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ESSAY REVIEW

The European birth of modern science: an exercise in macro and comparative history

H. Floris Cohen: How modern science came into the world: Four civilizations, one 17th-century breakthrough. Amsterdam: Amsterdam University Press, 2010, xl+784pp, €65.00 HB

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> The rise of the West is, quite simply, the pre–eminent historical phenomenon of the second half of the second millennium after Christ.… It is perhaps the most challenging riddle historians have to solve … it is only by identifying the true causes of Western ascendancy that we can hope to estimate with any degree of accuracy the imminence of our decline and fall. (Niall Ferguson, *The West and the Rest*)

Typically, for Niall Ferguson, these bold claims and big questions are routine business. Yet, they are the sort that give many academic historians of science a frisson of fear and excitement, to be exorcised with a smirk of ironic dismissal. To economic historians like Ferguson, with large historical (hence contemporary) problems to tackle, the rise of modern science in the West after 1500 is not a challenge to be dissolved by administering a slow drip of the dilute acid of expert micro studies. Modern European science is, in his metaphor, one of the West's 'killer applications', along with democracy, the rule of law, capitalism, individual freedom, and the separation of church and state. It is emblematic and partially causative of the rise of the West and is entangled in questions about its prospects and that of the world which the West largely brought into being.

Experts in fields neighbouring history of science regularly problematise the rise of modern science, as do popular writers and documentary makers. It follows that more historians of science than presently seem interested should once again attend to this problem. In doing so, it is to be hoped that the issue not be, on the one hand, reduced to tales of revolution and rupture in some intellectual or social mono-factor (be it metaphysics, method, natural law, social norms, trust, experimental

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philosophy, etc.); or, on the other hand, relegated to a narrative confection of simple continuity from the high Middle Ages. Rather, as with all the 'killer aps', it surely is a case of a long historical process, involving quite novel emergences of concept and practice, as well as tangled skeins of intended and unintended consequences, all from time to time exposed to decisive contextual drivers, the depiction of whose nature and mode of action is the job of historians of such cognate phenomena. Moreover, if to this drawn out process of often surprising outcomes, we apply the term revolution, perhaps we should now do it in the nuanced, considered way that social and economic historians go about their business of treating huge but long changes, that is to say, more in the manner first limned by De Tocqueville (of which more anon).

Luckily for us, into this cultural moment and towards precisely this challenge has been launched H. Floris Cohen's long-anticipated study, *How Modern Science Came into the World*: *Four Civilizations, One 17th–Century Breakthrough*. At once highly scholarly and daring in its scope, goals and historical technique, it certainly can stand on its own, despite the fact that it also remarkably resides upon the shoulders of his earlier, equally admirable tome, *The Scientific Revolution—A Historiographical Inquiry* (1994), a magisterial guide to the history of historiographical takes on the Scientific Revolution from the late eighteenth century to the 1990s. Their combined nearly fifteen hundred pages will rightly sit side by side on the shelves of all serious students of the problem for generations to come, an enviable scholarly heritage. Readers of both volumes will easily see the many and often subtle ways in which Cohen's earlier historiographical winnowing has shaped what he does, and what he avoids, in the intricately constructed argument of the present volume.

Two large goals frame Cohen's project, both achieved with impressive results. First of all, Cohen offers a sequence of structured comparisons of the regimes of natural knowledge that prevailed in classical Athens, Hellenistic Alexandria, medieval Islam, China (in several periods), high Medieval and then Renaissance Europe. This paves the way for and frames the accomplishment of his second aim, to both broadly and thickly narrate the course of the Scientific Revolution of the seventeenth century *and* sharply explain it in terms of what I would call a model of processes of change in European structures of nature-knowledge. Cohen weaves both his comparative analyses and his account of the process of the Scientific Revolution around the trajectory, interactions and contextual shapings of two sets of classical achievements: (1) The ancient schools of systematic philosophy of nature—Platonist, Aristotelian, Atomist and Stoic, which he terms 'Athens' after the classical seat of their deepest cultivation. (2) The suite of mathematical disciplines first systematically and theoretically cultivated in classical antiquity, including pure geometry and arithmetic, as well as the mathematical disciplines applied to physical questions, such as geometrical optics, astronomy, mechanics and music theory. All these mathematical disciplines he terms 'Alexandria', after the Hellenistic seat of their most concentrated and productive cultivation in classical civilisation. The categorical separation correctly signifies the small degree of crossfertilisation between the two suites in classical antiquity (and indeed in most of their subsequent loci of cultivation). It also signals that there is no question of finding Modern Science in either.

The comparative dimension of Cohen's study considers the varied manners in which Athens and Alexandria were recovered, interpreted and articulated in four other cultural loci: early Medieval Islam, high Medieval Europe, Renaissance Europe and finally seventeenth-century Europe (An additional comparison, with classical Chinese doctrines of nature, is carried out in relation to the initial delineation of Athens and Alexandria.). In the first three sites, nothing like modern science emerged, despite the partial recovery and assimilation of Athens and Alexandria in these cultures, and the advent of fruitful embroideries upon the two foundational traditions. Cohen pursues one key question within each case and comparatively across all the cases, returning to it continually throughout the text: Why, in each case, except Renaissance Europe, was the initial uptake and upswing followed by decline? Europe during the course of the seventeenth century was the unique site where a long and complex process of the emergence of modern science was played out, itself initially launched on the Renaissance foundation by an unprecedented simultaneous triple transformation in the two generations after 1600.

The flavour of the comparative treatment is best conveyed in Cohen's judgements about the character of medieval Islamic nature-knowledge. In Islam, compared to the European late Renaissance and early seventeenth century, an intellectual and institutional separation existed between its highly developed practical arts and techniques on the one hand, and its innovatively cultivated, recovered Athens and Alexandria traditions on the other. Moreover, Athens did not enjoy wide acceptance by orthodox religious authorities, hence natural philosophising tended to be marginalised from the main stream of the culture. This became even more the case later in Medieval Islam after invasions and political fragmentation stimulated a more inward looking and literalist religiosity and the rise of the madrasas. In contrast, from the late Middle Ages, Europe possessed a well-established university system, wherein the tools of thought and the rudiments of one species of Athens, scholastified Aristotelianism, were taught to thousands of young men. Despite turbulence and resistance, this could occur because this natural philosophy, suitably modulated, was to a first approximation consensually adjudged to be acceptably religiously orthodox—a condition preserved both in emerging Protestant contexts and in Catholic Counter Reformation Europe. Moreover, in Islam, few dynamic linkages were encouraged between the highly developed practical arts and innovations within the field of natural philosophical alternatives. This was no recipe for continuing development of Athens and Alexandria within Islamic civilisation, let alone their fruitful interaction, and hence the emergence of modern sciences was in no way a possible outcome in this context.

Renaissance Europe saw a recovery and articulation of Athens and Alexandria of a somewhat different character, but not in itself constituting the emergence of modern science, or even the first step towards it. The Renaissance recovery of more Athens did feed into an elite culture that was natural philosophically adept and literate. Eventually, fruitful competition and debate ensued. Moreover, the recovery of Alexandria picked up tremendous pace during the latter half of the sixteenth century. But, whatever the scope and depth of sixteenth century natural philosophical and higher mathematical developments, and despite a natural tendency to want to label them the most important developments of Athens and Alexandria since

antiquity, Cohen insists that these traditions might have been, once again, on the verge of stagnation by the 1590s, had it not been for the inexorable growth, throughout the period, of a new, third species of nature-knowledge, culturally and characteristically European and also decisive in its long-term effects. This he terms European 'coercive empiricism'. Evident in fits and starts as early as the mid fifteenth century, it was concerned with a new form of natural knowledge, more practically, experimentally and action oriented than Athens or Alexandria, yet not reducible simply to the content of the practical arts and techniques. It was expressed around practical mathematics, navigation and discovery, natural history, anatomy, alchemy, Galilean experiment and, definitively, 'Baconian empiricism'.

Note that the latter two examples do not belong to Cohen's analysis of the Renaissance Europe comparative case, but rather to the beginning of his description and explanation of the post 1600 emergence of modern science. This commences between 1600 and about 1640 with a unique and portentous triple transformation which lifted European natural knowledge beyond its Renaissance moorings (in this case, stagnation and decline did not set in). The triple transformation marks the first stage in the century-long sequence of three more transformations (and contingent events and outcomes) by the end of which Modern Science had come into existence. These three immediately post 1600 transformations are treated by Cohen as follows: (1) Alexandria begins to be transformed into a more obviously realist mathematical approach to physical problems by Kepler in celestial mechanics and optics and Galileo in terrestrial mechanics. Although obviously 'Alexandrian' in origin and temper, these achievements mark the first historical emergence of results and techniques decisively novel from within the tradition. Cohen dubs these developments 'Alexandria plus'. (2) The second transformation concerns Athens, the rise of the mechanical philosophy, or 'kinematic corpuscularianism', particularly Descartes' highly systematic version. This, for Cohen, is 'Athens plus' similarly marking the first decisive and truly novel emergence within this tradition since antiquity. (3) To these epochal articulations of the classical traditions is added, according to Cohen, that novel and typically European, dynamic movement of 'coercive empiricism'. The transformation here is of the more diffuse Renaissance expressions of coercive empiricism into a set of programs for the organisation and pursuit of useful natural knowledge, under the banner of Baconianism and example of Galileo, with his experimental tacking between revisable theory and hard-won empirical evidence. This crystallisation and magnification of coercive empiricism in turn energised the other two developments and their own eventually increasing crosslinkages later in the process.

Nothing like any of these three developments, let alone their simultaneous and increasing mutual interactions, had ever occurred before. These transformations in turn supplied necessary but far from sufficient resources and impetuses to the modern science-producing transformations to come, during the course of the seventeenth century. The programs and products of Kepler, Galileo, Descartes and Bacon do not equate to modern science. But what had eventuated by roughly 1640 changed the resources and terms of work and aspiration, forming unique bases for the unfolding further sequence of transformations that did amount to Modern Science coming into the world. Two hundred and forty-four pages set out the

threefold initial transformation, its achievements and limitations, while the remaining three hundred and thirty-eight pages set out the subsequent phases, stages, twists and contingencies in the process: The initial triple transformation is followed by a period of crisis in which the legitimacy of the new developments is put to the test. Cohen's conception of this crisis overlaps with traditional views of a critical or crisis period in the middle third of the seventeenth century as a pivot in the entire process. Cohen's crisis has two distinct advantages over previous conceptions, such as those of Popkin or Lenoble: (1) Cohen sees the crisis as consisting of debates and challenges either entirely within the realm of Athens and Alexandria pluses, or directly concerned with the status and legitimacy of events and claims therein—it is not a 'general crisis' with a scientific tail, but a crisis of the emergent new forms and practices themselves. (2) Cohen gives this crisis inside and about the changing nature-knowledge seeking domains a complex internal structure and rhythm. There follows next the fourth transformation, the geometrisation of corpuscular motion, and overlapping in time the fifth, the flowering of the Baconian movement and its spread to the Continent. This sets the tone for the description of a later seventeenth century 'legitimacy of a new kind', which attaches to the new European conceptual, practical and organisational modes of studying nature, now products of a concatenating quintuple transformation. The penultimate chapter takes 1684, just prior to Newton's *Principia*, as a point to assess the state of the new European modes of nature-knowledge, before the sixth transformation wrought by Newton takes centre stage.

My skeletal description of the comparative and seventeenth-century developmental axes of the book cannot do justice to the many sections of subtle comparative analysis and complexly layered causal inquiry cleverly dispersed throughout the text, in counterpoint to the magisterial scholarship in history of science that densely and engagingly documents Cohen's argument. All this must be read slowly, patiently and sympathetically, to be fully appreciated as the masterly, towering historical edifice it is—the product of an adept macro and comparative historian of a type that current training regimes for historians of science are not likely to produce. I briefly turn, therefore, to two possible sets of difficulties in Cohen's approach—the issue of teleology and the question of whether 'Athens-plus' has been suitably modelled.

Perhaps the greatest apparent pitfall of the model is what some critics have identified as its teleological character—the suspicion that the original Athens and Alexandria somehow contained in potential the essence of later modern science, awaiting only suitable socio-cognitive conditions in which to be actualised through unfolding of a foreordained process. However, in my view, such teleology plays no part in Cohen's model. It is clear, first of all, that both in his comparative studies and in his long explanation/narrative of the process of the Scientific Revolution, Cohen observes the following state of the art practices: In each comparative locus of study and in each phase in the Scientific Revolution, he is clear about what resources were available to the actors of the day; their modes of adoption and use of those resources and the institutional and ideological frames in which such adoption, renegotiation, invention and redeployment occurred. Moreover, the sheer diachronic complexity of Cohen's depiction of the seventeenth-century emergence of Modern Science mocks

any notion of teleological realisation of some potential already set in Athens and Alexandria. As noted, his opening triple simultaneous transformation 1600–1640 displays significant emergence of novel concepts, methods and achievements, well beyond the ken of Athens or Alexandria. And, the triple emergence is necessary but hardly sufficient to explain or even provide an unchanged base for the remainder of the process. The three further transformations, constituting that remainder, also involve novel emergences and are conditioned by intervening contingencies and crisis. All this thus demonstrates that Cohen's story is neither one of actualised Aristotelian potential nor one of accumulation of incremental changes.

In sum, Cohen's seventeenth-century process is one of long, non-predictable concatenations of emergences, which broke very deeply with the oldest Athens and Alexandria resources the players initially had to hand. Hence, it was a revolution, but more of the type de Tocqueville deemed the French Revolution to have been, rather than some sudden and putatively total rupture. The process is long in gestation, stirring first late in the Renaissance. It can be traced progressively over the next three generations from 1600 within sedimentary layers of theories, practices, institutions and values, as the triple transformation takes place, faces crisis and is further articulated. Then, finally gathering take off velocity and conceptual and legitimatory mass, the process climaxes with rather great speed in the course of the single generation that encompasses the waves of Cohen's fourth and fifth transformation, rising and breaking over results of the earlier changes, before the swiftly following sixth (Newtonian) transformation in turn breaks upon and encompasses much the fourth and fifth, as they continue to run forward. Cohen's Scientific Revolution is neatly conceived on the model of how large scale and comparative social and economic history are practiced, rather than the arguably ahistorical ruptural fantasies of Koyré, Kuhn and Popper. It also stands as a living challenge to puny attempts to (in American parlance) 'nickel and dime it to death' by reciting this or that micro counter example.

All of which is not to say that the model cannot be constructively interrogated and perhaps usefully modified, which brings us to the second set of difficulties. One might ask whether, with regard to Cohen's modelling of the key initial simultaneous triple transformation (1600–1640), and beyond, Alexandria-plus and Athens-plus were actually two separate traditions and whether Athens-plus has not been sold short in important ways. Despite the fact that mathematics and mathematicians (of various types) did form social groups quite independent of natural philosophising, it may be suggested that all the action of interest to us about the 'emergence of modern science' took place in and around the seething, complex and contested field or institution of natural philosophising, where some expert mathematicians (who were also expert natural philosophers) assayed radical reforms, changes of the rules of natural philosophising and bids for hegemony in the field.

The way into this issue is to begin by noting the ways Cohen usefully deploys his Athens and Alexandria model against earlier externalist simplifications: First of all, it was not unusual for a society to possess highly developed and efficacious traditions of practical arts and techniques, so that is not the relevant differential between seventeenth-century Europe and Medieval Islam, or late Medieval Europe, or Sung China, or even the Roman Empire at its height. What is unusual is for

experts in natural philosophy and mathematics to be present in a culture and for some of them to be interested in those crafts and techniques, at the same time that some elite craftsmen similarly delve into natural philosophy and higher mathematics. This surely is the historiographical cash value, and functional meaning, of Cohen's category of a unique European coercive empiricism—it does explanatory work on our problem only where, when, and in so far as, it had relevance to the elite natural knowledge-making communities. However, even if Athens and Alexandria exist in a culture and have traffic with the practical arts, it is additionally unusual for there to be intense (and increasing) interaction between Athens and Alexandria. Cohen's correct contention is that by the turn of the seventeenth century, Europe was about to see a series of just such developments, whose long-term outcomes by around 1640 constitute the three simultaneous transformations.

Now, in all this, Cohen is targeting the traditional externalist explanation that invokes European practical arts and artisans as not only the efficient cause, the trigger of the Scientific Revolution, but also in a sense the formal cause, by providing some sort of proto scientific method, or key to mathematisation. Cohen is saying: (1) that coercive empiricism, for all its artisanal efflorescences, had to have articulations with both Athens and Alexandria for any initial emergences to have occurred; and (2) that there was not some essence of modern science home-grown by the craftsmen and mechanics and passed on to visionary 'scholars'. Cohen is thus asserting the absolute necessity of invoking Athens and Alexandria, and changes within them, to explain the Scientific Revolution. He is saying that the 'scholars' in traditional externalist tales of 'scholars and craftsmen' were in fact very particular sorts of scholars, with their own long and meritorious traditions: they were devotees of natural philosophising and/or higher mathematics (including the mixed mathematical fields therein). Buying into, or co-opting from, 'coercive empiricism', they were building inside their own traditions, not in some *de novo* space of origination of modern science, let alone one created and owned by practical artisans.

So far, so good, therefore, for Cohen and his conception of the initial triple transformation. However, it may be asked, and this is my key point, whether Cohen's Athens and Alexandria set up, even after it is bumped up to Athens-plus and Alexandria-plus from the turn of the seventeenth century, remains the best way of thinking through the very process Cohen has identified. Perhaps it would be better to take the wide, deep, long-lived and highly contested field of natural philosophy as central to the story and to locate the transformations as effects of moves within and about it by certain natural philosophical actors. After all, in the past generation, quite a few historians of science have stressed that the Scientific Revolution was importantly, perhaps definitively, a process that unfolded in and around a continuously existing field or institution of natural philosophy. They have tended to hold that the neo-Scholastic inhabitants and products of the universities were only one group within the field, albeit the majority and hegemonic group until well into the seventeenth century, and that the dissolution of natural philosophy or its *débouchments* into successor disciplines, experimental and physico-mathematical, from the last third of the seventeenth century, marked the *dénouement* of the process of emergence of modern science[s]. For such historians of natural philosophy, the period 1600–1640 is one of turbulence, competition and crisis in the field, itself

partly shaped by the religio-political crisis of these two generations. Hence it is not simply the emergence of kinematic corpuscularianism that marks 'Athens-plus', but just this desperate contestation in the long-lived, deeply institutionalised European culture of natural philosophising, at the time the common heritage of every educated man in Europe.

Moreover, recent research suggests that when we consider how the mixed mathematical fields, such as astronomy, optics, mechanics and music theory developed in this critical period, we should think in terms of what some actors labelled 'physico-mathematics', turning their label into an historians' category as well. The term denotes attempts radically to recast the mixed mathematical sciences from their Aristotelian understanding as somewhat detached from and inferior to natural philosophising, by virtue of being merely instrumental and non-explanatory. The aim was to render the mixed mathematical disciplines capable of dealing, mathematically, with issues of matter, cause and cosmic structure; that is, capable of dealing mathematically with natural philosophical issues. What was happening was not so much the mathematisation of natural philosophy as the 'physicalisation' of mixed mathematics. We see this in the entire debate about *realist* Copernicanism, ignited from the later sixteenth century and brought to white heat by Kepler, Galileo and Descartes, for the issue was the reality, the truth in terms of matter and cause, of this mathematically couched astronomical system. Similarly, we see that the late sixteenth century attempts to reform traditional mechanics were essentially attempts to make some form of mechanics, a mixed mathematical discipline, into a part, perhaps the central part, of natural philosophy.

All this suggests that rather than setting up the Alexandria-plus Kepler and Galileo over against the Athens-plus Descartes, it is plausible to locate all three as aggressive, realist Copernican, physico-mathematically inclined, anti-Aristotelian bidders in natural philosophy. Descartes, like Kepler was a master physico-mathematical optician, and we now know that much of the causal register of his natural philosophy was extracted from his physico-mathematical optical work. Kepler's celestial mechanics was supposed to be the master stroke for realist Copernicanism and implied the need to change the dominant natural philosophy to Kepler's brand of empirically and harmonically oriented neo-Platonism. But similarly, Descartes' vortices, seemingly vague and nonsensical, can be read as a verbally expressed exercise in applying concepts he had arrived at via his physico-mathematical hydrostatics and optics, and, of course, as a contrasting bid to establish a version of realist Copernicanism as part of a new, hopefully hegemonic natural philosophy. All these plays were within the domain/field/institution of natural philosophy. Alexandria is only relevant insofar as, and to the extent that, natural philosophical claims and capital, howsoever radical, were being produced using mathematical tools and concepts, whilst whole domains of mixed mathematical endeavour were being rendered much more intimately 'of the nature of natural philosophy'; that is, concerned with issues of matter and cause. Galileo himself, whilst not a committed systematiser in natural philosophy, was involved in various physico-mathematical bids to establish Copernicanism as true and definitively to displace Aristotelianism. Like Kepler and Descartes, he deployed physico-mathematical tactics inside the field of natural philosophy in order to topple

Aristotle, establish (his version of) realist Copernicanism and win primacy within the field. So, just as in the case of coercive empiricism, it turns out that Alexandria-plus has a functional meaning or cash value, which, strictly construed, refers to moves inside natural philosophy, where varied attempts were made to physicalise parts of the revived mathematical fields.

In short, if we enlarge and more deeply model the category of natural philosophy as a long-lived, highly structured field of reproduction and contention over change, things actually become simple. An enhanced model of natural philosophy supplies the missing 'subject' or 'carrier beam' of the key changes and emergences and is the 'shapée' of the drivers often mentioned. Moreover, recalling the issue of Athens and Alexandria continuing or not continuing in previous sites, the following conclusion sneaks up on us concerning the basis for this natural philosophy-centric revision of the model. Given the continuous existence, since the high middle ages, of a European system of what twenty-first century university executives might term 'natural philosophy teaching and learning centers', then we see that in the case of high medieval Europe something absolutely necessary, though not sufficient, for 'modern science' did 'continue', even though the partial recoveries of Athens and Alexandria in the late Medieval Europe did not lead to a continuous process of emergence of modern science and may be taken to have 'stalled' in that respect.

In any case, it may be left to sympathetic scholars to investigate how Cohen's post 1640 account can similarly be modified and articulated so that it too can be draped upon the armature of such a model of natural philosophy—its evolving rules of contestation, dynamics and eventual fate of dissolution. They are free to create a family of related but competing macro descriptions and explanations of 'the scientific revolution'. But in doing so, they must from now on recognise that Cohen's argument—which spans six cultural domains, marshals huge masses of evidence and easily deploys a sophisticated historical style of comparative analysis and layered causal explanation—forms an obligatory point of passage for any such large endeavour.