A NEW BENCHMARK FOR THE HISTORY OF SCIENCE AND TECHNOLOGY

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I arrived at the Wissenschaftskolleg with the cuckoos in early April, having packed off my ten-year-old son to Madagascar, where his mother was doing anthropological fieldwork (I was delighted to discover that I could speak with them once a week on their solar-powered mobile phone). In Berlin I found kind weather, congenial Fellows and staff, and wonderfully efficient and courteous librarians. Contrary to many other Fellows' experiences, I didn't stay long enough to abandon my original project for something more interesting, intriguing or suddenly pressing – but that is probably just as well, since the project was becoming increasingly hard to pin down in any case.

The project is part of a research programme on the origins and expansion of European capitalism, which aims to enlarge on current explanations for the "rise of the West", the process by which the Western European economy and technology caught up with and subsequently forged ahead of Asia's great premodern civilisations between c. 1250 and 1750. Although it's been recently suggested that living standards in parts of Southeast Asia before the Industrial Revolution may have matched those in the more developed parts of Europe, we have yet to understand why the European economy grew more rapidly from a lower base between 1250 and 1750. My guiding hypothesis is that Europe's long-term development was shaped by how political authorities enforced and co-ordinated markets for goods and services and by the institutions and organisations that defined how technical knowledge was generated and disseminated. At the Wissenschaftskolleg I worked on how premodern technical knowledge was generated and transmitted – specifically, on craft and engineering *heuristics*. I focused on two broad themes: technical secrecy and technical codification.

A long-standing debate in the history and sociology of science concerns the craft-based origins of the Scientific Revolution and the epistemological and methodological demarcation of modern science. Both sides of the argument are problematic. Those who argue that scientific empiricism and openness originated in the observation of Renaissance craft practice have been unable to prove a clear genealogical descent and appear to ignore the widespread evidence of craft "secrecy". Those who claim the distinctiveness of modern science emphasises the latter's intellectual openness (as opposed to craft "secrecy") and practical reliability and reproducibility (as opposed to the ad hoc, "unthinking" or uncodified nature of craft activity). Neither of the latter claims stands up to detailed scrutiny, either. On the one hand, it appears that the propensity for craftsmen to protect their "secrets" against outsiders is to a large extent a myth established by natural philosophers in the seventeenth century, for reasons that included an inability to understand the technicians' experiential knowledge without long and tiresome training and a strong desire to establish their own intellectual credentials in opposition to older or "obscurantist" practices. There is abundant evidence that craftsmen did share their knowledge widely, although of course only similarly trained craftsmen and engineers could understand it. On the other hand, it is well known that the "practical" sciences (biology, chemistry, metallurgy, etc.) made a very slight contribution to technological progress before the second (chemical) Industrial Revolution, because their theories were *less* reliable than those of practising technicians. Tracing the contours of intellectual debates in England and France over the epistemological and cognitive value of craft and "tacit" knowledge in the sixteenth and seventeenth centuries, which appear to have established the "black legend" of the crafts' propensity to technological secrecy and conservatism, required working on premodern theoretical treatises, autobiographical material, and travel descriptions to identify contemporary descriptions of manufacturing and designing practices.

Like other forms of knowledge, technical and scientific knowledge includes – to differing degrees – *implicit* knowledge, based on rule finding and abstraction, which enables the acquisition of skills; *non-propositional* and *non-linear* knowledge, including imagery, with both implicit and explicit components; and *explicit, linear, propositional* knowledge, expressed symbolically in alphabetical and numeric terms. What distinguishes them from other forms of knowledge is the use of symbolic systematisation – *written and drawn codification* – for knowledge transmission to other users. Understanding how useful and reliable knowledge was increasingly codified through drawing and design, modelling, and patenting required working in the literature in psychology, philosophy, and the history of science on tacit knowledge, particularly on the limits to expressing knowledge in codifiable terms, and in the history of art, architecture, engineering, and science on premodern processes of codification.

Although codification was at the heart of the increasing efficiency in the organisation and performance of economic activities during the twentieth century, codification is not a new discovery among technicians. I found strong evidence that premodern technicians also codified their heuristic rules in response, on the one hand, to growing pressures for technical standardisation and growing mobility among skilled workers, and on the other hand, in order to reduce labour times in edifice and machine building, mining, shipping, instrument making, and other sectors that included, significantly, the most innovative sectors in the Industrial Revolution.

This discovery is important for economic and technological historians. But inasmuch as the central feature of modern science is the capacity to generate competing codes of knowledge, the evidence I charted of widespread *heuristic codification* by premodern European technicians may also cut the classic Gordian knot of how to demarcate and distinguish technical and scientific epistemologies and practices. Both similarities and differences between the practices of scientists and those of technologists are brought to light: both scientists and technicians codify rules, but differ significantly in the degree and intensity with which they do this. Whereas craftsmen and engineers codify as a means to the end of making things work, which arises quasi-incidentally from the technical and cognitive requirements of standardisation, codification is the main aim and purpose of scientific work. Yet, in fundamental ways, scientific and technological practices occur along an epistemological continuum.

The project's main theoretical contribution is thus the proposal to use forms and degrees of codification – which is a universal feature of human cognition – as the principal demarcators distinguishing scientific from technological practices and to employ codification as the principal benchmark (comparator) for a comparative history of technological progress. This focus on technical heuristics and codification can help integrate the work of economic historians with that of historians and sociologists of science.

The project's main empirical result has been to identify and begin to chart the historical patterns of technological codification, which have received little sustained attention to date. This has included an extensive survey of the literature in the history of science, of technology, of architecture and design, and of art, and in cognitive psychology, concerning the historical and cognitive frameworks for the codification and transmission of tacit, experiential knowledge. My work on codification and "secrecy" has a special interest in:

– the introduction of perspective in Renaissance painting and architectural drawing and the transition from "geometrical" to "mathematical" methods of calculation
– the debates over the professional and intellectual status of architects vs. master builders, which revolved (though seldom explicitly) around the contrast between formally codified and tacit forms of expertise
– discussions in theoretical and practical treatises in ceramics, engraving, metalworking, machine building, and architecture about technicians' heuristics and their "logics of discovery"
– the proliferation of treatises codifying naval dimensions, chronologically, from late fifteenth-century Venice to sixteenth-century Portugal, Spain, France, and England
– the introduction and diffusion of 3D models in edifice and machine building
– the cognitive advantages and limitations of patenting
– the significance of "collective invention" and knowledge sharing among premodern craftsmen and engineers

The work I pursued at the Wissenschaftskolleg has led me to hypothesise that premodern technological progress was bounded by two fundamental processes: the codification of generic technical knowledge, which increases the intensity of invention and innovation; and "collective invention", which is an efficient means for technological diffusion, but offers weak incentives for individuals to invent.