their own behaviors always conform literally to its strictures governing the organization and conduct of research. The norms of 'the Republic of Science' that have famously been articulated by the sociologist Robert K. Merton (1973: esp. Ch. 13; 1986: Pt. III) sometimes are summarized under the mnemonic CUDOS: communalism, universalism, disinterestedness, originality, skepticism. (See Ziman 1994, p. 177). The 'communal' ethos emphasizes the cooperative character of inquiry, stressing that the accumulation of reliable knowledge is an essentially social process, however much individuals may strive to contribute to it. The force of the universalist norm is to render entry into scientific work and discourse open to all persons of 'competence' regardless of their personal and

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Economic Organization of Science' (May 1998), which included brief, chronologically ordered contributions by David 1998, Lenoir 1998, Lécuyer 1998, and Blumenthal 1998.

ascriptive attributes. A second aspect of 'openness' concerns the disposition of knowledge: the full disclosure of findings, and methods, form a key aspect of the cooperative, communal program of inquiry. Full disclosure, in turn serves the ethos legitimating and, indeed, prescribing what Merton called 'organized skepticism'; it supports the expectation that all claims to have contributed to the stock of reliable knowledge will be subjected to trials of replication and verification, without insult to the claimant. The 'originality' of such intellectual contributions is the touchstone for the acknowledgment of individual scientific claims, upon which collegiate reputations and the material and non-pecuniary rewards attached to such peer evaluations are based.

Whence did we come by this distinctive set of governance norms for the search for reliable knowledge? How did they become institutionalized as the legitimate ethos—even where they are not strictly adhered to in practice – among the class of academic organizations that flourish in the democratic societies of the modern world? These questions about the nature and origins of the fundamental lines of cultural and institutional demarcation that distinguish the sphere of 'open science' activities—supported by state funding and the patronage of private foundations, and carried on in universities and public (not-for-profit) institutes – form the central substantive historical problem that I address in this paper.[6] It will be seen that in the particular answers to which I have been led, there is also a broader message for contemporary science and technology policy-making.

The Problem: Why 'Open Science'?

Judged by historical standards, 'open science' is a comparatively recent organizational innovation. Accompanying the profound epistemological

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6 This paper draws upon David (1997: December), which should be consulted for fuller historical documentation and references to the relevant literature. Space there also permits proper acknowledgement of the help of Avner Greif, Mario Biagioli, Partha Dasgupta, Weston Headley, Scott Mandelbrote, Joel Mokyr, Noel Swerdlow, and many other colleagues, institutions and foundations who generously contributed both intellectually and materially in support of my researches in area since 1991. The present essay has benefited from the comments and suggestions by Kenneth Flamm, Zvi Griliches and David Mowery, which could not be accommodated within David 1998—the very abridged version read at the January 1998 AEA Meetings in Chicago, and published shortly thereafter in the *AEA Proceedings.*

transformations effected by the fusion of ‘experimentalism’ with Renaissance mathematics, the cultural ethos and social organization of western European scientific activities during the late 16th and 17th centuries underwent a significant reorganization, a departure from the previously dominant regime of secrecy in the pursuit of Nature’s Secrets. This development should be seen as a distinctive and vital aspect of the Scientific Revolution, from which there crystallized a new set of social conventions, incentive structures, and institutional mechanisms that reinforced scientific researchers’ commitments to rapid disclosure and wider dissemination of their new discoveries and inventions. Yet, the puzzle of why and how this came about has not received the notice it would seem to deserve, especially in view of the completmentarities and tensions that are recognized to be present today in relations between the regimes of ‘open’ and ‘proprietary’ science.

Even superficial reference to the antecedent intellectual orientation and social organization of scientific research in the West suggests the utter improbability of the historical bifurcation in which a new and quite antithetical mode of conducting ‘the hunt for knowledge’ emerged alongside (and in some sense in competition with) the older, secretive search for ‘Nature’s Secrets.’ Virtually all of the intellectual traditions and material conditions in the medieval West inveighed against ‘openness’ of inquiry and public disclosure of discoveries about the natural order of the world, let alone the heavens. Medieval experimental science, was shaped by a political and religious outlook that encouraged withholding from the ‘vulgar multitude’ arcane knowledge that might bring power over material things (see Thorndike 1950: vol. II,; Eamon 1985, 1994). The imperative of secrecy was particularly strong in the medieval and Renaissance traditions of Alchemy, where, indeed, it persisted side-by-side with the emergent institutions of open science throughout the 17th and into the 18th century (see Dobbs 1975, Vickers 1984, Westfall 1980). Social and economic regulations during the Middle Ages, along with the relatively primitive and costly technologies available for scientific communications, also reinforced the moral and philosophical considerations arrayed against open disclosure of discovered secrets. Economic rent-seeking worked in the same direction: knowledge of recently discovered geographical secrets that were held to be of potential mercantile value, such as trade routes, would be kept from the public domain. Similarly, technological recipes normally were closely held by

craftsmen, even when they were not compelled by guild restrictions to preserve the 'mysteries' of the industrial arts.[7]

Why then, out of such a background of secrecy and obfuscation, should there have emerged a quite distinctive community of inquiry into the nature of the physical world, holding different norms regarding disclosure, and being governed by a distinctive reward system based upon priority of discovery? Why so, especially when in the modern context we see that there is little if any difference between the methods of (scientific) inquiry used by university scientists working under the institutional norms of open science, and the procedures that they (or others with the same training) employ in the setting of a corporate R&D laboratory? Can the social organization of open science then be simply an epiphenomenon of the profound philosophical and religious reorientations that have been presented as underpinning the Scientific Revolution, if not the epistemological transformation that latter had wrought? Or, should the intellectual achievements of that epoch instead be read as consequences of what might be called the 'Open Science Revolution'? To state the problem more synthetically, is it not plausible that these two discontinuities—the one taking place in the social organization of scientific inquiry and the other transforming its intellectual organization—were interdependent, and entangled with each other in ways that need to be more thoroughly understood?

A start towards answering this question is provided by considering the economic logic of the organization of knowledge-producing activities, for, it is possible in such terms to give a complete functionalist account of the institutional complex that characterizes modern science (see, e.g., Dasgupta and David 1987, 1988, 1994). In brief, the norm of 'openness' is 'incentive compatible' with a collegiate reputational reward system based upon accepted claims to priority; and it is conducive to individual strategy choices whose collective congruence reduces excess duplication of research efforts, and enlarges the domain of informational complementaries. This brings socially

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[7] From the 14th century to the early 18th century in Europe, the issuance of 'letters patent' and granting of royal 'privileges' conferring monopoly rights in exchange for the disclosure of technological information was aimed primarily at effecting the transfer and application of existing industrial arts and engineering practices, i.e., techniques already known to master-craftsmen and engineers in other territories; and not at inducing fresh inventive activity. Many early patent monopolies were, in effect, local franchises designed to shelter immigrating expert-practitioners from the subsequent competition of the apprentices and journeymen they were expected to train, or others who would try imitate them once their particular 'mysterie' had been successfully established in the new cities and principalities to which they were recruited. See David and Olsen (1992), David (1993 a), and sources cited therein.

beneficial ‘spill-overs’ among research programs, and abets rapid replication and swift validation of novel discoveries. The advantages of treating new findings as ‘public goods’ in order to promote the faster growth of the stock of knowledge, thus, are contrasted with the requirements of secrecy for the purposes of securing a monopoly over the use of new information that may be directly or indirectly exploited in the production of goods and services. This functionalist juxtaposition suggests a logical basis for the existence and perpetuation of institutional and cultural separations between two normatively differentiated communities of research practice, the open ‘Republic of Science’ and the proprietary ‘Realm of Technology’: the two distinctive organizational regimes serve different and potentially complementary societal purposes.

The foregoing, ‘logical origins’ style of explanation for the institutions of modern science (and technology), however, is one in which all details of their historical evolution are ignored. Such a rationale would seem, at best, to presuppose a form of ‘creationist’ fiction—namely that these arrangements were instituted *ab initio* by some external agency, such as an informed and benevolent political authority endowed with fiscal powers. That objection calls for an explicit examination of the ‘historical origins’ of the institutions of open science, since these remain outside the set of ‘logical origins’ that one arrives at by simply considering the present-day functional value of an already extant, cooperative mode of scientific research.

The Argument: Noble Patrons, Mathematicians, and Principal-Agent Problems

Rather than trying to construe the reorganization of scientific activities in early modern Europe as having somehow derived automatically from the intellectual changes represented by the new style of ‘scientific’ activity, I contend that the historical emergence of the norms of disclosure and demonstration, and the rise of ‘cooperative rivalries’ in the revelation of new knowledge, had independent and antecedent roots. These are to be found in the social and institutional contexts in which the new breed of scientists in that era were working. My central thesis here is that the formation of a distinctive research culture of open science was first made possible, and, indeed, was positively encouraged by the system of aristocratic patronage in an era when kings and nobles (both lay and ecclesiastical) were immediately concerned with the ‘ornamental’ benefits to be derived by their sponsorship of philosophers and savants of great renown.

To support this interpretation, I argue that the economic logic of the patronage system in post-Renaissance Europe induced the emergence and promoted the institutionalization of reputation-building proceedings, all of which turned upon the revelation of scientific knowledge and 'expertise' among extended reference groups that included 'peer-experts.' The mechanisms involved spanned the range from participation in informal networks of correspondence, to public challenges and contests, open demonstrations, and exhibitions, and the certification of individuals by co-optation and election to 'learned societies.' Patronage, however, was an old system in the 17th century, and the sponsorship of intellectuals was a long-standing prerogative and responsibility of Europe's social and political elites. It is necessary, therefore, explain why something new appeared on the scene; why some of the conventions and norms now associated with open science—in particular, the reliance upon peer appraisal and collective evaluation expressed through the formation of professional reputations—were induced in primitive form at this particular juncture in history. The key propositions for this part of my argument derive from first considering the economics of patronage in general, and then noticing the specific implications of the newly arising problems of 'principal-agent contracting' that were created by the encounter of the late Renaissance patronage system with the new (mathematical) form of natural philosophy practiced by Galileo, Kepler and their contemporaries.[8]

Aristocratic patronage systems have reflected two kinds of motivation: the utilitarian and the ornamental. Most political elites, in addition to recognizing some need in their domain for men capable of producing new ideas and inventions to solve mundane problems connected with warfare and security, land reclamation, food production, transport facilities, and so forth, also have sought to enlist the services of those who professed an ability to reveal the secrets of Nature, and of Destiny. Kings and princes, and lesser nobles too sought to surround themselves with creative talents whose achievements would enhance not only their self-esteem, but their public image—those aspects of

8 Galileo's involvement in the system of court patronage in Italy, and his communications during 1610 with Kepler, then in the service of Emperor Rudolph II in Prague, is documented by Biagioli (1993), and further considered in David (1997:November, pp.32-36). The situations of many other notable scientific figures elsewhere in Europe also can be mentioned, e.g. as by Mokyr (1990: p. 73 on Leibnitz; p. 84 on Torriceli; p.169 on Borelli.) See also the extensive discussions in Moran (1991) on the patronage of science and medicine in the court of Prince Henry of Wales (d.1612) at Richmond Palace, the Court of Rudolph II and the Habsburg circle in the mid-seventeenth century, the Munich Court of Ferdinand Maria, the Elector of Bavaria (r. 1654-1679), and elsewhere in Europe.

grandeur and ostentatious display which might serve to reinforce their claims to rightful authority. Thus, poets, artists, musicians, chroniclers, architects, instrument-makers and natural philosophers found employment in aristocratic courts, both because their skills might serve the pleasures of the court, and because their presence 'made a statement' in the competition among nobles for prestige. These dyadic patron-client relationships, which offered the latter material and political support in exchange for service, were often precarious, uncomfortably subject to aristocratic whims and pleasures, and to the abrupt terminations that would ensue on the disgrace or demise of a patron. Nonetheless, they existed in this era as part of a well-articulated system characterized by elaborate conventions and rituals that provided calculable career paths for men of intellectual and artistic talents (see Biagioli 1990, 1993; Moran 1991).

Those motives for entering into a patron's role that reduce to symbolic acts of self-aggrandizement are here subsumed under the heading 'ornamental.' Such reasons, however, should be understood to have been no less instrumental in their nature and roots than were the utilitarian considerations for the patronage of intellectuals. The public display of 'magnificence,' in which art and power had become allied, was a stock item in the repertoire of Renaissance state-craft (see Strong, 1984). This is significant, because inventions and discoveries that met utilitarian needs in some instances would have to be kept secret if they were to be most useful, whereas it is in the nature of the ornamental motive that its fulfillment elicits the disclosure of new, marvelous discoveries and creations; that the client's achievement on behalf of the patron be widely publicized. Indeed, it was very much in the interest of a patron for the reputations of those he patronized to be enhanced in this way, for their fame augmented his own.[9] A second point of significance is that only some utilitarian services but most ornamental services had 'positional' value from the patron's point of view. Although having a skilled artist or a clever astronomer in one's court was altogether a good thing, it was far better if such clients were personages of greater accomplishments and renown than those who happened to be in the service of a rival's court. The pressure on Europe's ruling families to have intellectuals of recognized eminence in their service was thus exacerbated by the

9 Galileo understood this well, as was evident from the adroit way in which he exploited his ability to prepare superior telescopes for the Grand Duke of Tuscany, Cosimo II de' Medici: he urged his patron to present these to other crowned heads in Europe, whereby they too might observe the new-found moons of Jupiter which the *Sidereus Nuncius* (March 1610) had proclaimed to be 'the Medicean stars.' See Drake (1957, 1978), Westfall (1985), and Biagioli (1990, 1993: Ch.1).

existence of rival rulers and their courts, and so lent additional strength to the ornamental motives for their patronage of such clients.

Into this setting a new element had been interjected during the 16th century. The more extensive and rigorous use of mathematical methods formed an important aspect of the work of the new breed of natural philosophers.[10] But, one surely unintended side-effect of this intellectual advance was to render the basis of the mathematically sophisticated savants' claims and reputations less immediately accessible for evaluation by the elites in whose service they wished to be employed. The difficulties thereby posed by the asymmetric distribution of information were rather unprecedented, not having been encountered to the same degree in the patronage of intellectuals and artists who followed other, less esoteric callings. The new breed of scientists, however, claimed to specialize in revealing the unfamiliar. Opportunities for charlatanry here were more rife, and so were the risks of embarrassment for the patron, should it turn out that one had sponsored a fraud—or much worse, a heretic. Thus, even where the services of the mathematically trained intelligentsia might be sought for essentially practical, utilitarian motives (such talents being useful in designing machinery for public spectacles, surveying and cartography, ballistics and correct use of perspective in pictorial arts), the soundness of the candidates' qualifications had become more problematic and far from inconsequential.

In other words, this line of argument directs attention to the emergence of especially compelling reasons for noble patrons in the late Renaissance to delegate part of the responsibility for evaluating and selecting among the new breed of 'savants', devolving those functions upon the increasingly formalized communities of their fellow practitioners and correspondents. Except for those few who were themselves versed in mathematics or other experimental practices associated with the new learning, patrons were inclined to refrain from passing personal judgement on scientific assertions and involving themselves in substantive controversies (see Biagioli, 1993). It was left to the initiative of the parties dependent upon such patronage to organize the production of credible testimonials to their own credibility and scientific status.

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10 Following the fusion of Arabic and classical mathematics, the significance of algebra, the geometry of conic sections, trigonometry, and still more esoteric developments was recognized and openly proclaimed in terms that drew upon a rhetorical tradition reaching back to the great Renaissance mathematician 'Regiomontanus'—as Johannes Muller of Konigsberg (1432-1476) styled himself. See Swerdlow (1993), Boyer (1985: Ch. XV) on Renaissance mathematics; Keller (1985) on the program and rhetorical developed on behalf of mathematical training during the 1570's and 1580's; Feingold (1984:Ch.IV), Westfall (1985), Biagioli (1989, 1990, 1993) on the patronage of mathematicians.

Not altogether surprisingly, therefore, the mid-16th century, which is frequently taken as the beginning of the era of modern mathematics, also witnessed the formation of active networks of correspondence among Europe's adepts in algebra, announcing newly devised techniques and results; this era initiated the modern tradition of publicly posing mathematical puzzles, issuing scientific challenges, announcing prizes for the solutions of problems, and the holding of open competitions to test the claims of rival experts in the mathematical arts (see e.g., Boyer 1985: esp., 310–312; Feingold 1984; Keller 1985). On the interpretation proposed here, the new practices of disclosure constituted a functional response to heightened asymmetric information problems that the mathematization of natural philosophy and the practical arts posed for the Renaissance system of court-patronage.

Rival Principals and Common Agency Contracting—The Legacy of European Feudalism

The conditions I have sketched regarding the late Renaissance and early modern system of court patronage present a situation economists would describe as 'common agency contracting' involving the competition among incompletely informed principals for the dedicated services of multiple agents. This correspondence suggests several noteworthy points about the economic organization of scientific activities in Europe during the late 16th and early 17th centuries.

First, since what the scientist-clients had to offer was 'novelty,' at any point in time the welfare of several patrons could not be jointly advanced in the same degree. As a consequence of the dominance in the early history of modern science of patrons who were concerned with the ornamental rather than the utilitarian value of scientist-philosophers, the services a client provided to his several patrons were essentially 'substitutes' rather than 'complementary' commodities.

Second, in the majority of cases the material rewards offered to clients by any single patron were not sufficiently large and certain to free the former from the quest for multiple patrons. The situation typically being that of common agency, we may draw on Avinash Dixit's (1996) recent theoretical exposition to point out that in the absence of full information, and concerted action on the part of principals, the nature of the incentive contracts offered by the latter would reflect their awareness of the possibility that a client/agent could use the means provided by one patron to serve the ends of another. The resulting Nash

equilibrium in the game among rival principals would then be a set of patronage-contracts that offered clients comparatively weak material incentives to devote their efforts exclusively to the service of any one patron. Such an equilibrium outcome, of course, would be consistent with the necessity of seeking to serve a number of patrons concurrently (however arduous and demeaning a scientist like Galileo might feel that to be); it would thereby reinforce the choice on the part of would-be clients of research and publication strategies that would lead towards widening the circle of their repute.

Third, as has been shown by Lars Stole's (1990) analysis of mechanism design under common agency contracting, the equilibrium outcome in the case of 'contract substitutes' is in general more favorable to the agent than is the case when the services performed for different principals are complements. In effect, the competition among patrons to command the faithful attention of an agent/client would lead to contracts that allowed the latter to retain more 'rents' from the specialized information he possessed. This provided greater rewards for scientific activities than would have resulted otherwise, were there only a single possible patron on the scene, or had the patrons predominantly enjoyed positive externalities from others' support of the agent's efforts—the characteristic situation where there are significant 'spillovers' of utilitarian benefits from new knowledge.

There is in the story related here an historical irony well worth remarking upon, especially as it serves also to underscore the tenacity of the past's hold on the incrementally evolving institutions that channel the course of economic change.[11] The nub of it is simply this: an essentially pre-capitalist, European aristocratic disposition to award patronage for the purposes of enhancing rulers' political powers symbolically (through displays of 'magnificence),' came to confer value upon those who pursued knowledge by following the 'new science' in the late 16th and 17th centuries. The norms of cooperation and information disclosure within the community of scientists, and their institutionalization through the activities of formal scientific organizations, emerged—at least in part—as a response to the informational requirements of a system of patronage in which the competition among noble patrons for prestigious clients was crucial.

Those rivalries, in turn, were a legacy of western European feudalism: it was the fragmentation of political authority that had created the conditions of

11 On the theme of 'path dependence' in the dynamics of economic systems, see, e.g. David (1988, 1993b, 1994, 2000) .

'common agency contracting in substitutes.' An instructive contrast therefore might be drawn with the alternative circumstances of a monolithic political system, such as had prevailed elsewhere—as in the Heavenly Empire of China during an earlier epoch, to cite a well-known case of a society that clearly possessed the intellectual talents yet failed spectacularly to institutionalize the practice of open science.

Sequelae: Open Science in the 'New Age of Academies'

The foregoing necessarily brief treatment of immensely complex matters has focused upon the economic aspects of patronage in the production of knowledge, and the latter's influence upon the historical formation of key elements in the ethos and organizational structure of *open* science. Those developments preceded and laid the foundations for the later seventeenth and eighteenth century institutionalization of the open pursuit of scientific knowledge under the auspices of State-sponsored academies. The Royal Society of London was founded in 1660 and received charters from Charles II in 1662 and 1663, and within another few years, in 1666, the Académie Royale des Sciences was created on the initiative of Colbert. The activities of these two State foundations, and the ensuing formal institutional 'reorganization of science' in Europe which they inspired, have received much attention from more than one generation of historians of science.[12] Although from some perspectives this concentration of scholarly focus might be judged inordinate, it may also be justified by the fact that another 70 officially recognized scientific organizations have been identified by McClellan (1985) as having been established between the 1660s and 1793, specifically on the models provided by those archetypal institutions.

Just as I have argued in the foregoing text that the intellectual reorientation represented by the scientific revolution cannot be held to have been a motor cause of the emergence of the 'open' mode of searching for Nature's Secrets, so there are good grounds in the work of other scholars for resisting the interpretation of the 'new Age of Academies' as constituting a radical organizational departure. Furthermore, there is reason also to contest the view that the so-called 'New Age of Academies' had been called forth by the enlarged scale and costs of the new modes of scientific inquiry, and the supposed failures of private patronage in the mid-seventeenth century.[13]

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12 See, e.g., Brown (1934/67), Orenstein (1963), Hahn (1971), Hunter (1981), McClellan (1985).

13 See, e.g., Lux (1991) for discussion and references to the relevant literature.

The post-1660s phase in the evolution of the institutions of modern science is better viewed essentially as the continuation of a much broader cultural movement that had been taking place in Europe outside the medieval universities. One aspect of this movement manifested itself in the appearance, around the turn of the *sixteenth* century, of numerous privately patronized scientific societies and 'academies'. Seventeenth century science proper thus has been found to have played only a very minor part of that wider intellectual reorganization: of the 2500 learned societies that are known to have been instituted in Europe between 1500 and 1800, at least 700 were formed during the sixteenth century alone. Although some among these organizations were scientific in purpose, they were not in the pre-1550 vanguard; according to McCllelan (1985), the overwhelming majority were formed in response to interests broader than anything that resembling the organized pursuit of science.

The following passage from the work of David Lux (1991:pp.189,196) serves well to articulate the present state of understanding about the nature of the causal relationships in this complicated sequence of developments:

> '[T]he traditional points of departure for discussing organizational change in science—della Porta's *Accademia Secretorum Naturae* [founded in Naples, 1589] or Cesi's Accademia dei Lincei [founded in Rome, 1604]—offer nothing to suggest the intellectual novelties of sixteenth-century science produced real organizational change....Rather than producing organizational change, sixteenth- and seventeenth-century science followed other intellectual activity into new organizational forms. Indeed, in strictly organizational terms there is no obvious justification for attempting to isolate science from other forms of intellectual activity before the end of the seventeenth century. Nor is there any obvious justification for portraying science as honing the cutting edge of organizational change. Despite the literature's claims about novel science creating needs for new organizational forms, the institutional history of science across the sixteenth and seventeenth centuries actually speaks to a record in which scientific practice changed only after moving into new organizational forms.'

Thus, the institutional context provided by the early academies had readily accommodated the needs for 'social legitimization' and, for theatres for disclosures where patronage-seeking practitioners of the new natural philosophy might enhance their *public* repute. Subsequently, the institutionalization of the

nascent ‘open science’ mode of organization was carried forward upon an elevated stage under the aegis of the early modern state, where it mobilized augmented resources and applied the new methods of scientific inquiry on a scale that eventually altered the character of scientific practice.

In a still later era, beginning mid-way through the nineteenth century with the introduction of modern scientific research into the German state-sponsored universities, mimetic inter-institutional competition created a new set ‘academic market’ conditions that proved propitious for the establishment of research scientists, and graduate research seminars within the ambit of the university. In this new setting, the fundamental problems of reputation and agency—upon which the foregoing economic analysis has been focused – soon re-emerged in different, but nonetheless recognizable forms.[14] Even today, university patrons, both private and public, along with academic administrators, and members of the professoriate find themselves confronted by informational asymmetries, agency problems, and reputational reward mechanisms that parallel in many respects those that once had characterized the system of European court patronage.

Some things change, however. As the ornamental value of supporting esteemed scholars and scientists has given way to the instrumental power of scientific knowledge, the ability of individual members of ‘the Republic of Science’ to extract a large part of the ‘information rents’ has been circumscribed; correspondingly, there has been an enlargement of the relative share of the benefits that flow—in the form of ‘knowledge spill-overs’—to the ultimate patrons the publicly supported regime of ‘open science. Yet, some continuities are preserved: in the modern system of devolved patronage of science, those having the responsibility for the management of academic institutions and non-profit research institutes appear simultaneously in the roles of agents *vis-à-vis* the public, and *principals vis-à-vis* the research agents upon whose expertise they must rely. In their dual capacities the administrators of academic institutions (and the individuals who staff them) must continue to seek effective ways of mediating conflicts between the divergent interests of the principals and their respective agents. On the one hand, they are enjoined to seek the larger societal, public goals that are best served by preserving the organizational modes and norms open scientific inquiry; while, on the other hand, they are being encouraged to try to appropriate a larger portion of the ‘information rents’ for use in more narrowly parochial institutional and private undertakings – even

14 See, e.g., Ben-David 1991:Ch.8; Lenoir 1998, and references cited therein.

when to do so entails circumscribing open access to the new knowledge gained from the research conducted under their auspices.

Conclusion

The moral of all this goes further than merely providing another attestation to the truth in the aphorism that the more things seem to change, the more they stay the same. Some important part of the power of modern science today derives from the radical social innovation that the 'open science' regime constituted. A corollary proposition, to which the historical experience recounted here also lends support, is that the methods of modern science themselves have not been, and still are not sufficient to create the unique cultural ethos associated with 'the Republic of Science.' Nor can they be expected to automatically induce and sustain the peculiar institutional infrastructures and organizational conditions of the open science regime, within which their application has proved so conducive to the rapid growth of the stock of reliable public knowledge, and all that flows therefrom.

Rather than emerging and surviving as robust epiphenomena of a new organum of intellectual inquiry, the institutions of open science are independent, and in some measure fortuitous, social and political constructs. They are in reality intricate cultural legacies of a long past epoch of European history, which through them continues to profoundly influence the systemic efficacy of the modern scientific research process.

Major features of the institutional infrastructure of public science, thus being to a considerable degree exogenous to actual scientific practice in the contemporary world, can be subjected to substantial amounts of experimental tinkering, and even major re-design, without jeopardizing the methodology of current inquiry. In one sense, this freedom this affords the manipulation institutional incentives and constraints as instruments of modern science and technology policy can be read as 'the good news.'

It should be taken with a grave caution, however: wise policy-making in this sensitive area must pay especial heed to those organizational instruments' own complex and contingent histories, and so respect the potential fragility of the institutional matrix within which modern science evolved and flourished. Along with a sense of awe and gratitude for the good fortune of having received this remarkable gift from the past, we shall do well to maintain a sobering awareness of the extent to which our future welfare has come to depend upon the continued smooth workings of an intricate and imperfectly understood piece of

social machinery—one that need have no adequate capabilities for self-repair, but readily may be damaged by careless interventions.

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