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The Making of Useful Knowledge

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THE MAKING OF USEFUL KNOWLEDGE

PRELIMINARY REMARKS

Thomas Morel, Giuditta Parolini, Cesare Pastorino

In the past two decades, debates on the making and transmission of knowledge have increasingly focused on its social implications. Terms such as 'knowledge economy' and 'knowledge society' have become ever more popular, alongside a growing interest in the impact which scientific theories, techniques and technologies, artisanal practices and so on have had on economic development and material life. In this context, the notion of 'useful knowledge' has 'become a term of choice in historical debates on the relation between economic growth and technological change'.[1] However, the term is more than a modern historiographical categorisation. For at least four centuries, useful knowledge has been an actor's category used to describe the processes taking place in mines and manufacturing, workshops and factories, teaching institutions and apprenticeship schemes, processes which would not be included within present-day definitions of science and technology.[2]

'The Making of Useful Knowledge' workshop, held at the Max Planck Institute for the History of Science (MPIWG) on 30–31 October 2014, was intended to provide an opportunity for reflection on the present state of discussions around useful knowledge.[3] Organized under the umbrella of the Berlin Center for the History of Knowledge, a joint initiative of the MPIWG and the Freie Universität Berlin (FU), the Humboldt-Universität zu Berlin (HU), and the Technische Universität Berlin (TU), 'The Making of Useful Knowledge' brought together an international group of academics who had a special interest in the theme for two days of presentations, talks and discussions.

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[1] Karel Davids, 'Introduction: Useful Knowledge Reconsidered', in: Ian Inkster (ed.), *History of Technology*, 31 (2012), 1.

[2] The notion of 'useful knowledge' is popular among scholars working, for instance, on the material origins of early modern science and the origins of the Industrial Revolution. For a discussion of the former aspect see Harold J. Cook, *Matters of Exchange: Commerce, Medicine, and Science in the Dutch Golden Age* (New Haven, 2007), Lissa Roberts, Simon Schaffer, and Peter Dear (eds.), *The Mindful Hand: Inquiry and Invention from the Late Renaissance to Early Industrialisation* (Amsterdam, 2007), Pamela H. Smith, *The Body of the Artisan: Art and Experience in the Scientific Revolution* (Chicago, 2004), and Matteo Valleriani, *Galileo Engineer* (Dordrecht, 2010). See Peter Jones, *Industrial Enlightenment Science, Technology and Culture in Birmingham and the West Midlands 1760–1820* (Manchester, 2008), Henry E. Lowood, *Patriotism, Profit, and the Promotion of Science in the German Enlightenment: the Economic and Scientific Societies, 1760–1815* (Garland, 1991), and Joel Mokyr, *The Gifts of Athena: the Historical Origins of the Knowledge Economy* (Princeton, 2002) regarding the latter. See Nina E. Lerman, 'The Uses of Useful Knowledge: Science, Technology, and Social Boundaries in an Industrializing City', *Osiris*, 12 (1997) on the role of useful knowledge as an actor's category.

[3] Although the case studies examined in the workshop focused on the West, the theme of useful knowledge can also offer some interesting perspectives on the East, contributing to the current debate about the different material development of Europe and Asia since the eighteenth century, see Davids, 'Introduction', 3–4.

Useful Knowledge, Past and Present

Joel Mokyr's work, particularly his book, *The Gifts of Athena* (2002), has stimulated debate on the notion of useful knowledge among his fellow economic historians, but also among historians of science and technology, and those concerned with global history.[4] Mokyr's use of the term followed that of the Nobel Laureate economist and economic historian Simon Kuznets. For both authors, useful knowledge essentially represented the true 'source of modern economic growth'.[5] In *The Gifts of Athena*—tellingly subtitled *the Historical Origins of the Knowledge Economy*—Mokyr argued that the growth and spread of useful knowledge in early modern Europe was the major factor accounting for the origin of the Industrial Revolution. For Mokyr, 'the true key to the timing of the Industrial Revolution' had to be sought 'in the scientific revolution of the seventeenth century and the Enlightenment movement of the eighteenth century'.[6] He invited his colleagues in economic history to 're-examine the epistemic roots of the Industrial Revolution', taking into account its interconnections with 'those parts of the Enlightenment movement that sought to rationalize and spread knowledge'.[7]

Mokyr's work on useful knowledge has received substantial attention and apposite critique.[8] As Karel Davids has reminded us, one reason why the notion of useful knowledge is so widespread is the concept's 'flexible' character and the 'bridging function' that it can perform across and between disciplines and domains which are often traditionally separate, such as the history of science, technology and economics.[9] In fact, useful knowledge has been adopted as a term of reference that avoids a strict, narrow dichotomy between scientific and technological subjects and investigations. Challenging established demarcations between disciplines, many historians have explored the trading zones where useful knowledge has been historically produced and developed.[10]

As Maxine Berg has observed, even though Mokyr advocated a role in the making of useful knowledge for the skills, practices and informal know-how exchanged in the artisanal workshops,

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[4] For instance, see the works of Maxine Berg, 'Britain, Industry and Perceptions of China: Matthew Boulton, 'Useful Knowledge' and the Macartney Embassy to China 1792–4', *Journal of Global History*, 1/2 (2006) and Kenneth Pomeranz, *The Great Divergence: China, Europe, and the Making of the Modern World Economy* (Princeton, 2000).

[5] Simon Kuznets, *Economic Growth and Structure: Selected Essays* (New York, 1965), 85–87; Mokyr, *The Gifts of Athena*, 2.

[6] Mokyr, *The Gifts of Athena*, 27–28.

[7] Mokyr, *The Gifts of Athena*, 28.

[8] See, for instance, the *Useful Knowledge and Technological Practice* workshops in Warwick and London, 2003; *Useful Knowledge*, London School of Economics (LSE) Global Economic History Network, Leiden, 2004; and *Conceptualising the Production and Diffusion of Useful and Reliable Knowledge in Early Modern Europe*, London School of Economics, 2011. The two workshops in 2003 and 2011 produced special issues of journals, respectively: Maxine Berg (ed.), *Special Issue: Reflections on Joel Mokyr's* The Gifts of Athena, *History of Science*, 45/2 (2007), and the issue of *History of Technology* (Ian Inkster (ed.), Special Issue: Conceptualising the Production and Diffusion of Useful and Reliable Knowledge in Early Modern Europe, *History of Technology*, 31 (2012)).

[9] Davids, 'Introduction', 1.

[10] Pamela Long defines trading zones as 'arenas in which the learned taught the skilled and the skilled taught the learned, and in which the knowledge involved in each arena was valued by both kinds of traders', Pamela O. Long, 'Trading Zones: Arenas of Exchange During the Late-Medieval/Early Modern Transition to the New Empirical Sciences', *History of Technology*, 31, ed. Ian Inkster (2012), 7. One collection that tried to overcome the traditional oppositions of scholar/artisan, science/technology, and theory/practice overview of the historical research that has grown around useful knowledge is Roberts, Schaffer and Dear, *The Mindful Hand*.

he remained mainly focused on industrialists, entrepreneurs, inventors offering only a limited overview of the contributions to useful knowledge given by artisanal techniques and practices.[11] Moreover, *The Gifts of Athena* presented useful knowledge as a feature of the Western world, only superficially mentioning the development of the concept in other geographic areas. In fact, as Ting XU has pointed out with regard to traditional China, useful knowledge was not peculiar to Europe. The notion existed in China, but was conceptualised differently in terms of institutions, cultural factors and the role of the ruling elites in defining such knowledge.[12]

Research Questions

Beyond Economic History

One goal of our workshop was to problematize the apparently coherent picture of useful knowledge that has arisen out of the works of economic historians. This was because we realised that a growing number of scholars from a variety of disciplines are addressing issues and questions concerning practices of knowledge production, diffusion and usage. These diverse studies about Europe do not necessarily stem from economic history, or the history of science and technology; indeed, some of them do not even explicitly address the theme of useful knowledge and economic growth. Our intention was to bring this wider historiographical context into the study of useful knowledge, and the workshop presentations reflected this larger scope.

In addition to contributions from the history of science and technology, our speakers included cases from disciplines such as architecture and economic history. They discussed the history of constructing models, commercial accounting, experiments, mineralogical expertise, plant breeding, practical mathematics, maritime technology, theories of water wheels, instrument making, the history of carcinogens and the use of statistics in agriculture.[13] Some papers focused on the experts, engineers, practitioners and policymakers, involved in the making of useful knowledge. Others considered the institutions, analysing their structural evolution and influence on actual practices. Finally, a group of papers looked at how specific tools and methods—be they the use of statistics in agriculture, early modern mercantile accounting techniques or three-dimensional models in architecture—were invented or adapted, in order to tackle and solve new problems.

Usefulness in the Longue Durée

The original group of studies on useful knowledge had focused on the preconditions and factors that underpinned the Industrial Revolution, in the period between the seventeenth and the nineteenth centuries. In contrast, our intention from the start was to test and evaluate the employment of notions of usefulness in the *longue durée*, moving away from a specific focus on pre-industrial economic growth. This opened the door to the analysis of case studies which dated from the early modern period to the twentieth century. In fact, the very suitability of the notion of

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[11] Maxine Berg, 'The Genesis of 'Useful Knowledge'', *History of Science*, 45/2 (2007), 127–29.

[12] Ting XU, 'A Cultural and Institutional Study of Useful and Reliable Knowledge: the Case of Traditional China' (unpublished discussion paper, 2010), available online at http://www.lse.ac.uk/economicHistory/Research/URKEW/papers/Xu.pdf. Ting XU's contribution was written as part of the 'Useful and Reliable Knowledge in Global Histories of Material Progress in the East and the West' (URKEW) project, hosted by the LSE.

[13] It would not be possible for a single workshop to cover every aspect relating to the making of useful knowledge. Although we aimed to include some of the most significant topics, others were unavoidably missed, such as the history of military technologies, geography or medicine before the twentieth century.

useful knowledge for twentieth-century and contemporary features of science and technoscience is crucial to our approach. This point brings us to one further question that is central to our reflection—the extent to which the concept of useful knowledge should be applied as an appropriate historiographical, analytical category in examining historical facts or, instead, be only considered relevant as far as such a notion was adopted as an actor's category in specific historical settings and social environments.[14] Leaving this alternative open, our primary intention was not to offer a new, comprehensive concept of useful knowledge that would be valid across times and disciplines. Rather, by stepping back, we wanted to collect case studies from various fields in order to examine their common problems and stable elements.

Local and Global Knowledge

At its onset, the making of knowledge is inevitably bound to a network of local conditions, and the local character of knowledge production is made abundantly clear from the studies in this collection. Workshops and factories, but also experimental stations, technical schools, and shipyards comprised micro-environments where useful knowledge was created. The skills and tacit knowledge of workers and the material conditions, for instance the availability of resources, are strongly dependent on local circumstances. This geographical determination was not just a characteristic of the early modern period, as papers presented during the workshop discussing the nineteenth and twentieth centuries also show that there is no such thing as global useful knowledge *per se*. As science historian Ivo Schneider argues, we can distinguish two phases in the design and production of useful knowledge. Conceptually, the first stage deals with the 'preparation and realization of a form that is useful in practice'. This moment gives way to a second phase, the 'actual assimilation of the proposed resources in practice'.[15] Alongside the investigation of how useful knowledge is locally produced, we can explore how it is diffused and received, and if local results can be replicated and applied on a global scale. It is crucial to examine the role of the state when considering these questions. The state was a stable and major implementer of useful knowledge in the *longue durée*, even though its scope, goals and organization evolved significantly. In many cases, the state's political and economical power, permanence and long-term objectives, encouraged this role. For instance, the paper about navigation and shipbuilding included in this collection shows the important role early modern European states played in the gradual convergence of maritime technologies. Other papers in this volume also reveal how the costly exploitation of natural resources, such as salt or mining, led the mercantile states of eighteenth-century Europe to implement various policies aimed at producing profitable knowledge—with varying degrees of success.

The Rhetoric of Usefulness

A final key element in the study of useful knowledge concerns its rhetorical component. The claim of usefulness has invariably been used as a sales pitch for knowledge makers, but can also be read as evidence of the status and worth of specific knowledge in society. Given that we cannot always distinguish between these two components, the rhetoric of usefulness should be seen as an interesting, if ambiguous, object of analysis: the very rhetorical strategies used by the various actors can be helpful for understanding the actual making of useful knowledge. The case studies

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[14] A recent reflection on useful knowledge as an analytical category (in relation to the early modern period) is presented in Marcus Popplow, 'Formalization and Interaction: Towards a Comprehensive History of Technology-Related Knowledge in Early Modern Europe', *Isis* (forthcoming), 7.

[15] Ivo Schneider, 'Die mathematischen Praktiker im See-, Vermessungs- und Wehrwesen vom 15. zum 19. Jahrhundert', *Technikgeschichte*, 37/3 (1970), 231.

included here do not contemplate the merits of usefulness or judge the extent of its rhetorical character. However, the study of rhetorical arguments can help us to analyse the political and cultural issues at stake, by asking the question: ‘who benefits from useful knowledge?’

Discussion

Discussions during the workshop addressed both historical and historiographical issues related to useful knowledge. As Dagmar Schäfer noted in her round table introduction, usefulness can be viewed from multiple perspectives. Because of the specific case studies examined in the workshop, we focused on investigating such diversity within a European context. As Schäfer commented, usefulness can be addressed as a tool of conservation, when there is a need to preserve and teach a certain type of knowledge, but usefulness can be also a tool for promoting economic growth, for instance in relation to industrialization, or it can stimulate change at a social and institutional level. Moreover, certain global and local issues related to scientific and technological expertise are involved in the production and consumption of useful knowledge, while institutional spaces and social conditions are relevant in deciding what is useful, who is entitled to determine this, and who such useful knowledge is created for.

We wish to draw attention to a few aspects that emerged as key elements in the discussions. The first is whether to define useful knowledge as an analytical or an actor’s category. One question recurred frequently during the workshop: whether we can agree on a general definition of useful knowledge which is valid across time and space, or if we should examine how certain types of knowledge have been labelled useful in different ages. Supporters of the analytical approach stress that useful knowledge is an autonomous concept valuable for probing different historical materials and dealing with issues that cannot be strictly categorized inside the boundaries of science, technology, art and so forth. On the other hand, sceptics questioned the normative character that such an analytical definition of useful knowledge has—in particular in relation to Mokyr’s work—and suggested that an examination of the specific theories, technologies etc. that have been claimed as useful over time would be more productive. These workshop discussions challenged the participants to rethink their own attitudes towards the issue.

A second point was the demarcation between professional expertise and useful knowledge. The two notions are certainly linked, but how? Several categories of scientific and technical expertise have been described at various times as useful knowledge in fields such as shipbuilding, mining and agriculture. Two examples out of the many cases presented during the workshop are the master shipwrights and naval engineers in eighteenth-century France discussed by Davids, or the twentieth-century German agricultural experts described in Harwood’s paper. Yet, the concept of useful knowledge can also refer to episodic and limited contributions, either practical or theoretical, deployed to solve a specific problem or in a localized situation. It is also suitable to describe the circulation of knowledge when traditional practices, and not only codified scientific or technical knowledge, are at stake. Agriculture provides a good example of this, because its scientific experimentation co-exists alongside farmers’ own trials, and results and information are transferred between farmers and scientific advisers.

A third aspect that emerged repeatedly in the workshop discussions was the relationship between useful knowledge and intellectual property. It is challenging for historians to understand whether the value of useful knowledge is connected to its free dissemination, or rather to the possibility of establishing and maintaining intellectual property. Issues of openness and authorship are not specific to twentieth- and twenty-first-century industrial and intellectual culture, however. As Pamela Long argues, ‘the concept of ‘intellectual property’ developed in the context of the medieval craft guild', well before the idea found its legislative codification.[16] Since then, there has been great ambivalence in addressing the issue. The latest manifestation of this ambiguity can be found in the contemporary debates over *open access* to knowledge deemed useful for society at large—be it software code or the outcome of publicly-funded research in science, technology and the humanities—that are taking place alongside the increasing *propertization* of scientific data, in particular in biomedicine.[17]

Finally, we ended up asking who the real beneficiaries of knowledge claimed to be useful are, and how a political dimension is hidden in their identification. Is useful knowledge made for the rich or the poor, for society at large or for a ruling elite? The answer, of course, is not clear-cut. For instance, military technologies heralded as useful for national defense have often been used in practice as instruments of domination and political pressure, and modern systems of intensive agriculture have contributed to increasing wealth in the Western world, but have not succeeded in many developing countries. It would be possible to provide many more examples of cases where useful knowledge has failed its alleged beneficiaries. It might even be that the contested arena of potential recipients of useful knowledge is precisely what makes the concept so powerful for historical analysis, because it leads us to explore a whole network of economic, social, scientific and political relations, examining how useful knowledge is made, promoted and shared.

Overview of the Contributions

This preprint contains six working papers, outlined here in alphabetical order. Each paper addresses several of the issues introduced above, based on a specific case study.

Karel Davids's paper analyses the role of institutions that claimed to make knowledge 'useful' in shipbuilding and navigation technology during the eighteenth and early nineteenth centuries, comparing the cases of Britain, France and the Dutch Republic. Davids focuses on the interplay between theoretical advances and actual practices of shipbuilders. He also investigates new methods for the determination of longitude at sea, the production of improved nautical charts, and the establishment of formal examinations for testing the competence of navigators. Similarities can be found in the roles played by national and institutional hierarchies in all of these fields. However, the example of shipbuilding shows that important factors—like differences in the consensus about the reliability of knowledge, professionalization and resistance to regulation—created considerable variations in institutional strategies among the three countries.

In his paper, Jonathan Harwood examines the case of 'peasant-friendly' plant breeding in South Germany at the turn of the twentieth century. Harwood's contribution enriches the debate on the making of useful knowledge by addressing the phenomenon of differential utility and the development of appropriate technology in agriculture, not only in relation to the German case examined, but also with reference to the 'Green Revolutions' of the twentieth and twenty-first centuries and their failure to respond to the needs of peasant farmers.[18]

In her contribution, Ursula Klein discusses the concept of 'useful science' in late eighteenth-century Prussia. Building on two case studies, the history of mining and salt sciences, Klein argues that the 'useful sciences' were more than an application of new theories to existing

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[16] Long, 'Trading Zones', 5.

[17] Helga Nowotny, 'The Changing Nature of Public Science', in: Helga Nowotny, Dominique Pestre, Eberhard Schmidt-Assmann, Helmuth Schulze-Fielitz and Hans-Heinrich Trute, *The Public Nature of Science under Assault: Politics, Markets, Science and the Law* (Berlin and Heidelberg, 2005).

[18] On the concept of 'appropriate technology', see Adrian Smith, 'The Alternative Technology Movement: An Analysis of its Framing and Negotiation of Technological Development', *Human Ecology Review* 12/2 (2005).

practices. Instead, they aimed to develop new forms of teaching (through mining academies) and organization to carry out coordinated and far-reaching studies. In that respect, they were the forerunners of the nineteenth century technological sciences.

Thomas Morel's paper focuses on the evolution of the concept of 'useful mathematics' in Germany during the eighteenth century. Morel shows how the creation of new institutions, the academies, demonstrates the emergence of a narrower definition of usefulness. Mathematics in mining academies was intended to be directly applicable in practice, while the professors not only taught 'practical' mathematics, but also closely interacted with the state administration to improve its mining operations.

In her paper, Giuditta Parolini considers how inferential statistics was used to improve farming practices in Britain during the 1920s and 1930s. Parolini evaluates the contribution statisticians working at Rothamsted Experimental Station made to field experiments and agricultural meteorology and discusses how inferential statistics became a form of useful knowledge in agriculture.

Cesare Pastorino discusses a specific type of useful knowledge, cost and management accounting in the early modern period. His paper looks at the way in which this particular form of expertise was employed in commercial and industrial domains. In addition, Pastorino explores the possibility that mercantile accounting became an important model for establishing techniques and practices of experimental reporting among natural philosophers, mediated through its industrial and institutional forms.

Conclusion

In conclusion, we are convinced that useful knowledge is a challenging and productive concept for historical research. Whether it is regarded as an analytical category, endowed with a general definition, or an actor's category, tracing people's attitudes in different ages, it provides a flexible tool of investigation across time and place and offers insights into issues that are missed by purely disciplinary investigations. Although it proved impossible to agree whether useful knowledge should be defined as an analytical or actor's category during the workshop, this did not hinder the discussions that took place and involved scholars working on very different time periods. Mokyr's original view of useful knowledge was based on a discussion of economic growth which, despite raising interesting questions, has proved to be too reductionist in approach. Instead, the diverse case studies explored during the workshop demonstrate that, although economic issues are certainly relevant for discussing useful knowledge, they are by no means the only aspect that should be taken into account. Institutional constraints and social issues are just as important, as exemplified by the cases of plant breeding, navigation technology and mining discussed during the workshop. In particular, Jonathan Harwood's paper, originally developed as a contribution to the history of agricultural science, brings to the fore the issue of 'differential utility', crucial also for the debates on the economic impact of useful knowledge.[19]

We believe that the links between useful knowledge, social progress and economic growth are a conundrum that historians should address, because this could lead to finding novel perspectives on human development. The notion of useful knowledge is at once local, situated in time and space, when conceived as an actor's category, and necessarily global, when regarded as an analytical category. This tension cannot, and indeed should not be overcome, for it is precisely this that makes useful knowledge such an interesting topic. Therefore, within its framework we can

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[19] Starting from his examination of the history of plant breeding, Harwood notices how breeding techniques and technologies developed by scientific experts, although claimed to be useful in general, proved instead to be profitable only for the richest and business-oriented part of the farming community.

ask broad questions about agency and development in human history. Moreover, as became evident during the workshop, the same framework provides the opportunity for productive historical debates that range beyond chronological boundaries and engage scholars working on codified knowledge and scientific practices, material culture and technological innovation, experimentation and policy issues.

In the near future we hope to see continuing interest in a diachronic approach to the making of useful knowledge. The case studies presented in this preprint volume are a first contribution towards this goal, and we hope that they will stimulate curiosity and lead to further investigations on the subject.

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Making Knowledge 'Useful' in Europe Between c.1750 and 1850: a Comparison of Shipbuilding and Navigation Technology

Karel Davids

'Useful knowledge', according to Joel Mokyr, is the 'knowledge of natural phenomena and regularities that (has) the potential to affect technology'. Ian Inkster has offered a slightly different definition. In his view, 'useful and reliable knowledge' comprises 'the knowledge that (is) brought to bear at points of significant technological advancement'. Both of these are *ex post* definitions by historians. Both definitions determine in retrospect what kind of knowledge was 'useful' in some way at a specific historical time and place—namely, knowledge with potential (Mokyr) or actual (Inkster) technological impact. Contemporaries during the early modern period also expressed diverse ideas about the 'usefulness' of knowledge, and their definitions of 'useful', 'utility' and 'usefulness' varied across periods and social contexts.[1] Using the concept of 'useful knowledge' in historical analysis thus gives rise to a number of questions. Apart from the issue of 'who defined useful knowledge?' which I have discussed elsewhere[2], other important questions are: how exactly was knowledge made 'useful'? And who made knowledge 'useful' in practice? These are the two central questions of this essay.

Historians of science today often tend to view the process of circulation and exchange of knowledge in terms of capitalist market logic. Harold Cook, notably, has connected the Scientific Revolution with the rise of global trade in the sixteenth and seventeenth centuries. Cook claims that increasing amounts of time, effort and other resources were devoted to expanding knowledge in that period by discovering 'matters of fact', rather than by cultivating reasoned discourse. This shift was closely linked to the rise of commercial values in Europe.[3] The exchange of objects became a central factor not only in economic life, but also in the acquisition of scientific and medical knowledge. 'Scientific objects', according to Daniel Margócsy, were turned 'into consumer goods, that circulate(d) commercially' in national and international markets. Knowledge became increasingly commodified.[4]

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[1] Joel Mokyr, *The Enlightened Economy. An Economic History of Britain 1700–1860* (New Haven, 2009), 35, Ian Inkster, 'Potentially Global: "Useful and Reliable Knowledge" and Material Progress in Europe, 1474–1914', *The International History Review*, 28 (2009), 238, Karel Davids, 'Gatekeeping. Who Defined 'Useful Knowledge' in Early Modern Times?', *History of Technology*, 31 (2012), 69.

[2] Davids, 'Gatekeeping', 71–84.

[3] Harold J. Cook, *Matters of Exchange. Commerce, Medicine, and Science in the Dutch Golden Age* (New Haven, 2007), 20–41, 410–16.

[4] Daniel Margócsy, 'A Museum of Wonders or a Cemetery of Corpses? The Commercial Exchange of Anatomical Collections in Early Modern Netherlands', in: Sven Dupré and Christoph Lüthy (eds.), *Silent Messengers. The Circulation of Material Objects of Knowledge in the Early Modern Low Countries* (Berlin, 2011), 213. See also Sven Dupré and Christoph Lüthy, 'Introduction: Silent Messengers. The Circulation of Material Objects of Knowledge in the Early Modern Low Countries', in: Sven Dupré and Christoph Lüthy (eds.), *Silent Messengers. The Circulation of Material Objects of Knowledge in the Early Modern Low Countries* (Berlin, 2011), Benjamin Schmidt, 'Accumulating the World: Collecting and Commodifying "Globalism" in Early Modern Europe', in: Lissa Roberts (ed.), *Centres and Cycles of Accumulation In and Around the Netherlands during the Early Modern Period* (Berlin, 2011), Claudia Swan, 'Collecting Naturalia in the Shadow of Early Modern Dutch Trade', in: Londa Schiebinger and Claudia Swan (eds.), *Colonial Botany. Science, Commerce, and Politics* (Philadelphia, 2004), Pamela H. Smith and Paula Findlen (eds.), *Merchants and Marvels. Commerce, Science and Art in Early Modern Europe* (New York, 2002).

Commercial values and forces were relevant to the process of making knowledge 'useful', but the logic of the market only offers a partial explanation of what happened. In fact, concentrating on the market might even obscure other driving forces that were instrumental in turning knowledge into 'useful' methods, practices or devices. The making of 'useful' knowledge in the early modern period can therefore only be understood by looking at both market *and* non-market forces, and at combinations of the two.[5] It is also important to note that such mixtures of market and non-market forces varied by country, by period and by area of knowledge. Variations between countries could diminish over time, but not necessarily at the same time in all areas of knowledge. In this essay, I will examine the extent and the ways to which this convergence, or divergence occurred, by comparing two domains of knowledge—shipbuilding and navigation technology—in three European states (Britain, France and the Dutch Republic) in the eighteenth and early nineteenth centuries. Although the maritime sector comprised of course only a part of the entirety of knowledge on natural phenomena during that period, from an early date it was subject to a degree of intervention from non-market forces (such as states)—which was by no means typical of the period. There is plenty of material on these two areas available to examine how knowledge was made 'useful', so this sector is particularly suitable for an analysis of the relationships between market and non-market forces.

In particular, this paper explores whether the presence, or absence, of institutions made the transformation of 'knowledge' into 'useful knowledge' possible. Douglass North defined institutions as 'the rules of the game in a society, or more formally, […] the humanly devised constraints that shape human interaction. In consequence they structure incentives in human exchange'.[6] Whether institutions are intended to 'maximize wealth', as many economists and economic historians have contended, is a moot point. In contrast, Sheilagh Ogilvie has notably argued that, even if the formation and function of some institutions may appear rational from the point of view of individual actors, they might have 'bad effects' on the economy at large. 'A given institution does many things […] and all its activities must be taken into account before we declare whether it is efficient or inefficient', she insists.[7] In this paper, I prefer *not* to assume *a priori* that all institutions in the early modern period were efficient, wealth-maximizing phenomena.

The first section of this essay examines institutions for making knowledge 'useful' in ship construction, while the second section considers navigation technology. Section three compares the two and analyses why convergence between countries in the shipbuilding domain of knowledge went further than that of navigation technology. The conclusion summarises my argument and proposes some general implications.

1. Shipbuilding

Shipbuilding is an apposite case to start with when studying the question of how, and to what extent, knowledge was made 'useful' in the eighteenth century. On the one hand, the literature agrees that earnest efforts were made after 1700 to bring knowledge about 'natural phenomena and regularities' to bear on the construction of ships. On the other hand, serious doubts remain whether this knowledge was actually of much genuine 'use' for the practice of shipbuilding. *Ex*

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[5] Karel Davids, *The Rise and Decline of Dutch Technological Leadership. Technology, Economy and Culture in the Netherlands, 1350–1800* (Boston/Leiden, 2008), vol. II, 366–88, 460–72, Karel Davids, 'Dutch and Spanish Global Networks of Knowledge in the Early Modern Period: Structures, Connections, Changes', in: Lissa Roberts (ed.), *Centres and Cycles of Accumulation In and Around the Netherlands during the Early Modern Period* (Vienna/Berlin, 2011).

[6] Douglass C. North, *Institutions, Institutional Change and Economic Performance* (Cambridge, 1990), 3.

[7] Sheilagh Ogilvie, *Institutions and European Trade. Merchant Guilds 1000–1800* (Cambridge, 2011), 5–6.

ante perceptions do not tally with *ex post* observations, since the expected potential of knowledge was apparently not fully achieved in reality. Moreover, the case of ship construction reveals some interesting differences between countries.

In France, the institutionalisation of supposedly 'useful' knowledge in ship construction under the aegis of government agencies started much earlier, and advanced much further, than in Britain or The Netherlands. This divergent trajectory was closely linked with two specific features of the French context. First, in the eighteenth century, French Navy ships were almost exclusively built in government dockyards[8], and the master shipwrights who designed the King's vessels were nearly all employees of the state. Second, ever since Colbert's time, the French government had been actively promoting research into a mathematical approach to ship design, especially at the *Académie Royale des Sciences* in Paris and at hydrography schools which had been founded at a number of port cities. *Académiciens* and professors at hydrography schools such as Paul Hoste (1652–1700), Pierre Bouguer (1698–1758), Jean Bernoulli (1667–1748) and Daniel Bernoulli (1700–1782), Leonhard Euler (1707–1783) and Jean le Rond d'Alembert (1717–1783) wrote profound theoretical studies on subjects such as calculating the displacement and stability of a ship, determining water resistance or understanding the movements of rolling and pitching. One of the highlights in the development of this mathematical approach to ship design came in the 1730s when the notion of the 'metacentre' as a crucial element in determining the stability of a ship was first suggested.[9]

French naval administrators regarded these theoretical advances as knowledge 'useful' for shipbuilders. From the 1740s onwards, they encouraged improvements in ship design by creating institutes for the formal schooling of shipwrights, by assembling shipwrights together at royal dockyards in a newly-established corps of naval engineers, by introducing formal examinations as a requirement for promotion, and by sponsoring the publication of textbooks and treatises that would make allegedly 'useful' insights from theory easily accessible to ship constructors. A model text of this kind was the manual published by the first director of the *École des Ingénieurs-Constructeurs de la Marine*, Henri-Louis Duhamel du Monceau in 1752, *Élémens de l'Architecture Navale,* which combined new ship construction theory, presented in a simplified fashion, with rules and principles based on best practice.[10]

Nonetheless, historians have shown that the actual impact of this mathematical approach to ship design has been much more modest than bureaucrats and scientists believed at the time. True, French warships in the eighteenth century were thought to be superior in some respects to those of other nations, including Britain, but this perceived excellence cannot be ascribed to the results of state-sponsored scientific research.[11] The idea that state support for scientific research was key to the French pre-eminence in building faster warships is largely based on the polemics of the Society for the Improvement of Naval Architecture, which was active in Britain in the early

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[8] According to Jan Glete, *Navies and Nations. Warships, Navies and State-building in Europe and America, 1500–1860* (Stockholm, 1993), vol. I, 287–8, little is known about private shipyards in France in this period.

[9] James Pritchard, 'From Shipwright to Naval Constructor: The Professionalization of 18th-Century French Naval Shipbuilders', *Technology and Culture*, 28 (1987), 6–7, 16, Larrie D. Ferreiro, *Ships and Science. The Birth of Naval Architecture in the Scientific Revolution, 1600–1800* (Cambridge, Mass., 2007), chapter 4, David McGee, 'From Craftsmanship to Draftsmanship: Naval Architecture and the Three Traditions of Early-Modern Design', *Technology and Culture*, 40 (1999), 230–32.

[10] Pritchard, 'Shipwright', 11–12, 15–23, Ferreiro, *Ships*, 59–62, 259–72, McGee, 'Craftsmanship', 230–32, Charles Coulston Gillispie, *Science and Polity in France at the End of the Old Regime* (Princeton, 1980), 23.

[11] Pritchard, 'Shipwright', 1–3, 7, McGee, 'Craftsmanship', 232, Ferreiro, *Ships,* 303–4.

years of the Revolutionary Wars.[12] In fact, it was shipwrights, rather than scientists, who made the difference in France. Shipbuilders in French naval yards became professionalised over the course of the eighteenth century, both as a consequence of deliberate government policies aimed at enhancing the status of shipwrights and as an outcome of their own efforts. The knowledge that they employed in the actual practice of shipbuilding was based less on mathematical theory than on precepts derived from observations and experiences accumulated over the years.[13]

No such institutionalisation of supposedly 'useful' knowledge from above took place in shipbuilding in Britain or the Netherlands before 1800. In The Netherlands, such formal training in ship construction, professionalization of shipbuilders and the diffusion of mathematical theory in ship design through new institutions did not begin until the early nineteenth century—partly as a consequence of the country's temporary alliance with France. In Britain, naval administrators, Fellows of the Royal Society and other self-declared experts in the theory of ship design who formed the Society for the Improvement of Naval Architecture in the late eighteenth century tried hard to reform work practices in dockyards. And although they established the first School of Naval Architecture in Portsmouth in 1811 it nevertheless took some time before their efforts produced any discernible effect.[14]

Still, both countries *did* see some significant changes in the process of ship construction. In Britain, the use of measured multi-view plans in ship design, pioneered by shipwright Matthew Baker in the 1580s, had become standard practice in warship building by the eighteenth century. This 'architectural tradition' in shipbuilding, as David McGee has called it, was also adopted at the Rotterdam and Amsterdam Admiralty dockyards in The Netherlands in the 1720s and 1730s, as well as those of the Dutch East India Company (VOC) from the 1740s onwards. Warships and East Indiamen were built to standardised dimensions according to measured plans drawn up before the keel was laid.[15] Pieter van Zwyndregt Pauluszoon (1711–1790), who was master shipwright at the Rotterdam dockyard in the 1750s, also conducted a number of tests with models to improve the hull lines of his ship designs.[16]

In this way, and like the shipwrights in France, shipbuilders in Britain and the Netherlands made use of rules and principles acquired from their personal observations and experience over the years. In contrast to France, however, their construction practices showed more variation *between* shipyards, because master shipwrights received their training in a local apprenticeship setting rather than through a uniform, nationwide schooling system and—in Britain at least—warship construction was partly contracted out to the private building industry throughout the eighteenth century.[17]

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[12] Simon Schaffer, '"The Charter'd Thames": Naval Architecture and Experimental Spaces in Georgian Britain', in: Lissa Roberts, Simon Schaffer and Peter Dear (eds.), *The Mindful Hand. Inquiry and Invention from the Late Renaissance to Early Industrialization* (Amsterdam, 2007), 298–99.

[13] Pritchard, 'Shipwright', 6, 9, 13–14, 24.

[14] Ferreiro, *Ships*, 296–98, Glete, *Navies*, vol. I, 49, Schaffer, '"The Charter'd Thames"', 294–303.

[15] McGee, 'Craftsmanship', 222–27, Ab J. Hoving and Alan Arthur Lemmers, *In tekening gebracht. De achttiende-eeuwse scheepsbouwers en hun ontwerpmethoden* (Amsterdam, 2001), chapters II and III. Jaap R. Bruijn, Femme S. Gaastra and Ivo Schöffer (eds.), *Dutch-Asiatic Shipping in the 17th and 18th Centuries* (The Hague, 1987), vol. I, 44–47, Johan de Jong, 'Drawings, Ships and Spices. Accumulation at the Dutch East India Company', in: Lissa Roberts (ed.), *Centres and Cycles of Accumulation In and Around the Netherlands during the Early Modern Period* (Berlin, 2011), 182–84, 188–90.

[16] Hoving and Lemmers, *In tekening gebracht*, 102–3, 183–88.

[17] Cf. Glete, *Navies*, vol. I, 288, Ferreiro, *Ships*, 296–98.

2. Navigation Technology

In navigation technology, variations between countries in the eighteenth century diminished more markedly than in the domain of shipbuilding. Institutional arrangements in Britain, France and the Dutch Republic did show a remarkable degree of convergence. This striking convergence in arrangements largely, though not exclusively, correlates with the introduction of practicable methods for finding longitude at sea. While solutions to this problem had been worked out, in theory, in the early sixteenth century, it took almost 250 years before adequate techniques and instruments were developed to make this knowledge usable in practice. From the 1760s onwards, two different 'useful and reliable' methods finally became available for seafarers: finding longitude by lunar distances and finding longitude with the aid of timekeepers.

The convergence in institutional arrangements was linked to the nature of the materials that were needed to put these methods into operation. Applying lunar distances or finding longitude by chronometers demanded the availability of particular sets of aids, which involved larger and more prolonged investment than had previously been the practice in navigation technology. Calculating lunar distance required the continuous availability of a nautical almanac containing tables with all the necessary astronomical data, as well as a set of sextants and octants to measure angles. To apply the chronometer method, a ship needed to carry three timekeepers (as a single piece was not reliable enough); moreover, the error margin and daily rate of each of these had to be regularly checked. The adoption of these new methods of finding longitude thus required investment to a degree and extent that few individual navigators or private entrepreneurs were able, or willing, to make. In response, state agencies started to play a different, more active role.

The governments of all three countries began to produce nautical almanacs according to a bureaucratic model. State agencies assumed responsibility for providing these essential tools for calculating lunar distances, albeit in slightly different ways. In Britain, the publication of a nautical almanac was entrusted to the Royal Observatory in Greenwich from 1765 onwards. The Observatory was headed by the Astronomer Royal, who was assisted by a small staff of observers and computers. The almanac, using Greenwich as the prime meridian—0° longitude—was always published a few years ahead of the period it covered.

In the Dutch Republic, a new agency was created by the Admiralties of Amsterdam and Rotterdam in 1787, called the *Commissie tot de Zaaken, het Bepalen der Lengte op Zee en het Verbeteren der Zeekaarten Betreffende* (Committee on Matters Relating to the Determination of Longitude at Sea and the Improvement of Charts). After 1795, this Longitude Committee served as an agency of the newly-centralised Navy. Except for one interlude between 1811 and 1815, the Committee continued to function until 1850. Its role was to track, filter and communicate any relevant information about techniques, instruments and aids that could be useful for measuring longitude at sea. One of its principal activities was the translation and adaptation of the British nautical almanac for the use of seamen from The Netherlands, using a meridian through the Peak of Tenerife instead of Greenwich as its prime meridian.[18] When the Committee was reinstated after the Napoleonic period, its task was redefined to include the examination of naval officers, the improvement of charts and the annual publication of a nautical almanac. The Longitude Committee consisted of three or four members, namely one or two professors from either the Athenaeum Illustre in Amsterdam, the university of Leiden or the university of Utrecht, along with an expert from the Navy and a representative of Hulst van Keulen firm, the leading Dutch publishing house of nautical books and charts.[19]

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[18] Karel Davids, *Zeewezen en wetenschap. De wetenschap en de ontwikkeling van de navigatietechniek in Nederland tussen 1585 en 1815* (Amsterdam/Dieren, 1986), 188–90.

[19] G.D. Bom, *Bijdrage tot eene geschiedenis van het geslacht 'Van Keulen'* (Amsterdam, 1885), 61–65. Cf. for

Similarly, the French Republican government established a *Bureau des Longitudes* in 1795. Its main tasks were, first, to ensure the timely publication of the *Connaissance des Temps*, which included the requisite tables for applying the lunar distance method, using Paris as the prime meridian; second, to bring astronomical tables and methods for finding longitude to greater perfection; and, third, to publish all sorts of astronomical and meteorological observations. In order to execute these tasks successfully, the Bureau was put in charge of the Paris Observatory, minor observatories in the capital and the provinces, as well as all the astronomical instruments that belonged to the state. The Bureau consisted of mathematicians, astronomers, naval officers, a geographer and an instrument maker, assisted by four adjunct-astronomers who carried out calculations and observations.[20] The Bureau's composition and scope of operations thus encompassed a mixture of features of the Board of Longitude (established by the British Parliament in 1714), the Royal Observatory and the Dutch Longitude Committee.

The convergence between European states went one step further when the Dutch officially adopted the Greenwich meridian as their prime meridian. This was based on a recommendation from the Longitude Committee to the Navy Secretary in 1826, which suggested that henceforth the Greenwich meridian should be used instead of that of Tenerife as the basis for the lunar tables in the Dutch almanac. The Committee argued that other seafaring nations no longer used the meridian of Tenerife as their reference point and that Dutch seafarers rarely used it as a prime meridian either. Naval officers had already switched to the Greenwich meridian because they often used British charts, however, those published by the Longitude Committee from 1815 onwards indicated longitude with regard to Paris, Greenwich and Tenerife. The Committee itself considered the proliferation of prime meridians rather 'ridiculous' and a source of 'error, uncertainty and inaccuracy', stating that nations should agree on a common prime meridian, which it proposed, in theory, should be, the meridian of the Peak of Tenerife. Their justification was that this would produce 'a good division of the globe': the whole of Europe would lie in the eastern hemisphere and the Americas in the western hemisphere. However, as the proposal continued, this was an unlikely outcome, so the more realistic choice was the meridians of Greenwich or Paris. Furthermore, the Committee concluded, because 'England was the first seafaring nation' and most of the charts and relevant nautical reports came from England, preference should be given to the Greenwich meridian.[21] This recommendation was accepted without any further debate and a royal decree in this sense was issued in July 1826. The first Dutch nautical almanac with lunar tables based on the Greenwich meridian was produced for 1828, after this Van Keulen simply published translations of the British nautical almanac.[22]

There was also a notable convergence in institutional arrangements for supplying the instruments required for these new methods of finding longitude. In all three countries under discussion, most of the marine chronometers used on board in the late eighteenth and early nineteenth centuries were provided by each country's naval authorities and were, therefore, not

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the following also Karel Davids, 'Longitude Committee and Navigational Practice in the Netherlands, c.1750–1850', in: Richard Dunn and Rebekkah Higgitt (eds.), *Navigational Enterprises in Europe and its Empires, 1730–1850* (London, 2015).

[20] *Loi Relative à la Formation d'un Bureau des Longitudes du 7 Messidor, An III* (25 Juin 1795) articles 2, 5, 9 and 12, http://www.bureau-des-longitudes.fr/textes-references/loi-an3-formation.htm (consulted 13 August 2014), Charles Coulston Gillispie, *Science and Polity in France: The Revolutionary and Napoleonic Years* (Princeton, 2004), 455–56.

[21] *Almanak ten dienste der zeelieden voor het jaar 1828* (The Hague, 1827), 212–17.

[22] National Archives The Hague, Archief Marine 1813–1900, nr. 3912 index op Verbalen 1826, nr. 334 Verbaal 1 August 1826, nr. 2929 agenda 15 July 1826; the original letter of the Longitude Committee has been destroyed; nr. 341 Verbaal 30 November 1826. See also Davids, 'Longitude Committee'.

the personal property of ship's navigators. In addition, state agencies were responsible for checking and maintaining timekeeping devices. The reason that these arrangements were adopted was the prohibitive cost of these new types of nautical instruments. Although a few naval officers bought their own timepieces after the late 1770s, the purchase and upkeep of a single chronometer (let alone three) was way beyond the means of the vast majority of navigators. In Britain, one alone would cost around 60 to 100 guineas apiece.[23] Prior to the 1820s, even navies did not possess many timekeepers—for instance, in 1802, less than 7% of the British Royal Navy's ships carried a chronometer.[24] The Dutch Navy purchased eighteen timepieces between c.1790 and 1815; ten of these came from France, five from Britain and two from The Netherlands, while the provenance of one chronometer was unknown.[25] By 1835, this number had increased to eighty-five, of which seventy-four originated from Britain, nine from The Netherlands and one from France[26].

Increased costs of the altitude-measuring instruments needed for the lunar distance method also contributed to institutional change, but only to a certain degree and with more mixed effects than in the case of timekeepers. Even though finding longitude by lunar distance was cheaper than using chronometers, because:

> no instrument more expensive [was required] than the essential [octant] (costing about three guineas in the 1760s) […] or the new sextant (twelve guineas) which could measure angles up to 120°[27]

The relatively high price of these new instruments compared to traditional devices such as cross-staffs or back-staffs nevertheless was the reason why the Dutch Navy changed its rules concerning the provision of equipment in the late eighteenth century. From that point on, Admiralties in the Dutch Republic the first time carried part of the burden of purchasing instruments needed to make astronomical observations at sea. Starting in 1788, the Dutch naval authorities began to issue sextants to naval officers on a regular basis and, after 1802, they granted officers a standard sum of money to buy the necessary equipment.[28]

Convergence in institutions between countries was not exclusively related to the introduction of new methods for finding longitude, however. A similar development can be seen in arrangements concerning the production and provision of charts even *before* the problem of longitude had finally been solved. In 1720, the *Conseil de Marine* in France founded a *Dépot des Cartes et Plans de la Marine* under the supervision of a naval officer, which was charged with examining and preserving '*des plans, cartes, journaux des voyages, rapports et autres memoires envoyés par les officiers commandants des vaisseaux à leur retour de la mer*'.[29] In fact, the *Dépot* fulfilled much the same function as the Dutch East India Company's hydrographic offices that—in imitation of those in Portugal and Spain—had been founded in Amsterdam and Batavia a century earlier, although

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[23] Nicholas A. M. Rodger, *Command of the Ocean. A Naval History of Britain, 1649–1815* (London, 2004), 382–83, Davids, *Zeewezen en wetenschap*, 186.

[24] Rodger, *Command of the Ocean*, 383, W.E. May, 'How the Chronometer Went to Sea', *Antiquarian Horology* (March 1976), 638–63.

[25] Davids, *Zeewezen en wetenschap*, 260–61, J.H. Leopold, 'The Third Seafaring Nation. The Introduction of the Marine Chronometer in the Netherlands', *Antiquarian Horology*, 22 (1996), 486–500.

[26] Based on H. Spek, *Tijdmeters en waarnemingshorloges van de Departementen van Marine en Koloniën in de negentiende eeuw* (Oegstgeest, 1982); the provenance of one timekeeper is unknown.

[27] Rodger, *Command of the Ocean*, 383.

[28] Davids, *Zeewezen en wetenschap*, 190, 253.

[29] Olivier Chapuis, *A la mer comme au ciel. Beautemps-Beaupré et la naissance de l'hydrographie moderne (1700–1850)* (Paris, 1999), 160, Joseph W. Konvitz, *Cartography in France. Science, Engineering and Statecraft* (Chicago, 1987), 73, Daniel R. Headrick, *When Information came of Age. Technologies in the Age of Reason and Revolution, 1700–1850* (Oxford, 2000), 113.

it initially operated on a smaller scale. While the VOC's hydrographic office in Amsterdam in the second half of the seventeenth century consisted of a chief hydrographer with four assistants, the *Depôt* opened with a staff of only two junior employees.[30]

For many years, the *Depôt* concentrated on copying, preserving and analysing ship's journals, plans and maps rather than on producing new charts or aids for seamen. It did not produce many charts until the middle of the eighteenth century, especially in the early stages of the Seven Years War: 48 charts and 57 prints were published between 1737 and 1758, more than half of which appeared between 1754 and 1758.[31] In 1773, the agency was officially designated as the exclusive producer of cartographic aids for seamen in France. By the mid-1780s, the *Depôt* had grown into a department comprising two chief officers and nineteen employees, including six *ingenieurs-dessinateurs* who specialised in drawing maps and copying geographic materials.[32] By this point, France had surpassed the Dutch Republic as the leading European producer of marine charts.

Britain and The Netherlands next adapted their arrangements to keep up with the French. In the 1790s, the British naval authorities created a hydrographic office modelled on the French *Depôt*. Alexander Dalrymple was appointed Hydrographer to the Admiralty in August 1795.[33] Meanwhile, the Dutch Longitude Committee, founded in 1787, was given the additional task of improving existing charts for the use of seamen. Many of the improved charts that were made available for Dutch seafarers were based on French or English designs.[34]

At this time, formal rules were introduced to monitor navigators' technical competence and the three European countries showed a certain degree of convergence in institutional arrangements in this area too. Following the examples of Portugal and Spain, chartered trading companies and navies in the Dutch Republic, Britain and France enacted regulations that required ship's officers, masters and mates to take a formal competency test before they could be considered for appointment or promotion. The VOC's chamber in Amsterdam introduced a compulsory examination for mates and created a separate position of examiner of pilots as early as 1619. The company's other five chambers had followed suit by 1730, and the statutory obligation to pass certain examinations was gradually extended to all masters and mates seeking employment with the VOC. By 1750, it was impossible to attain a higher rank in the hierarchy of navigating personnel without proving proficiency in the theory and practice of navigating to one or more pilot examiners. To become a captain of a Dutch East Indiaman, candidates had to pass no less than four assessments: as third mate, second mate, first mate and master.[35] Other chartered trading companies, such as the Dutch West India Company and the English East India Company, likewise introduced examinations for navigators in the later seventeenth and early eighteenth centuries.[36]

England was the first European state to introduce a qualifying examination for officers of the Navy. Even if a potential officer began his career under the patronage of senior officers, the naval

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[30] Kees Zandvliet, *Mapping for Money. Maps, Plans and Topographic Paintings and their Role in Dutch Overseas Expansion during the 16th and 17th Centuries* (Amsterdam, 1998), 125, Chapuis, *A la mer comme au ciel*, 161–62.

[31] Chapuis, *A la mer comme au ciel*, 164–65, 183, 943 note 49.

[32] Chapuis, *A la mer comme au ciel*, 222–25, Olivier Chapuis, 'Hydrographical Departments', in: John B. Hattendorf (ed.), *The Oxford Encyclopedia of Maritime History* (Oxford, 2007) vol. II.

[33] Chapuis, 'Hydrographical Departments', 165.

[34] Davids, *Zeewezen en wetenschap*, 223–24, Karel Davids, 'Florijn, Van Swinden and the Longitude Committee (1787–1818)', in: Martina Schiavon et al. (eds.), *Le Bureau des longitudes (1795–1930): contexte national et international* (forthcoming Nancy, 2016).

[35] Davids, *Zeewezen en wetenschap*, 294–96.

[36] Davids, *Zeewezen en wetenschap*, 296–97, 364–65.

authorities nonetheless demanded a formal measurement of their aptitude. From 1677 onwards, anyone applying for a role as a lieutenant was obliged to have served a certain length of time at sea and to have passed a seamanship exam overseen by a panel of captains. These exams were conducted by panels appointed by local commanders-in-chief abroad, or by the Navy Board in Britain.[37] In the Dutch Republic, statutory examinations for naval officers and mates were instituted by a number of Admiralties at the end of the seventeenth century and became general after c.1750.[38] France introduced qualifying examinations for both naval officers and navigating personnel in the merchant marine and, from 1681 on, masters and mates in ocean shipping and coastal navigation were also required to take an exam overseen by a state-appointed professor of navigation.[39]

3. Comparisons

Why was convergence across the three countries more extensive in navigation technology than in ship construction? After all, there were similar forces at work in both domains, pushing for convergence in institutional arrangements. Given the persistent rivalry between certain European maritime powers, especially between Britain and France, it is not surprising to find that they actually copied each other's best practice in navigation technology. The creation of the *Bureau des Longitudes* in France was inspired by the Board of Longitude in Britain, just as the foundation of the Hydrographic Office in Britain was inspired by the *Dépot des Cartes et Plans de la Marine* in France. Moreover, every state involved in this naval rivalry faced a sharp rise in the equipment costs in both ship construction and in navigation technology, as warships and nautical instruments became much more expensive over the eighteenth century.[40] This consideration may also have led to a certain amount of convergence in both domains of knowledge.

However, there were important differences between the two spheres as well. Bureaucrats, scholars and practical experts regarded the new methods of finding longitude as both *reliable* and *useful* knowledge. Even though opinions about the merits of particular innovations (such as John Harrison's timekeeper) may initially have differed, formal trials and observations eventually led to a broadly shared agreement that these techniques and instruments produced dependable results. As a consequence, their value was no longer seriously contested. In contrast, no such consensus emerged about the use of mathematical theory for ship design. There was not enough evidence, gathered from trials at sea or in other ways, to conclusively convince the various groups concerned that one particular approach led to trustworthy outcomes in ship construction.

In navigation technology, moreover, naval authorities and directors of chartered trading companies in Britain and The Netherlands were not just more willing, but also more capable of imposing 'useful' knowledge within their organisation than in the case of shipbuilding. They were not faced with the countervailing power of local traditions and vested interests entrenched in guilds or private shipyards.[41] And, navigators working for the British Royal Navy or Admiralties

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[37] Rodger, C*ommand of the Ocean,* 121–22, 519–20.

[38] Davids, *Zeewezen en wetenschap*, 297–99.

[39] Abbel Anthiaume, *Évolution et enseignement de la science nautique en France et principalement chez les Normans* (Paris, 1920), Book II, chapter 5, Jacques Aman, *Les officiers bleus dans la marine française au XVIIIe siècle* (Geneva, 1976), 31–33.

[40] On the costs of warships, see McGee, 'Craftsmanship', 226, and John Brewer, *The Sinews of Power. War, Money and the English State, 1688–1783* (London, 1989), 34–35; on the cost of nautical instruments, see above.

[41] Cf. Glete, *Navies*, vol. I, 49, Hoving and Lemmers, *In tekening gebrach.*, 142–43, Bruijn, Gaastra and Schöffer (eds.), *Dutch-Asiatic Shipping*, vol. I, 47.

in the Dutch Republic and the VOC became more 'professional'. Like ship constructors in eighteenth-century France, they increasingly acquired the trappings of a distinct 'corps', including uniforms, fixed ranks and formal rules for admission and promotion.[42] Adopting 'useful and reliable' knowledge in navigation technology was therefore seen as an asset contributing towards professionalisation, rather than an unnecessary luxury for the successful performance of their job.

Conclusion

This essay analyzed to what extent and why convergence, or divergence, took place in the way knowledge was made 'useful' in the eighteenth and early nineteenth centuries. It compared developments in two domains of knowledge—shipbuilding and navigation technology—in three European countries (Britain, France and The Netherlands). Choosing these domains of knowledge ensured that both market and non-market forces were taken into consideration.

This comparative analysis has shown that, although knowledge could be made 'useful' through institutional arrangements imposed by governments and managers of large organisations such as navies and chartered trading companies, significant variations still emerged between these countries and domains of knowledge. There was markedly more convergence in institutional arrangements surrounding navigation technology than shipbuilding. I suggest that these differences were due to three crucial variables: the degree of consensus or conflict about the reliability of knowledge, the degree of professionalisation and expertise among practitioners of knowledge (such as shipbuilders or navigators), and the countervailing resistance to institutional regulation from above. Even hierarchies have their limits.

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[42] Rodger, *Command of the Ocean*, 324–25, 380–94, Jaap R. Bruijn, *The Dutch Navy of the Seventeenth and Eighteenth Centuries* (Columbia, 1983), 173–91, Jaap R. Bruijn, *Commanders of Dutch East India Ships in the Eighteenth Century* (Rochester NY, 2011), chapter 16.

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USEFUL KNOWLEDGE BUT FOR WHOM? THE DEVELOPMENT OF APPROPRIATE AGRICULTURAL TECHNOLOGY IN SOUTH GERMANY, 1890–1920

Jonathan Harwood

This paper originated from a workshop which intended, amongst other things, to identify the characteristics of 'useful knowledge'. So let me begin with what may seem to be obvious: that what is called 'useful knowledge' is supposed to be useful(!). However banal this statement seems at first sight, it nevertheless has an important implication: namely, that knowledge intended to be useful is sometimes *not* very useful to some of its users. This, therefore, raises the interesting question of how we can explain the fact that one particular form of knowledge is more useful to some users than to others.

This is a modern phenomenon which I call 'differential utility'. In past times, when most users made their own tools, usefulness would not have been a problem, because any tool which was less than ideal could be modified, subject to the user's skill and the availability of materials. Up until the nineteenth century, farmers throughout Europe and North America continually developed their own tools and cultivation techniques by experimenting with whatever was available (and this is still true today for large parts of the developing world). Fertilisers were derived from locally-available materials such as manure, bonemeal and fermented sediment from riverbeds. Farmers often 'reshaped' the indigenous animal and crop species by selecting and breeding from the individual animals or plants which fared relatively well in those specific agricultural conditions and thus produced more food. It is, therefore, apparent that this differential utility only began to emerge historically as the locus of invention (and intervention) gradually shifted away from users and towards experts. The fact that experts are often distanced from (at least some) users, because they are based at specialist institutions, results in a lack of communication between inventor and user and may consequently lead to less-than-useful knowledge. As Erich von Hippel notes, for example, in some manufacturing companies today, managers are often surprised to find that most of the innovations in their sector originate from users rather than from the firm's own R&D laboratory. The reason, he argues, is that managers seldom track where new product improvements come from because they think, wrongly, that they can adequately judge users' needs.[1]

During the 1970s the desire to improve poorly-designed technology was embodied in a political movement called 'appropriate technology'.[2] Perhaps its best known advocate was E.F. Schumacher, whose book, *Small is Beautiful* (1973), articulated the concept of 'intermediate technology' ('IT'), which he defined as an intermediate form, situated half-way between relatively simple 'traditional' technology and 'modern', advanced technology. Like its traditional precursors, 'IT' was cheaper, simpler and more small-scale than advanced technology but, it was also more efficient than traditional technology because it included improvements produced by scientific and engineering know-how.[3] Although Schumacher is probably best known today as a champion of communitarian ideals and environmentalism, it is worth noting that he was trained as an

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[1] Eric von Hippel, *Democratizing Innovation* (Cambridge, MA, 2005), 175–76.

[2] Langdon Winner, 'Building the Better Mousetrap: Appropriate Technology as a Social Movement', in: Franklin Long and Alexandra Oleson (eds.) *Appropriate Technology and Social Values: A Critical Appraisal*, (Cambridge, MA, 1980); Adrian Smith, 'The Alternative Technology Movement: An Analysis of its Framing and Negotiation of Technological Development', *Human Ecology Review*, 12/2 (2005).

[3] Ernst Friedrich Schumacher, *Small Is Beautiful: A Study of Economics as if People Mattered* (London, 1993 [1973]).

economist and dedicated much of his career to promoting forms of technology which were designed to be more suitable for use in developing countries.[4]

Schumacher was not alone in this endeavour.[5] During the 1960s a number of political movements sprang up, which heightened awareness of the limitations of well-established large-scale technologies. These included a 'counterculture' (especially in the US), the environmentalist movement, criticism of the American use of chemical weapons in Vietnam, and a recognition that advanced agricultural technology was failing to help small farmers in the developing world. The resulting uncertainty was further compounded by the 1970s' oil crisis and declining public confidence in nuclear power.[6] In response, a variety of voices—most broadly on the political left—called for an 'alternative technology' which would be subject to greater public control. For instance, David Dickson suggested that technology should be not only less environmentally wasteful and damaging, but also less alienating for the workforce.[7] The same year a collection of works by several dozen international authors was published, offering a wide range of critiques of contemporary technology alongside proposals for developing alternatives.[8] While much of this literature had been prompted by the failures of industrial or military technology, similar arguments were being made at that time for alternative agricultural technologies suitable for developing countries.[9] Many of these claimed that public participation in the design and use of technology—and thus its democratic control—would be impossible without decentralisation.[10]

Although the movement for appropriate technology flourished during the 1970s, some of its underlying ideas were much older.[11] A case in point is the movement for what I call 'peasant-friendly' agricultural technology in late nineteenth century Europe, at a time when much of western European agriculture was undergoing a fundamental transformation. The rise of a new

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[4] In 1965 he played a major role in founding the Intermediate Technology Development Group (later renamed 'Practical Action', now a well-known London-based development charity) and, during the 1950s and '60s, he served as adviser on development policy to a number of governments in the global South.

[5] A decade before the publication of Schumacher's book, for example, Lewis Mumford had published an essay which, in effect, made the case for appropriate technology, although he used different terminology, Lewis Mumford, ('Authoritarian and Democratic Technics'), *Technology & Culture,* 5/1 (1964), 1–8. For other examples, see Carroll Pursell, 'The Rise and Fall of the Appropriate Technology Movement in the United States, 1965–1985', *Technology & Culture*, 34/3 (1993), 629–37.

[6] Smith, 'The Alternative Technology Movement'.

[7] David Dickson, *Alternative Technology and the Politics of Technical Change* (Glasgow, 1974).

[8] Nigel Cross et al., *Man-Made Futures: Readings in Society, Technology and Design* (London, 1974).

[9] Dickson, *Alternative Technology*, 156; Stephen Biggs and Edward J. Clay, 'Sources of Innovation in Agricultural Technology', *World Development,* 9/4 (1981).

[10] As is evident from Cross et al., *Man-Made Futures*, these critiques can perhaps be seen as one specific example of a more general phenomenon: the growing public suspicion of planners and other technical experts charged with formulating public policy—although not all studies of users as innovators shared this critical stance. Although von Hippel and his collaborators, for instance, also stressed the importance of users as innovators at that time, their primary concern was neither to challenge the centralised control of innovation nor to promote the development of appropriate technology, but rather to make innovation more efficient by alerting managers to the fact that innovation often occurred outside the firm. See Eric von Hippel, 'Users as Innovators', *Technology Review*, 80/3 (1978).

[11] For example, Schumacher's eagerness to combine the practical skills of farmers and artisans with formal scientific knowledge to create a more communicable and useful kind of knowledge was already evident in the eighteenth century. See Marcus Popplow, 'Knowledge Management to Exploit Agrarian Resources as Part of Late-eighteenth-century Cultures of Innovation: Friedrich Casimir Medicus and Franz Von Paula Schrank', *Annals of Science*, 69/3 (2012); Ursula Klein, 'Depersonalizing the Arcanum', *Technology & Culture,* 55/3 (2014).

commercial sector which produced fertilisers, chemical pesticides and improved plant varieties, was heralded by many contemporaries as a revolutionary breakthrough which would guarantee higher productivity. As this paper shows, however, in some regions such as south Germany, the new technology did not meet the needs of a large section of the farming community.[12] I address four questions:

1. Why were the new commercial plant varieties problematic in south Germany?
2. How was alternative, 'peasant-friendly' plant breeding established in Bavaria?
3. What kinds of useful knowledge were produced in the new plant breeding stations?
4. How was this knowledge transmitted between experts and farmers?

The paper first considers some doubts about the suitability of commercial seed, then reviews the 'peasant-friendly' plant breeding programme that was established. The next section examines the kinds of useful knowledge created, followed by a review of institutional mechanisms for knowledge transmission in south Germany during 1890–1920. The essay concludes by comparing late nineteenth-century plant breeding with the decline of the twentieth-century appropriate technology movement and current debates around genetically modified crops.

1. Doubts About the Suitability of Commercial Seed

Commercial plant breeding in Germany began during the nineteenth century, the earliest successes occurring with sugar beets. The first sugar factories were built around 1800 and began to proliferate from the 1830s, mostly concentrated in Lower Silesia and, particularly, the Prussian province of Saxony, whose fertile soils were well-suited to cultivating the sugar beet. Several horticultural breeding firms in the region began attempting to increase the sugar content of beets during the 1850s and, by the 1890s, they had succeeded in roughly doubling their sugar content. Because of the high grain prices which persisted into the 1860s, cereal growers began to take an interest in adopting the methods which had proved so successful with sugar beet. Hence, in the 1870s and 1880s, a number of estate owners in Saxony set about trying to improve the best of the existing cereal (and sometimes potato) varieties. Between about 1880 and the First World War the yield of various cereal and potato species in Germany increased by between 60 and 90 percent. Such technical success was bound to attract others to the sector and, by 1914, there were between 200 and 300 commercial breeders in Germany, far more than in any other European country or the US at that time.

Predictably, the growth of this sector led to a huge increase in the number of crop species available. By the 1890s one observer estimated that there were some 500 different types of wheat alone on the German market.[13] Needless to say, these varied considerably in quality and suitability for particular growing conditions, so any farmer who was keen to take advantage of the improved varieties was confronted with a serious problem of choice. As a result, a new item was added onto the agricultural policy agenda— 'the varietal question' (*die Sortenfrage*) —with farmers calling for a system of testing which would establish which species would provide the best yields under specific conditions. Accordingly, this was one of the first tasks undertaken by the new German Agricultural Society (*Deutsche Landwirtschafts-Gesellschaft*), which was established in 1885. The

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[12] The remainder of this paper draws upon empirical material from Jonathan Harwood, *Europe's Green Revolution and Others Since: The Rise and Fall of Peasant-Friendly Plant-Breeding* (London, 2012), which is analysed from a different perspective.

[13] Harwood, *Europe's Green Revolution*, 37ff.

following year the Society created a Seed Breeding Division which brought together breeders and agricultural scientists in order to obtain information about new varieties and disseminate this knowledge among the Society's members. Soon afterwards, the Society set up the country's first systematic programme of varietal testing in a number of regions across the country.

While the Seed Breeding Division's activities were an important step in promoting the use of improved varieties among farmers, they did not serve all sectors of the farming community equally well. As various observers pointed out, the Division's varietal testing programme was too geographically restricted to sufficiently consider the enormous diversity of growing conditions across the country.[14] For example, it soon became evident that many commercial varieties were faring poorly in south Germany, partly for ecological reasons. Because of the enormous variation in its soils and climates, south Germany held few attractions for plant breeders. Commercial breeding was, therefore, concentrated in the far more uniform soils and climates of central and north Germany. Unfortunately, however, this made them ill-adapted to the very different conditions in the south. Moreover, commercial species also had certain economic disadvantages for southern farmers. For one thing, they had been bred to produce their maximum yield only when large amounts of commercial fertiliser were applied; for another, commercial seed was significantly more expensive than good quality local types. As a result, commercial seeds were just too expensive for the smallholders who dominated the south German farming community. By focusing almost entirely upon commercial varieties, therefore, the Agricultural Society's varietal tests were distinctly unhelpful for southern farmers.

It was fairly predictable that the Seed Breeding Division's activities were not much help to small farmers, because the German Agricultural Society had been established by a group of estate owners keen on technical innovation which would serve a limited constituency of like-minded peers. Regarding itself as an elite organisation, the Society made no attempt to recruit peasant farmers, which meant that south Germany was poorly represented, both in the Society's membership and on its committees. In many respects, therefore, southern farmers were stymied. The virtual absence of private sector breeders in their region meant that they had to turn to northern commercial breeders, only to find that their specimens were often unsuited to southern conditions. Meanwhile, the Agricultural Society's testing programme was too geographically restricted to identify the few varieties which might have been useful for them. How, then, could south German farmers identify more appropriate technology for their particular requirements?

Given the huge variety of seed types on the market, there was no way that a smallholder—or even an estate-owner—could hope to undertake the necessary testing himself. A limited amount of varietal testing was being done at some agricultural schools and colleges, but this was insufficient for the region's needs. Since south German governments did not show any interest in filling this gap during the 1880s and early 1890s, small farmers began to take matters into their own hands. They devised a range of institutional arrangements which enabled them to carry out activities including varietal testing, seed production and species development.

One such institution was the local seed growing associations (*Saatbauverein*). These were a kind of cooperative, often consisting of small farmers, which aimed to supply local smallholders with high-quality seeds at low cost. They did this by buying new specimens from commercial breeders, testing them alongside local varieties to identify which would prosper in local growing conditions, and then propagating large quantities of the best variety for sale locally. This kind of organisation spread rapidly all over Germany from about 1900 but was especially common in south Germany; by 1914, there were several hundred in Bavaria alone.

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[14] Cf. Harwood, *Europe's Green Revolution*, 40.

Seed growing associations provided a useful mechanism for small farmers to obtain good quality seed cheaply. But as already mentioned, the high-yielding commercial varieties available were frequently deficient in other respects, whereas those traditionally planted in the region were well adapted to southern growing conditions and had some valuable qualities, but did not produce high yields. The solution, some suggested, was to try to *improve* local varieties through breeding. In Dresden and in one region of Bavaria, for example, public sector agronomists were sympathetic to this approach and they offered advice and technical support during the 1890s to local farmers' cooperatives who wanted to begin using simple breeding methods to improve their own crops. By the late 1890s the success of these initiatives, along with that of the innovative Swedish public sector plant breeding centre established at Svalöf in 1886, had triggered a discussion among agronomists and state agricultural officials about the viability of state-sponsored, locally-based breeding.

2. Establishing 'Peasant-Friendly' Plant Breeding

Within a few years, all of the south German states had decided to establish their own plant breeding stations: Bavaria in 1902, Württemberg in 1905 and Baden in 1908.[15] These aimed to serve the small farms which predominated in those states (averaging around 3–5 hectares). The foundation of peasant-friendly plant breeding reflected the geographical differences in farming in Germany in 1890 to 1920. During this period, the north was farmed by large landowners, compared to smallholders in the south. The plant breeding programme was therefore concentrated in the south, which was considered controversial in some quarters, almost certainly because it was designed to assist a particular (disadvantaged) sector of the population.

Much the same has been true for agricultural development programmes aimed at peasant farmers in the developing world since 1945. Such programmes have tended to either be resisted by large landowners or, where the programmes looked attractive, hijacked by them ('elite capture'). The fact that peasant-friendly plant breeding circa 1900 was established in south—but not north—Germany is consistent with this pattern. For, unlike the southern states where large estates were few and far between, farms in the north were larger on average and the number of estate owners much greater.[16] As a result, estate owners in the north were far better equipped than their southern counterparts to oppose measures which favoured small farmers.

The institutional setting in which any invention takes place plays a crucial role in determining what kind of knowledge and artefacts are produced there, so it is important to examine how these south German stations were organised. Generally, the key question is one of control: which individuals or groups are in a position to influence the process of invention? If an institution is not managed by its intended beneficiaries, its work is likely to be directed along lines specified by powerful interest groups (or, on occasion, to deviate in directions favoured more by the institution's staff than its users). One way to ensure that activities remain client-focused is, of course, for it to be funded by users. This has worked well in some recent instances where plant breeding research is funded by wealthy farmers.[17]

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[15] The German stations were part of a more general central European movement towards peasant-friendly plant breeding at this time; similar institutions were created in Lausanne (1898), Vienna (1902) and Alsace (1904).

[16] For example, around 1907 there were between one to fifteen farms of 500 hectares or more in each of the south German states and Alsace, while the equivalent figure in various northern states ranged from 400 to 700, see Jonathan Harwood, *Technology's Dilemma: Agricultural Colleges between Science and Practice in Germany, 1860–1934* (Frankfurt, 2005), table 2.2.

[17] J. Witcombe et al., 'Participatory Plant Breeding Is Better Described as Highly Client-Oriented Plant Breeding. I: Four Indicators of Client-Orientation in Plant Breeding', *Experimental Agriculture*, 41/3

In late nineteenth-century Bavaria, though, this was not a feasible option, because most agriculture was carried out by small farmers with few resources, so some other guarantor of accountability was sought. Initially, the station was funded by the Interior Ministry (which was, at that time, responsible for higher education), because it was established at the Agricultural College (in Weihenstephan, north of Munich), where basic facilities were already available. Within a few years, however, its organisation began to diverge from the academic model. Responsibility for funding—and thus controlling—the station's work was transferred to the Ministry of Agriculture, whose priorities focused more on practical impact than on education. Moreover, unlike the academic departments at the College, the station was overseen by an advisory committee (*Beirat*), whose members were drawn from leading representatives of the state's agricultural community: the Bavarian Agricultural Association (*Landwirtschaftlicher Verein)*, the state agricultural council (*Bayerischer Landwirtschaftsrat*) and the Ministry. Their task was to ensure that the station remained focused on small farmers' interests.

3. The Kinds of Useful Knowledge Created

One of the main activities undertaken at the Bavarian centre was, of course, plant breeding. And, in line with its responsibility to small farmers, breeding was conducted in a particular way. As noted above, although commercial breeding firms developed their specimens at central facilities in Saxony or northern Germany, they sold them across Germany, convinced that these varieties were outstanding and would thus thrive everywhere (a breeding strategy which I have called 'cosmopolitanism').[18] In contrast, the south German stations' breeding strategy was 'local' in two respects. First, it began by modifying local varieties which had already proven themselves well-suited to Bavarian conditions. Second, the breeding process was decentralised—i.e. conducted at a number of sites across the state—in order to take the wide geographical variations in soil and climate into account. This strategy aimed to improve the performance of each separate genus in its own specific locale, which would free small farmers from their dependence upon either unsuitable commercial varieties or low-yielding traditional ones. It was too expensive to set up plant breeding outposts in all of the state's major agroecological zones, so the station opted to support farmers from all parts of the region to take up breeding species themselves. It was hoped that this would eventually produce a network of small breeders that would cover the entire state.

In order to meet small farmers' needs, the station had to concentrate on certain appropriate crops. It did this at first by improving barley (a cash crop destined for Bavaria's large brewing industry) and oats (which farmers commonly used as animal feed). As the station grew in size, breeding came to include all of the major cereals, as well as potatoes. Considerable attention was also given to improving crops which private sector breeders were not interested in, and which were often quite important to Bavarian smallholders. Clover and grasses were a case in point. Given the large scale of the Bavarian dairy industry, the quality of pasture and meadow was economically important, so farmers needed access to improved grass and clover seed, along with advice on how best to cultivate them. Around 1900, however, few German commercial breeders were interested in grasses or clovers because developing them was technically difficult and unprofitable. In consequence, the demand for such seed was largely met through imports, especially from Denmark and the US. Although these imported varieties were cheaper than native ones, they were also less suited to German growing conditions and thus much lower yielding. By developing the native species, therefore, the station was able to compensate for 'market failure' (to use contemporary terminology).

(2005), 307.

[18] Harwood, *Europe's Green Revolution*, 45–46.

The fact that the station's breeding programme was tailored to the needs of small farmers can also be inferred from the particular traits which it chose to select for. For example, most private sector breeders sought to increase yield levels, but these often fluctuated greatly from one harvest to the next, depending on weather conditions. Small farmers (like those in the global South today) could not afford to risk a poor harvest, so they generally preferred varieties which might not yield as much but which offered more stable and predictable yields from year to year. Consequently, the station developed crops for 'yield stability' rather than maximal yield. Similarly, while commercial varieties were bred to flourish under the sorts of favourable growing conditions common to large farms, small breeders working under the station's supervision aimed to develop seeds which would flourish under relatively poor growing conditions, to suit the circumstances of many farmers in the state.

In its attempt to invigorate Bavaria's small farm agriculture, however, the station also undertook a range of knowledge generation and dissemination activities which extended far beyond plant breeding. Because of the importance of 'the varietal question', for example, the station made a lot of effort to provide farmers with information about the best available varieties. All the species which might potentially be suitable in Bavaria were tested—including new varieties developed at the station, those bred by newly-trained Bavarian propagators, existing varieties which had traditionally been used by local farmers, and a limited number of commercial varieties from outside the state. Those which looked promising in preliminary tests were then sent to the appropriate growers' associations to be tested in the specific localities where it was thought they might thrive.

In addition to assisting farmers with their seed choice, the station was also responsible for facilitating the development of a new private breeding sector to develop specimens which were better suited to Bavarian conditions than those from northern commercial breeders. The station set out to achieve this by running free introductory courses on breeding for anyone interested. The first course took place in 1902 with 20 participants, and demand appears to have been buoyant, since courses were held annually over the next few years. Promising graduates who wished to continue propagation were given technical support from station staff for their first few years, as well as breeding material from the station which was deemed potentially useful.[19] Those who went on to become breeders were generally individual farmers, staff at public sector institutions (e.g. agricultural secondary schools and state farms), cooperatives or similar organisations.

In order to provide this kind of training, the station's staff had to conduct practice-oriented research to test issues such as the efficacy of different breeding methods. They also undertook work of a kind which they termed 'scientific' (which would be called 'strategic' or 'fundamental' research today). This consisted of research which was not of immediate utility but was nonetheless expected to be commercially valuable over the medium term. This included studies into the inheritance of important traits (e.g. ear forms in cereals, nitrogen content, kernel size and disease resistance), the physiological foundations of the growth process in particular crops, the causes of degeneration in potatoes, and the best ways to design varietal tests.

So far I have discussed knowledge transfer as if it were a one-way process. One of the questions raised in the workshop, however, was to what extent knowledge emerges through the *interaction* of 'learned' with 'skilled' individuals. From the available sources, it is clear that some kinds of knowledge and skill were, indeed, transferred 'one way', namely from experts to farmers, in the typical teacher-student direction. It is important to recognise that, in 1900, the idea of teaching

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[19] For example, some kinds of breeding (e.g. hybridisation, breeding for disease resistance or for wheat's baking quality) were either too complex or expensive for the new (and very small) breeding centres, so the station carried out the difficult preliminary steps of the process before handing the material over to the centres.

breeding to farmers—above all to small farmers—was considered highly controversial. A number of eminent agricultural experts were publically sceptical, asserting that it would be a failure, partly because small farms lacked the facilities thought necessary for breeding, but probably also because peasants in general were not well educated.[20] By ignoring the sceptics the Bavarian station was, in effect, embracing a key political aim of the later movement for appropriate technology—reversing the process of 'deskilling' so characteristic of industrial economies which retains knowledge within expert repositories, and reinstating know-how back in the hands of practitioners.[21]

It is more difficult to establish the extent of transfer in the reverse direction—from farmer to expert—because of a lack of available research material. There was plenty of face-to-face interaction between the two groups during which such learning *might* have occurred: for instance, when the station's staff visited crop improvement associations in order to provide advice, when breeding courses for farmers were held at the station, in discussions following staff lectures to farmers' organisations, or in correspondence columns of the regional agricultural newspaper (*Landwirtschaftliches Wochenblatt*) following the publication of an article by a staff member.

Although I have found little *direct* evidence that experts definitely did learn from farmers, it seems highly likely for several reasons. First, all of the south German state plant breeding stations used 'local varieties' (also known as 'traditional' or 'farmer' varieties) as the starting point for their developmental work. These were species which had been grown in a region for generations, so had necessarily survived a dual selection process—not only natural factors (such as soils, pests and climate), but also the seed choices made by *farmers* over a long period. As a result, they were well-adapted to local ecological and economic conditions. By choosing local specimens as their starting point, the stations were thus implicitly acknowledging the value of previous generations of farmers' judgement and skill. As Schumacher (following Mao) advised experts: 'Go to the practical people and learn from them; synthesise their experience into principles and theories; and return to the practical people and invite them to put those principles into practice in solving their own problems'.[22]

Furthermore, farmers' previous attempts to grow a range of species in their own local conditions must have provided a major source of information on varietal 'performance'. For example, one of the station's first steps in Baden was to ask farmers to send in local samples which were especially good and to share their experiences of growing fodder plants, so that it could inform the station's own experiments in that area. Similarly, the station director at Württemberg took the view that, although an expert would initially have to show a farmer how to carry out breeding, the farmer should have a say in which traits should be selected. The same learning process continues today. One of the points sometimes made by development experts attempting to promote agricultural growth in the global South throughout the twentieth and twenty-first centuries is the extent to which experts have learned from peasant farmers. Although many have been loathe to admit it, the more candid have conceded that local farmers generally know more about their own area's climate and soil conditions or the strengths and weaknesses of species grown there than the experts.[23]

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[20] Cf. Harwood, *Europe's Green Revolution*, 73.

[21] Dickson, *Alternative Technology.*

[22] Schumacher, *Small is Beautiful*, 213. Among the agricultural sciences, agroecology is the field which has most evidently taken this message on board. As a 'hybrid' discipline, it draws upon farmer knowledge (of cultivation practices which have survived over very long periods of time) for its empirical foundation, but it also analyses the reasons for that success in terms of ecological theory and attempts to improve upon it. Stephen Gliessman, 'Agroecology and Agroecosystems', in: Jules Pretty (ed.), *The Earthscan Reader in Sustainable Agriculture* (London, 2005).

[23] See, for example, Kenneth David Sutherland Baldwin, *The Niger Agricultural Project: An Experiment in*

Of course, experts can only learn from practitioners if they are *willing* to listen, which requires a certain degree of respect. In many places in the global South, agricultural experts have tended to look down upon peasants as being 'backwards', in comparison to their own, often urban, middle-class backgrounds. Significantly, this kind of social gulf does not seem to have characterised the south German case, partly because many of the stations' directors were of peasant origin themselves. For instance, although the Bavarian station's first director, Carl Kraus, was the son of a primary school teacher, his successors Ludwig Kiessling and Theodor Scharnagel were both peasant's sons, and the same was true of the longstanding director of Württemberg's station, Josef Wacker. Even those who came from urban middle-class backgrounds appear to have embraced the stations' service mission. For all of these reasons, it seems evident that knowledge and skill moved between experts and farmers in *both* directions.

4. Institutional Mechanisms for Knowledge Transmission

The stations' directors were fully aware that transforming Bavarian agriculture would require a lot more than just developing new species and generating useful knowledge. It was thought crucial that such knowledge actually *reached* farmers and other users.[24] This section examines how each station made their own improved varieties accessible to farmers. Since they were forbidden by statute from engaging in 'commercial activity', they were not permitted to sell the improved seeds. However, they could 'handover' new varieties—to farms, individual Bavarian seed growers or seed-growing cooperatives. These organisations were then allowed to propagate the improved seed in bulk to sell on. However, the station required them to keep their prices low, since these organisations had not had to bear the costs of breeding. In other cases where the station developed promising breeding material which was not yet ready for large-scale planting, the crop was given freely to breeding centres to complete the development process and sell the finished varieties. Both forms of distribution were intended to subsidise the nascent breeding industry as well as seed producers in a way that would make improved species available to small farmers as cheaply as possible.

In order to disseminate other kinds of knowledge and skill, the stations also offered a variety of 'outreach' activities. As noted above, staff gave lectures on crop improvement to local agricultural societies, published short articles containing useful information (either in the state's agricultural newspaper or in the form of flyers which were distributed by farmers' organisations), and held courses for teachers at agricultural secondary schools. However, staff were aware that these rather formal modes of knowledge transmission sometimes fell on deaf ears, so other channels of communication were employed, in which users played a more active role. For instance, farmers were encouraged to write to the stations with questions (and they did so on a large scale). In addition, believing that 'seeing is believing', the stations hosted visits by agricultural organisations and individual farmers and actively promoted 'crop shows' at a local level. These were agricultural fairs at which the best varieties exhibited were awarded prizes (by committees consisting of farmers, brewers, millers and experts). They also organised fact-finding visits to farms which grew or bred promising species, awarded prizes, and published the results in local newspapers. While all of these activities served to share information on best practice, they also provided staff with valuable feedback from farmers.

African Development (Oxford, 1957); Deepak Kumar, 'Science in Agriculture: A Study in Victorian India', *Asian Agri-History*, 1/2 (1997); William Beinart et al., 'Experts and Expertise in Colonial Africa Reconsidered: Science and the Interpenetration of Knowledge', *African Affairs*, 108/432 (2009).

[24] Remarkably, this fundamental point seems to have largely been ignored by many agricultural development programmes in the global South from the 1940s through the 1960s. Harwood, *Europe's Green Revolution*, 125–26.

Nonetheless, most of these activities were initiated by the stations and reflect a vision of knowledge transmission which economic historians and other students of innovation have called 'supply-push' rather than 'demand-pull'.[25] As every teacher knows, however, learning is often more effective if initiated by the student. Recognising this, the Bavarian station's second director, Ludwig Kiessling (1875-1942), invested a great deal of effort in promoting a new kind of farmers' organisation in every area across his state: crop improvement associations (*Ackerbauverein*). The idea behind these organisations was twofold. On the one hand, they would bring benefits of scale to small farmers, allowing them to sell their produce on more favourable terms than usual. This was an important issue in Bavaria, partly because of the predominance of small farms but also because of the importance of barley as a cash crop. By the end of the nineteenth century Munich's rapidly growing brewing industry was unable to obtain enough good quality barley from Germany and thus had to import much of it from central Europe. In fact, the brewers rated Bavaria's local barley very highly, but were only willing to pay premium prices for *large* batches of uniform and well-cleaned grain. Small farmers, who often grew different varieties from their neighbours and lacked access to grain-cleaning machinery, could not meet these requirements. One of the crop improvement associations' aims, therefore, was to get all their members to agree to plant the same high quality variety. The association would then arrange for their harvested grain to be cleaned and would pool all their harvests for sale in large batches to secure better prices.[26]

The other rationale for the crop improvement associations was that they would greatly simplify the process of communication between experts and farmers. As a peasant's son himself, Kiessling knew that making low-cost improved seed available for inspection at crop shows was certainly a useful activity, but was not sufficient to persuade most farmers of its merits, because they tended to be cautious about new practices. It was, therefore, essential to show farmers that it was in their own interest to *organise themselves,* becoming more aware of precisely what kind of useful knowledge they needed in the process. In seeking their own appropriate solutions, each association was encouraged to make use of technical advice available from a local expert, who was usually a teacher at a nearby agricultural secondary school (*Wanderlehrer*). Such teachers were well-suited to the task because they were generally familiar with local economic and ecological conditions as well as cultivation practices. These teachers were responsible for conducting varietal tests in the local area to advise members on their choice of best variety, but they also offered advice on cultivation, harvesting and storage procedures.

Significantly, the channels of communication in these associations were not just top-down. In addition to providing a meeting place where members could periodically learn about best practice from their local expert, they also provided an opportunity for farmers to learn *from each other* (a process which development experts today still regard as a major source of learning). Moreover, as one observer at the time put it, crop improvement associations transmitted best practice by exerting social pressure.[27] Because of the opportunity to receive better prices for a high quality product, the association put pressure on individual members to raise their own cultivation practices up to the required level. Experiments, demonstrations and varietal tests which local advisers organised for their members displayed the advantages of improved cultivation methods or apparatuses, and free or subsidised inputs encouraged smallholders to try them out for

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[25] Chris Freeman, 'The Economics of Technical Change', *Cambridge Journal of Economics*, 18/5 (1994).

[26] By acting in collaboration, members of an association could secure other additional advantages. For instance, advisers routinely encouraged them to make full use of all the facilities provided by public sector institutions as well as the Bavarian Agricultural Society, since high usage rates could then be used to lever more resources from the state.

[27] Cf. Harwood, *Europe's Green Revolution*, 68ff.

themselves. Then, once standards had been agreed by the association, the adviser would visit each member every year, which ensured that they all felt obliged to adhere to the agreed rules.

During the early years of the new associations Kiessling's efforts to promote them came up against a certain amount of scepticism from experts and officials. By the eve of World War One, however, he felt confident that he enjoyed the support of the Agriculture Ministry and other bodies. Officials could hardly fail to notice the speed with which the associations were spreading throughout the state, as well as the high proportion of farmers becoming members in some regions, indicating that smallholders themselves believed the associations to be a valuable resource. Other south German states soon adopted the Bavarian model and, by 1914, even north German observers were paying tribute to the station's role in promoting the associations.

Conclusion

On the whole, the south German stations were regarded by contemporaries as a resounding success. One indication of public support for the Bavarian station was its phenomenal growth; by the late 1920s its staff numbers and budget had increased roughly tenfold since its inception in 1902. Moreover, the station's strengths were noticed further afield. In the inter-war period, when the Prussian Agriculture Minister was considering how Prussian chambers of agriculture might begin to support plant breeding, it was suggested to him more than once that the south German stations might provide a suitable model to emulate. The Bavarian station in particular was cited as an institution which had already released a number of very productive varieties onto the market. Indeed, by the late 1920s, the large commercial breeding firms in central and northern Germany, unsettled by the extent to which the station's species had come to dominate south German seed markets, called upon the Bavarian government to put an end to such 'unfair competition' from a public sector institution.[28] To its credit, the government declined to do so. As proponents of appropriate technology half a century later were well aware, decentralising control over technology is necessarily a political act—and one which will be opposed by those in power who perceive their interests to be threatened.

The movement for alternative technology fell into decline from the 1980s —at least in the UK and the US—and, by 2000, the terms 'appropriate' or 'alternative' technology were relatively uncommon in the literature.[29] Some of the crises which the movement had sought to address, however, as well as the technologies which it advocated (e.g. renewable energy sources in place of dependence upon fossil fuels) are today much higher on the political agenda than they were in the 1970s. Moreover, the movement's central conviction—that citizens should have a greater say in the design of the technologies which affect their wellbeing—remains a major concern within fields such as the history of technology, science and technology studies, or science and technology policy, even though terms like 'appropriate technology' are no longer used.[30]

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[28] In France in recent years pressure from the private sector has been placed upon the National Institute for Agricultural Research (INRA) to discontinue encouraging farmers to participate in plant breeding. Christophe Bonneuil and Frederic Thomas, *Gènes, pouvoirs et profits: recherche publique et régimes de production des savoirs de Mendel aux Ogm* (Versailles and Lausanne, 2009), 521. *Plus ça change….*

[29] See Pursell, 'The Rise and Fall of the Appropriate Technology Movement'; Smith, 'The Alternative Technology Movement'. A search of the digitised English language literature using Google Ngram shows the frequency of the terms 'appropriate technology', 'alternative technology' and 'intermediate technology' rising steeply around 1970 but falling off steadily from about 1980.

[30] E.g. Adrian Ely et al., 'Broadening out and Opening up Technology Assessment: Approaches to Enhance International Development, Co-Ordination and Democratisation', *Research Policy*, 43 (2014).

Nevertheless, it is remarkable how many technologists seem not to have grasped the basic message, either through ignorance or wilful neglect.[31] It is precisely this issue that lies at the heart of recent debate about what has been called the 'new Green Revolution' (or 'second Green Revolution').[32] Like the original Green Revolution (GR) of the 1940s to 1960s, which greatly increased grain production in parts of Latin America and Asia through the introduction of high-yielding species, its contemporary successor promises once again to boost agricultural production in the global South by applying a new technology. While the original GR relied upon 'miracle varieties' (as they were sometimes called), supporters of the new GR are, in effect, championing a 'miracle technology': the form of biotechnology known as transgenic modification (or more popularly as 'genetic modification' or 'GM'). Advocates claim that using this technology is the only way to increase food production in the global South sufficiently so that it can stay ahead of future population growth and, thus, alleviate hunger and poverty.[33] Whether such biotechnology methods will actually produce consistently higher yields remains to be seen. It appears that the champions of this new technology have overlooked the fact that, historically, the GR's technology brought sizeable gains for large farms which enjoyed good growing conditions, but most smallholders benefitted very little. That was because the original GR's cereal varieties were ill-suited to the unfavourable growing conditions of most small farms and too expensive for most peasant families anyway, just like the situation in late nineteenth-century central Europe.

In view of this history, we ought to ask whether the new varieties produced via transgenic modification will be appropriate for the circumstances which today's small farmers are facing. From an economic perspective, the answer is 'probably not', since the price of genetically modified seed can be 10% to 300% higher than ordinary commercial seed (which is, in turn, far more expensive than the seed which most farmers in the South obtain through barter and exchange). From an ecological perspective, the answer is more uncertain. To be sure, some breeders—primarily in the *public* sector—are currently using transgenic modification in an attempt to develop varieties which will better tolerate stressful growing conditions (such as drought) or will save farmers the cost of commercial fertiliser (because they will be able to use airborne nitrogen). There is some doubt, however, whether these varieties will ever be available for sale, since funding for public sector research has steadily declined since the 1970s. In contrast, over this period private sector investment in agricultural research has increased rapidly, so that the vast majority of current research in biotechnology and plant breeding is being conducted in large multinational corporations. Their work on varietal development has focused upon cash crops which are important in commercial agriculture (whether in the global North or South), rather than upon the subsistence crops crucial for peasant farmers. This is clearly because there is little profit to be made from developing agricultural technology for the poor. As this paper has shown, the institutional locus of invention is crucial for determining what kind of technology is developed. As long as biotechnology remains concentrated in the private sector, therefore, it may well yield 'knowledge'—

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[31] A professor of precision agriculture at a US agricultural university, for example, has recently argued that precision technology is applicable to very small farms, at the same time noting that it is 'still expensive' for many such farmers. Redesigning the technology so as to reduce its cost does not seems to have occurred to him. The way around this obstacle, he suggests, lies in 'creating appropriate enabling environments' (presumably subsidies) to encourage take-up. Caspar van Vark, 'From Agribusiness to Subsistence: High-Tech Tools Now Available to All', Review of Reviewed Item. *Guardian Global-Development-Professionals-Network*, 4 (June 2014), http://www.theguardian.com/global-development-professionals-network/2014/jun/04/subsistence-farming-precision-agriculture/print (accessed 15.9.15). Making technology suitable, it would appear, is the responsibility of politicians, not of engineers.

[32] Cf. Harwood, *Europe's Green Revolution*, 152ff.

[33] Robert Paarlberg, *Starved for Science: How Biotechnology Is Being Kept out of Africa* (Cambridge, MA, 2008).

but which is only ‘useful knowledge’ for some—thus perpetuating the problem of ‘differential utility’.

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USEFUL KNOWLEDGE – USEFUL SCIENCE

Ursula Klein

At the beginning of the seventeenth century, the English philosopher and statesman Francis Bacon argued that knowledge was useful for the arts and crafts and for the common good. "Human knowledge and human power meet in one," he proclaimed. Hence, an important goal of his programme of scientific reform was to establish sciences that could "help us in finding out new works."[1] The sciences "should produce fruit and works," he further asserted, and should support "inventors and those who bring to perfection the things invented."[2] Bacon's basic idea concerning "the study of nature with a view to works" was simple: new insights into causality in nature would enable mankind to perfect existing things and invent new ones. For, "where the cause is not known the effect cannot be produced," he pointed out.[3]

The credo Bacon expressed was the following: the renewed natural sciences per se could generate knowledge that was both philosophically enlightening and useful in practice. Useful knowledge, he expected, would fly straight out of the academies and universities into the arts, crafts and technology. In his view there was a direct correspondence between causal natural science and useful knowledge. "That which in contemplation is as the cause is in operation as the rule," he asserted.[4]

The Baconian discourse about "useful knowledge," generated by the sciences, proliferated in the Enlightenment and the cameralist movement. In the second half of the eighteenth century it further extended to circles of reform-oriented ministers, state officials and consultants, who were involved in state directed manufacture, such as mining and metal production, civil architecture, and hydraulic engineering. Many of these men were technical experts, who carried out projects of innovation and invention.[5] They were well informed about the intricacies of practice. In this new social context, the concept of useful knowledge was significantly enriched and re-oriented towards practice. As a consequence, new questions were raised concerning what comprised useful knowledge and how it was taught. Which part of the existing sciences and mathematics taught by universities and academies was actually useful for improving manufacture? What kinds of teaching institutions would allow combining school-based knowledge, or "theory," with

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[1] Bacon, *The New Organon* (1620), aphorisms 3 and 11, in Francis Bacon, *Selected Writings of Francis Bacon*, with an introduction and notes by Hugh G. Dick (New York, 1955), 462, 463.

[2] Bacon, *The Great Instauration* (1620), Preface, in Bacon, *Selected Writings*, 429.

[3] Bacon, *The Naew Organon* (1620), aphorisms 5 and 3, in Bacon, *Selected Writings*, 462.

[4] Bacon, *The New Organon* (1620), aphorisms 8 and 3, in Bacon, *Selected Writings*, 462.

[5] On the notion of expert, see Eric Ash, 'Introduction: Expertise and the Early Modern State', *Osiris*, 25/1 (2010); Ursula Klein and E. C. Spary, 'Introduction: Why Materials?', in: Ursula Klein and E. C. Spary (eds.), *Materials and Expertise in Early Modern Europe: Between Market and Laboratory* (Chicago, 2010); Ursula Klein, 'The Prussian Mining Official Alexander von Humboldt', *Annals of Science*, 69/2 (2012); Ursula Klein, 'Introduction: Artisanal-Scientific Experts in Eighteenth-Century France and Germany', *Annals of Science*, 69/3 (2012). Ursula Klein, 'Savant Officials in the Prussian Mining Administration', *Annals of Science*, 69/3 (2012); Ursula Klein, 'Chemical Expertise: Chemistry at the Royal Prussian Porcelain Manufactory', *Osiris*, 29 (2014); Ursula Klein, 'Chemical Experts at the Royal Prussian Porcelain Manufactory', *Ambix*, 60 (2013); Ursula Klein, 'Chemical Expertise: Chemistry at the Royal Prussian Porcelain Manufactory', *Osiris*, 29 (2014); Ursula Klein, *Humboldts Preußen. Wissenschaft und Technik im Aufbruch* (Darmstadt, 2015); Ursula Klein, *Nützliches Wissen: Die Erfindung der Technikwissenschaften* (in print).

"practice"? In the context of these kinds of debates, a new concept of "science" emerged: that of the "practical" or "useful sciences."

The term "useful science" marks a turning point in the long discourse about useful knowledge. Compared to the older Baconian programme, it manifests a new goal: the creation of a middle ground between the academic and artisanal worlds, the natural sciences and technical knowledge. The goal of my paper is to illuminate the concept of useful science in late eighteenth-century Prussia. I will analyse two examples of useful science: the "science of mining" (Bergwerkskunde) and Alexander v. Humboldt's "science of salts" (Salzwerkskunde), followed by a summary of my argument.

The Science of Mining

The foundation of a mining academy in the Saxon mining town of Freiberg in 1765 is a well-known example of early efforts to create useful sciences along with supporting institutions. In the 1740s, the Saxon cameralist and official Carl Friedrich Zimmermann advocated the establishment of a mining academy that would bring together "scholars in mining" (Bergwerks-Gelehrte), whose main goal was to elaborate a science of mining. Zimmermann argued that as this type of science did not yet exist, it had to be created through the collective efforts of "mining scholars" and mining officials.[6] Two decades later, the leading Saxon mining officials and founders of the Freiberg Mining Academy—Friedrich Anton v. Heinitz and Friedrich Wilhelm von Oppel—adopted Zimmermann's ideas. The Freiberg Mining Academy was a teaching institution for mining officials, who were experts in one of the most advanced 'high-tech' industries of the time. Like Zimmermann, Heinitz and Oppel were conscious that any science of mining only existed in—at best—a rudimentary form. So, they argued for a new mining science that would bring together technical knowledge about mining with mathematics and sciences, such as chemistry, mineralogy, physics and knowledge about the Earth's crust or "geognosy" (later "geology").[7]

In 1770, five years after the foundation of the Freiberg Mining Academy, the Prussian Minister Ludwig Philipp Freiherr vom Hagen and the mining councillor and mineralogist Carl Abraham Gerhard tried to establish a mining academy in the Prussian capital of Berlin. I have shown elsewhere that they failed to achieve their original goal, due to the unwillingness of King Frederic II to finance a new institution. Nonetheless, they succeeded in establishing a series of lectures on the useful sciences, which was financed by the Department of Mining and Smelting Works.[8] These

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[6] Carl Friedrich Zimmermann, 'Vorrede', in: Johann Friedrich Henkel, *Kleine mineralogische und chymische Schriften*, ed. by J.F. Jahn (Wien und Leipzig, 2. ed. 1769 [1744]); Carl Friedrich Zimmermann, 'Der Nutzen und die Nutzung des Bergwerks, wie solche nach den politisch-ökonomischen Grundsätzen eines landesfürstlichen Kammerkollegium können betrachtet und verbessert werden', *Leipziger Sammlungen*, 1 (1745); Carl Friedrich Zimmermann, 'Abhandlung, ob die Art, das Bergwerk durch Gewerkschaften zu bauen, die vorträglichste sei', *Leipziger Sammlungen*, 1 (1745); Carl Friedrich Zimmermann, *Ober-Sächsische Berg-Academie, in welcher die Bergwercks-Wissenschaften nach ihren Grund-Wahrheiten untersuchet, und nach ihrem Zusammenhange entworffen werden, 3 Stücke* (Dresden und Leipzig, 1746).

[7] See Heinitz's explanation of his goals in Friedrich Anton von Heinitz, 'Bericht der Revisionskommission vom 2.3.1771', in: Hans Baumgärtel, *Bergbau und Absolutismus. Der Sächsische Bergbau in der zweiten Hälfte des 18. Jahrhunderts und Maßnahmen zu seiner Verbesserung nach dem Siebenjährigen Kriege*, Freiberger Forschungshefte D: Kultur und Technik, 44 (Leipzig, 1963 [1771]). For an overview of the eighteenth-century mining academies, see Hartmut Schleiff and Peter Konečný (eds.), *Staat, Bergbau und Bergakademie, Montanexperten im 18. und frühen 19. Jahrhundert* (Stuttgart, 2013).

[8] See Ursula Klein, 'Ein Bergrat, zwei Minister und sechs Lehrende, Versuche zur Gründung einer Bergakademie in Berlin um 1770', *NTM*, 18/4 (2010).

lectures were addressed to aspiring mining officials as well as officials responsible for forestry and civil architecture. In preparing his original proposal for a Prussian mining academy, Minister vom Hagen asked Gerhard to outline a teaching plan. This plan included considerations about the science of mining, which I examine in the following paragraphs.[9]

Gerhard's plan was to interconnect knowledge from different social and epistemic origins: first, technical knowledge, which was rooted in practices of mining and metal production and was largely acquired through apprenticeship training; and, second, scientific and mathematical knowledge acquired through reading and similar scholarly activities. Accordingly, Gerhard's science of mining comprised knowledge about the construction of mining buildings, shafts, and tunnels; techniques of extracting, transporting and roasting ores; techniques and machinery for metal smelting; and the economics of mining (Berg-Oekonomie). Furthermore, it included mathematics, mineralogy, mechanics and hydrostatics, as well as metallurgical chemistry. In his plan for a mining academy, Gerhard wrote:

> Es gründet sich die Theorie des Bergbaus und Hütten-Wesens auf die Kenntniß der Mathematic, der Mineralogie, der Physik und den damit unzertrennlich verbundenen Mechanic und Hydraulic; ferner auf die Chymie und besonders die Metallurgie und endlich auf das allgemeine Wissen um Anstellung des Gruben-Baues und Vorrichtung des Hütten-Wesens.[10]

The term "science of mining," thus denoted a collection of useful knowledge—rather than scattered bits of knowledge—that was systematically assembled in order to improve mining and metal production. It further meant that the different constituent elements of knowledge stemmed from both the academic world and from mining technology. This deliberate combination of scientific and artisanal, or technical, knowledge supports my argument that the historical actors regarded the science of mining as a new type of science, one which differed significantly from university-based sciences and natural philosophy. Like other founders of the science of mining, Gerhard did not envision a linear transfer of knowledge from the sciences to practical mining and metal production, but rather a symmetrical confluence of scientific knowledge and mining expertise. Hence, the eighteenth-century concept of mining science differed from Bacon's idea of useful causal knowledge that was engendered exclusively in the context of the natural sciences.

Another characteristic of the science of mining, and the useful sciences in general, is the practical, social scaffolding that connected the building blocks of knowledge. There was no common epistemic foundation of the different elements that constituted the science of mining, nor was there an underlying logic that would have guided the actors in assembling and weaving together the pieces of knowledge gained from different origins. Gerhard's plan lists various subjects that he believed contributed to the body of mining science, without providing any epistemic justification for their juxtaposition. Instead, it was the practical point of view that provided coherence to the science of mining.

While it is plausible to the modern reader to regard articulated knowledge about the construction of shafts or the techniques of smelting silver to be useful in practice, it is perhaps debatable whether the same was true with respect to mathematics, mineralogy, chemistry and other sciences. Equating science with theory, or with the abstractions of Newtonian mechanics,

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[9] Geheimes Staatsarchiv Preußischer Kulturbesitz (in the following GStA PK), I. HA, Rep. 121, Nr. 7957, folio 2-6.

[10] Ibid., folio 2. "The theory of mining and metal smelting is founded upon the knowledge of mathematics, mineralogy, physics and the connected [disciplines of] mechanics and hydraulics; in addition it relies on chemistry and metallurgy, in particular, and finally on the general knowledge about the performances of mining construction and smelting works."

philosophers and historians have highlighted the gap between learned and practical knowledge. Some historians have further suggested that the eighteenth-century actors' claim about useful science was merely rhetoric and an instrument of power over artisans and craftsmen.[11] These arguments rest on a simplification of the relationships between eighteenth-century science and technology, and between men of science and practitioners. They ignore the new figure of the engineer and inventive expert (Sachverständiger. Sachkundiger), who mediated between these two alternatives.[12] The historical actors' themselves presented more sophisticated arguments about the usefulness of sciences such as mineralogy, knowledge about "Gebirge" (geognosy) and chemistry. I will now take a closer look at Gerhard's claim that geological and chemical knowledge was useful in mining and metal production.

Gerhard argued that empirical knowledge gained in the context of traditional apprenticeship depended entirely on accidental, local circumstances. He stated that, as a consequence of this:

> seine [des Berg- und Hüttenmanns] ganze Erkenntnis nur auf einzelnen Erfahrung beruhet, die auf jedem Gebürge, auf jedem Hüttenwercke mannigfaltigen Veränderungen unterworfen seyn, welche zu entdecken wiederum erst neue Erfahrung erfordert werden, die gemeiniglich mit Verlust von Kosten und Zeit verbunden sind.[13]

Practical apprenticeship training, Gerhard asserted here, provided just local knowledge about mountains and stones (Gebirge). This kind of empirical knowledge was always tuned to a specific place. Likewise, learning by doing was conditioned by local techniques, and it yielded limited, local experiential knowledge about the smelting behaviour of metals. Experience acquired in traditional apprenticeship training varied widely, depending on local natural conditions, social traditions, and the individual knowledge of the master. Gerhard maintained that it was therefore difficult to understand variations of landscapes, ore deposits and smelting techniques in different places. This resulted in a loss of time and money for the mining officials, who usually inspected many mines and foundries located in different sites. Gerhard proposed that additional education in a mining school would give mining officials an overview of mining techniques and a more wide-ranging empirical knowledge about nature. Lectures and texts—but also mathematical exercises, chemical experiments, exercises in measuring, and instruction through scale models of mining machines and collections of minerals—would provide an accumulated, comprehensive experience.

Gerhard's argument about experience and the limits of local apprenticeship training reveals that the idea of a "science of mining" did not mean high theory or a Newtonian type of deductive science. In sciences like geology, mineralogy and chemistry, observation, experimentation and experimental history—that is, the collection of empirical knowledge from miners and other practitioners—played a crucial role. "Metallurgical chemistry," for example, was a field of eighteenth-century chemistry that implemented the knowledge gained in smelting works alongside that acquired through chemists' experimentation and physical measurement. It studied

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[11] For the former argument, see, for example, Rupert Hall, 'The Scholar and the Craftsman in the Scientific Revolution', in: Marshall Clagett (ed.), *Critical Problems in the History of Science* (Madison, 1959); for the latter see, for example, Warren Dym, *Divining Science: Treasure Hunting and Earth Science in Early Modern Germany* (Leiden, 2011) and Cynthia Koepp, 'The Alphabetical Order: Work in Diderot's Encyclopédie', in: Steven L. Kaplan and Cynthia J. Koepp (eds.), *Work in France: Representations, Meaning, Organization, and Practice* (Ithaca, N.Y., 1985).

[12] For an elaboration of this argument, see Klein, 'Chemical Expertise'.

[13] GStA PK, I. HA, Rep. 121, Nr. 7957, folio 2. "[…] his [the miner's and foundryman's] entire knowledge relies on singular experience alone, which is subjected to manifold variation in each mountain and each smelting work; the discovery of these variations requires additional, new experience, which is usually connected with a loss of money and time".

the properties of metals and their smelting behaviour through a broad range of experiments. Proponents of the science of mining were convinced that metallurgical chemistry provided an overview of knowledge about metals and that it had the potential to generate new experimental knowledge, which would help to promote improvements in metal smelting.

For a genuine historical understanding of Gerhard's ideas on the practical uses of the science of mining, it is important to bear in mind that it was intended for mining officials, not for ordinary miners. These mining officials fulfilled crucial technical functions in state-directed mining, and they needed technical competence and experience to do their job. They managed prospecting for new ores, inspected smelting works, designed proposals for improvements in metal production, performed mineral analyses, metallurgical experiments, and so on. Local artisanal knowledge about minerals and methods of metal production was an indispensable element of their expertise, but it was not sufficient to inspect different mines and foundries and introduce technical improvements that could compete economically at an international level. Mining officials needed agreed criteria and measurements for inspections and evaluations, which presupposed an overview of what technically feasible. After the economic crisis that followed the Seven Years' War, the latter was clearly felt in the Prussian state administration.[14] Formal teaching and the literature contributed to broader natural and technical knowledge, while decisions about technical improvements benefited from experience that went beyond the narrowly-confined knowledge that could be acquired in just one or two local mines or smelting works.

The Science of Salts

This brings me to my second example, Alexander v. Humboldt's "science of salts" (Salzwerkskunde). In the spring of 1792, shortly before he became a Prussian mining official, the young Alexander v. Humboldt (1769–1859) published an essay entitled Versuch über einige physikalische und chemische Grundsätze der Salzwerkskunde.[15] He had written this more than 100-page paper during a visit to the Freiberg Mining Academy, in order to prepare himself for his future duties as a Prussian mining official. A large part of the essay is devoted to detailed descriptions of existing techniques of common salt production in different German salt works. Humboldt also presents some ideas about how to improve common salt production, and he further proposes the uses of chemical inventions for introducing novel production technologies. What is more, his essay includes some broader thoughts on the useful sciences, which highlight their function of mediation between the natural sciences and technical practice.

Humboldt's goal was ambitious. His point of view, he stated, "naturally settles the quarrel between the theoretician, who often enforces instruction, and the practitioner, who often evades it."[16] The relationship between men of science studying salt works and practitioners was not unproblematic, as Jakob Vogel has shown.[17] University-educated men, or "theoreticians" in Humboldt's words, often knew little about practice. Accordingly, Humboldt emphasizes in his essay that practitioners did possess "knowledge." His statements show that he truly appreciated

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[14] See Klein, *Humboldts Preußen*.

[15] Alexander von Humboldt, 'Versuch über einige physikalische und chemische Grundsätze der Salzwerkskunde', *Bergmännisches Journal*, 5/1 (1792). On the history of knowledge about salts, see Jakob Vogel, *Ein schillerndes Kristall: eine Wissensgeschichte des Salzes zwischen Früher Neuzeit und Moderne* (Köln, 2008).

[16] Humboldt, 'Versuch über einige physikalische und chemische Grundsätze', 140. "Durch diese Ansicht der Dinge ist dann der Streit zwischen dem Theoretiker, der oft so ungestüm Belehrung aufdringt, und dem Praktiker, der sich ihr oft so absichtlich entzieht, von selbst entschieden".

[17] Vogel, *Ein schillerndes Kristall*.

artisanal expertise. He even went so far as to argue that the salt works practitioners could "continue their traditional way with certainty without possessing scientific knowledge."[18] As young Humboldt wrote the essay during his visit to the Freiberg Mining Academy, it is probable that it represents ideas that were quite common among the Academy's professors and mining officials. I assume that it was the sort of debate about the useful sciences that was shared in contemporary circles around the Freiberg Mining Academy and the State Department of Mining and Smelting works in Berlin.

So, what was the purpose of a science of salts from his perspective? Why would it be useful in practice? What kinds of changes would it produce? Clearly, Humboldt's goal was not the wholesale replacement of a traditional craft by scientific knowledge and methods. Instead, he proposed that the science of salts might add something to practitioners' traditional knowledge and techniques, and that it might help them to improve specific aspects of their work. Moreover, he argued that science would help to devise entirely new inventions and production technologies. "Technical chemistry" (technische Chemie, a recently-created term by Johann Friedrich Gmelin), he argued, would be particularly useful in this respect.[19] In the following paragraphs, I analyse the latter argument.

Humboldt pointed out that an understanding of the chemical composition of common salt and the way that its two components could be chemically separated into new substances were useful knowledge. "In the present state of chemistry," he observed, "we possess the knowledge about its components that is necessary to perform technical work on a large scale."[20] Through their experiments and analyses, eighteenth-century chemists had shown that common salt consisted of two components—an alkali and the "salt acid" (later "hydrochloric acid"). They had further discovered that, in certain chemical procedures, the salt acid yielded chlorine and the alkaline part yielded new salts. Humboldt surmised that these discoveries of new chemical substances might be transformed into useful inventions. His evidence for this idea came from chemists' experimental production of chlorine, based on the decomposition of common salt, and the subsequent commercial production of chlorine, which was used for bleaching in England and France. Thus, Humboldt proposed that new chemical factories should be established near to Prussian salt works, which would produce chlorine and new materials derived from the alkaline component of common salt. What he did not yet know was that chemists and technicians were on the verge on an important invention, based on knowledge about the alkali contained in common salt, and its experimental isolation. On 25 September 1791, while Humboldt was writing his essay, the Leblanc process for producing artificial soda was patented.

Humboldt's ideas and suggestions about the usefulness of chemistry resemble Gerhard's arguments discussed above. I now concentrate on those parts of his essay that highlight the specificity of technical chemistry and Salzwerkskunde as useful sciences. Humboldt advocated the creation of a new type of science that would act as a conduit between the natural sciences and technological expertise. This distinct type of bridging, or useful, science would build on carefully selected elements of the natural sciences and mathematics, as well as on technical expertise. Humboldt further emphasised the need to design new forms of research and teaching in the context of the useful sciences. Here is a long quotation that sums up his argument:

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[18] Humboldt, 'Versuch über einige physikalische und chemische Grundsätze', 2.

[19] Humboldt, 'Versuch über einige physikalische und chemische Grundsätze', 1.

[20] Humboldt, 'Versuch über einige physikalische und chemische Grundsätze', 2. "Bey dem jetzigen Zustande der Chemie sind wir mit den Bestandtheilen des Küchensalzes so genau bekannt, als es zu technischen Arbeiten im Großen erforderlich ist".

> Die *wissenschaftliche Bearbeitung* einer Kunst befolgt überdies eine Methode, die von der Ausübung selbst völlig verschieden ist. Bey jener müssen Grundsätze aus allen verwandten Wissenschaften gesammelt, Erfahrungen der Physiker mit den technischen verglichen, jeder auch noch so geringfügig scheinende Umstand beobachtet werden; diese hingegen, die Methode der Ausübung muß, wenn sie ihren Zweck nicht verfehlen will, nicht zu ängstlicher Unentschlossenheit führen soll, einen entgegengesetzten Weg einschlagen. Sie muß, wenn die Verfahrensart einmal gewählt ist, sich gleichsam auf ein Objekt isolieren, mehr auf Lokalverhältnisse, als auf allgemeine Spekulationen Rücksicht nehmen, sich durch kleine Umstände nicht zerstreuen lassen, geringere Vortheile den größeren aufopfern u. f. f. [21]

Instead of "useful science," Humboldt speaks here of the "scientific treatment of an art" (wissenschaftliche Bearbeitung einer Kunst), which he distinguishes from the performance (Ausübung) of an art. He first stresses that the two enterprises are "entirely different" (völlig verschieden) and then explains his understanding of the "scientific treatment of an art." In this explanation, he first highlights the need to collect basic knowledge (Grundsätze) from all the relevant sciences. He further suggests that the scientists' and technicians' experience should be compared with one another. In so doing, he points out, it is necessary to pay attention to all kinds of details.

I interpret these statements as a plea for a distinct kind of research to be carried out in the context of the useful sciences. According to Humboldt, systematic research demarcates the useful sciences (i. e. wissenschaftliche Bearbeitung einer Kunst) from the practical arts themselves. As a consequence of performing research, he points out, the useful sciences are time-consuming. Comparable to the natural sciences, premature conclusions must be avoided and even "speculations" are sometimes allowed. In contrast, a practical art, or technology, is always guided by clear economic considerations, because it must focus on the effective production of a particular object. As its commercial goal must be achieved in a reasonable time, it cannot afford to consider all the pros and cons of alternative tools and techniques. Instead it must forge ahead with a particular decision. A practical art, Humboldt adds, must concentrate exclusively on the local situations (Lokalverhältnisse), whereas the useful sciences also aim at generalisations of experience and "general speculations."

Conclusion

Unlike Bacon's idea that causal natural knowledge could be directly applied to produce useful effects in practice, the eighteenth-century concept of 'useful sciences' introduced a new meaning of "science": a body of knowledge that interconnected scientific and technical knowledge in order to improve certain fields of industrial practice. The Freiberg Mining Academy thus combined practical training with school-based education. In the mornings the students undertook practical work in mines and foundries, and in the afternoons they attended classes in the academy.[22]

The advocates of "useful sciences" did not propose that any single university- or academy-based science could be implemented in its entirety into practice. They argued instead that certain parts of the sciences—among them materials, instruments and methods—should be linked with reliable technical knowledge. Knowledge collection went hand in hand with a careful selection of those elements of mathematics, physics, chemistry, mineralogy, geognosy, and botany that the historical actors considered useful for a distinct field of practice. Much of the technical knowledge integrated into the useful sciences originated in practice. Thus, the "useful sciences" created an interface between "theory and practice." They bridged the academic and the industrial world.

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[21] Humboldt, 'Versuch über einige physikalische und chemische Grundsätze', 139–140, my emphasis.

[22] Klein, 'The Prussian Mining Official'; Klein, *Humboldts Preußen*.

In addition to the collection and assemblage of existing building blocks of knowledge, technical and scientific, the concept of useful science implied that new elements of knowledge should be generated through experimentation, field studies, mathematical explorations and other kinds of research. By the end of the eighteenth century, there was also a growing awareness in certain circles that the useful sciences needed new methods of research and teaching, along with new teaching institutions. Hence, the proponents of useful science advanced the demand for laboratories, collections of instruments, scale models of machines, experimental gardens, experimental fields, and travels. They further argued for the establishment of mining academies, academies of architecture, of forestry and of agriculture, as well as polytechnics.

"Useful science" meant a comprehensive body of knowledge that was systematically assembled and arranged in order to improve distinct technological areas such as mining, metal production, agriculture and forestry. It meant collective, long-term efforts to accumulate and generate knowledge about a broad variety of subjects that were relevant for a specific technical area. The science of mining, the science of salts and other "useful sciences" were a new type of "science," which was later designated "technological science."

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THE USEFULNESS AND PRACTICABILITY OF MATHEMATICS: GERMAN MINING ACADEMIES IN THE 18TH CENTURY

Thomas Morel

This paper provides an overview of changing attitudes to the role that mathematics play in eighteenth-century Germany, specifically in two kinds of institutions: universities and mining academies. I focus on 'useful mathematics', by which I mean the ways that mathematical sciences were used in everyday life, in this case in the flourishing mining industry. While German universities of the period were venerable and well-established institutions which enjoyed wide social support, mining academies succeeded in defining a new role for mathematics. By doing this, they dramatically changed the way that mathematical disciplines were conceived, taught, and put into practice.

This paper is structured around a central argument comprised of three main points. The first section describes the German institutional model in some detail, to illustrate the specific place of mathematics within it and to help explain why mining academies became an alternative model to the university. The second section describes the rise of the 'academy' model during the eighteenth century, showing how this led to a new, much narrower concept of the 'usefulness' of mathematics based on its 'practicability' for central European mining states. The third section focuses on the way that mathematics was taught in the mining schools and academies, highlighting some key innovations such as the introduction of a coordinated curriculum and teaching in a practical context. I conclude by showing how mining academies not only changed the way that mathematics was taught and understood, but also contributed to bridge the gap between scholars and practitioners.

1. Entertainment and Erudition: Mathematical Sciences in German Universities

Universities played a central role in Germany during the eighteenth century and improvements brought by *Bergakademien* (mining academies) can only fully be understood by first comprehending universities' significance and activities.[1] Many of the characteristics that are nowadays considered crucial features of mathematics teaching in any institution were not found in eighteenth-century German universities. In order to demonstrate the institutional influence of the model developed at Freiberg and Schemnitz, it is important to describe several shortcomings of the traditional university mathematics education. This will show how novel the *Bergakademien* were, and how important scientific policy was at that time.

1.1. Erudition as an Obstacle to the Development of 'Practical Mathematics'

I begin by defining what 'mathematics' was at the time. Although many university professors and students despised 'mathematical practitioners'[2], there was a general agreement that mathematics

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[1] Walter Rüegg (ed.), *A History of the University in Europe, vol. II: Universities in Early Modern Europe (1500–1800)* (Cambridge, 1996).

[2] See Christian Wolff, *Vollständiges Mathematisches Lexicon, Darinnen alle Kunst-Wörter und Sachen, Welche in der erwegenden und ausübenden Mathesi vorzukommen pflegen, deutlich erkläret*, vol. 1 (Leipzig, 1747), article "Mathematiker"; as well as Georg Grünberger, *Rede von der mannichfaltigen Brauchbarkeit mathematischer Kenntnisse, und dem Nutzen eines verbreiteten Unterrichts in denselben,*

ought to be 'useful'. However, this was problematic because what was defined as 'useful' had nothing to do with 'practical mathematics', that is the mathematics used in civic or economic life. From an eighteenth-century point of view, knowledge could be considered useful without having any concrete use in the modern sense. This was especially true for mathematics, which included any form of knowledge that was in any way based on measurements. The mathematician and philosopher Christian Wolff (1679–1754) defined it as the *scientam quantitatum*, 'the science of measuring all things that can be measured'.[3] Saying that mathematics was useful (*nützlich*) did not mean that it had to be usable, that is, useful within everyday life (*brauchbar*). This was especially true for German universities, where the concept of usefulness was very broad. Universities considered mathematics to be useful because it prepared students for study in the three higher faculties of law, medicine and theology.[4]

Consider the following example. Johann Bernhard Wiedeburg (1687–1766) was a mathematics professor at the University of Jena, one of the most respected universities in Germany. He was a prominent advocate of *biblical mathematics*, which might make him appear an eccentric or exceptional figure to modern scholars.[5] However, he was a highly-regarded lecturer who also taught infinitesimal calculus, thus putting Jena at the forefront of mathematics at the time. In that period, biblical mathematics was considered very useful for providing mathematical proof of the existence of God, and Wiedeburg himself strongly emphasised the particular usefulness and applicability of mathematics.[6]

Mathematics therefore played a dual role in German universities. Students had to learn the mathematical method, i.e. a way of thinking that could be applied in other sciences, as well as the basic methods that were needed to train as a lawyer, theologian or other professional. It was therefore a propedeutical science: one which students needed to understand in order to learn the other, more important disciplines.[7] This was the general intellectual meaning of 'usefulness'. The scholar and cameralist Julio Bernhardt von Rohr (1688–1742) provides a good illustration of this. Von Rohr was a typical scholar in eighteenth century Germany – a polyhistorian who wrote about everything from law to art, from philosophy to physics. He published a book in 1713 whose full title is, itself, very instructive: *Of the Constitution and Use of Mathematical Sciences in Theology, Jurisprudence and Medicine, for Journeys and in Everyday Life, as well as their Defence against the Usual Criticisms.*[8]

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gehalten in einer öffentlichen Versammlung der kurfürstl. Akademie der Wissenschaften an dem höchsterfreulichen Geburtstage Sr. Kurfürstl. Durchl. Karl Theodors (München, 1784), 5.

[3] Wolff, *Vollständiges Mathematisches Lexicon*, article 'Mathematick': "Mathematick ist eine Wissenschaft, alles auszumessen, wann sich solches ausmessen lässt".

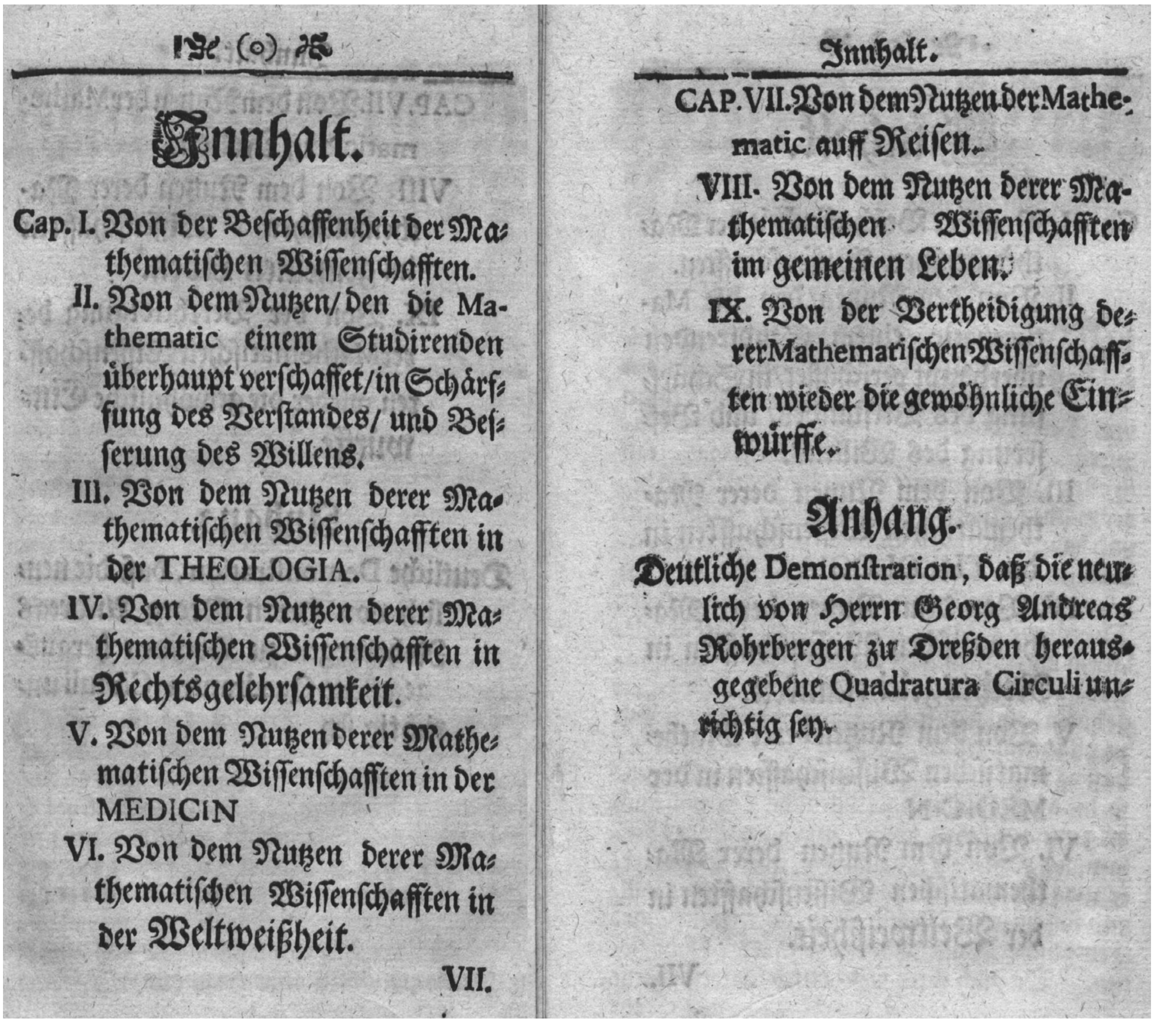
[4] Mathematics was instead taught in the lower, propedeutical faculty of philosophy. See Walter Rüegg, (ed.), *A History of the University in Europe, vol. II: Universities in Early Modern Europe (1500–1800)* (Cambridge, 1996), 493–518.

[5] See his notice in Siegmund Günther, "Wiedeburg, Johann Bernhard", in: *Allgemeine Deutsche Biographie*, vol. 42 (Leipzig, 1897), 379–80. He became professor of mathematics in 1718, and obtained in 1737 the title of Church counsellor, *Kirchenrath*.

[6] On the mathematical proof of the existence of God see J.B. Wiedeburg's doctoral thesis, Johann Bernhard Wiedeburg, *Demonstratio mathematica infinitatis dei, oder von der Unendlichkeit Gottes* (Jena, 1729). See also Johann Bernhard Wiedeburg, *Einleitung zu den mathematischen Wissenschaften für Anfänger auf hohen und niedrigen Schulen* (Jena, 1735), Introduction.

[7] In the universities of South Germany, this was even officially recognized and the students had to study 'philosophy' for two years, including mathematics and physical sciences.

[8] Julio Bernhardt von Rohr, *Derer mathematischen Wissenschafften Beschaffenheit und Nutzen, den sie in der Theologie, Jurisprudenz, Medicin, Philosophie, auff Reisen und im gemeinen Leben haben* (Halle, 1713).



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Cap. I. Von der Beſchaffenheit der Mathematiſchen Wiſſenſchafften.

II. Von dem Nutzen/ den die Mathematic einem Studirenden überhaupt verſchaffet/ in Schärffung des Verſtandes/ und Beſſerung des Willens.

III. Von dem Nutzen derer Mathematiſchen Wiſſenſchafften in der THEOLOGIA.

IV. Von dem Nutzen derer Mathematiſchen Wiſſenſchafften in Rechtsgelehrſamkeit.

V. Von dem Nutzen derer Mathematiſchen Wiſſenſchafften in der MEDICIN

VI. Von dem Nutzen derer Mathematiſchen Wiſſenſchafften in der Weltweißheit.

VII.

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CAP. VII. Von dem Nutzen der Mathematic auff Reiſen.

VIII. Von dem Nutzen derer Mathematiſchen Wiſſenſchafften im gemeinen Leben.

IX. Von der Vertheidigung derer Mathematiſchen Wiſſenſchafften wieder die gewöhnliche Einwürffe.

Anhang.

Deutliche Demonſtration, daß die neulich von Herrn Georg Andreas Rohrbergen zu Dreßden herausgegebene Quadratura Circuli unrichtig ſey.

Table of Contents (von Rohr 1713). Source: SLUB Dresden, http://digital.slub-dresden.de/werkansicht/dlf/11085/ (CC-BY-SA 4.0)

This table of contents clearly shows that mathematics was taught in universities in order to train scholars from the nobility. The first aim was to teach students how to think, to 'sharpen their understanding' (covered in von Rohr's second chapter). This was followed by further studies, then logic or 'universal wisdom' (*Weltweisheit*) and the uses of mathematics for travel.

This example reveals a question which could form the basis of future, in-depth studies: to what extent did the German notion of 'erudition' (*Gelehrsamkeit*) act as an obstacle to the training of competent engineers? If an individual was studying at a university, they were highly likely to want to become a *Gelehrte* – for example, a senior mining official. They would therefore only learn a qualitative approach to mathematics, which was very different from what was actually needed. This idea was explicitly expressed by many famous mathematicians, such as Abraham Gotthelf Kästner (1719–1800) and Wolff, but here I quote a lesser-known figure on the topic. Johann Peter Eberhard (1727–1779) was a German scholar and professor of medicine and mathematics at Halle, one of the biggest German universities. In 1757 he wrote a *Contribution to Applied Mathematics*, in which he stated:

> It is very annoying for someone who has studied mathematics at a university if, with all the theory he has learned, he knows nothing of the constitution of mills, although these are used everywhere and for various purposes. It is just as awkward, when he does not have the slightest idea of mining, because these [things] are also useful works.[9]

1.2. Institutional Settings and Mathematics Education

It is important to note that this attitude towards mathematics was not limited to scholars such as Wiedeburg, von Rohr or Kästner, but was implicit in almost all the mathematics books of the time, raising the question of where this general view on the usefulness of mathematics came from. There were, of course, numerous factors, some of which are well-known, such as the philosophical debates held in the intellectual atmosphere of the Enlightenment (*Aufklärung*). However, there is another, more tangible point which explains a lot: I believe that there was a structural problem relating to the way that mathematics education took place in the institutional settings of eighteenth-century German universities.

Although German universities have been the subject of numerous analyses, little has been written about the average student's knowledge of mathematics.[10] It is impossible to refer to mathematics students, because there was no such thing as a mathematical course of study at that time.[11] Considering all of the university students, rather than just the handful who were focused on mathematics, produces the sort of description provided by Kästner, the most famous mathematics professor of his time, who worked at the University of Göttingen:[12]

> Normally one either learns no mathematics at all, or at least much too little to get a real practical use [*einen eigentlichen praktischen Nutzen*] of it. What can easily be learned of it in one term [...] makes the one who knows it at best an animal that can count. But if he lacks decimal arithmetic and algebra as well as a thorough knowledge of logarithms, his arithmetic is far from any adequate practical usefulness [*zulänglichen praktischen Brauchbarkeit*]. And if his geometry is limited to the very first properties of the triangle, [...] he not even able to understand the work of the most common field surveying, or to check its accuracy.[13]

In fact, this was the case at most contemporary German universities. The ostensible reforms of universities such as Halle or Göttingen should have made mathematics and the natural sciences more 'practical'. But, as Kästner shows, this was not usually the case. Eberhard at Halle wrote a book in 1769 called *Thoughts on the Usefulness of Mathematics and its Influence on the State*, in

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[9] Johann Peter Eberhard, *Beiträge zur Mathesi applicata: Hauptsächlich zum Mühlenbau, zu denen Bergwerks-Machinen, zur Optik und Gnomonik* (Halle, 1757), Introduction. It is remarkable to note that one had to defend the idea that mills and mines are useful objects, while it was commonly accepted that theology and law are useful.

[10] For a recent and detailed study of the university of Göttingen, see for example Johannes Tütken, *Privatdozenten im Schatten der Georgia Augusta*, 2 vols. (Göttingen, 2005).

[11] Thomas Morel, 'Mathématiques et Naturphilosophie: l'exemple de la controverse entre Johann Jakob Wagner et Johann Schön (1803–1804)', *Revue d'Histoire des Sciences*, 66/1 (2013).

[12] Handful should here be taken literally. If we consider the biggest German University, Göttingen, at the end of the eighteenth century, the mathematician J.C.M Bartels, who was at the time student, states that among the more than thousand students there were only six studying mathematics, Johann Christian Martin Bartels, *Vorlesungen über mathematische Analysis* (Dorpat, 1837), vi.

[13] Abraham Gotthelf Kästner, *Commentarius über eine Stelle des Varro von einer der Ursachen warum die Mathematik in Deutschland immer noch für unnütz gehalten wird, in Einige Vorlesungen in der Königlichen deutschen Gesellschaft zu Göttingen gehalten* (Göttingen, 1768), 40–41.

which he stated: "I present here both the general and the specific usefulness of mathematics, in theology, law scholarship, the art of medicine, for war and civic life".[14]

An examination of textbooks and speeches by all the major eighteenth-century professors provides a clear picture of mathematics teaching in universities. Most students had either received no mathematics instruction in schools or only very limited tuition before arriving at university. They therefore followed a standard course of 'elementary pure mathematics', which included basic arithmetic and geometry, for one term. Most of the students would stop there, but the few who wanted to learn a little bit more would take a course on 'applied mathematics' the following term. It is important to remember that this course was intended as foundation training for students to continue to study at a higher faculty; they merely expected to gain an overview of the various uses of mathematics.

For one term, for three or four hours every week, they were required to learn the sciences of mechanics, statics, hydraulics, hydrostatics, optics (including catoptrics and dioptrics), acoustics, aerometry, mathematical geography, chronology and astronomy. All of this had to be done without using calculus or higher mathematics, which most of the students were not aware of. This system had far-reaching consequences, partly because at that time universities were almost the only higher education institutions in German-speaking countries. For instance, since all the main textbooks—from Kästner, Wolff, Wenceslaus Johann Gustav Karsten (1732–1787) to Christlieb von Clausberg (1689–1751) were made for universities and aimed to sell as many copies as possible, they all followed the same structure. This resulted in a lack of any textbooks which explained practical mathematics that could be used in mining or in industry.

This type of teaching followed a very qualitative and descriptive approach. Although it could not be used in practice, it was nevertheless considered to be useful, because it corresponded to an existing need in the contemporary institutional system. This meant that mathematics at that time was used almost exclusively to prepare people for study in the higher faculties. Because mathematics was so intrinsic to the existing system, it was difficult to imagine a completely different model of mathematics education. For example, it was impossible to conceive of a separate mathematics curriculum that comprised a coherent body of courses designed to gradually introduce knowledge with a specific purpose. The existing university structure could not support a technical education based on mathematics.

2. A New Kind of Institution: Science Policy and the Mining Academies

In Germany during the eighteenth century, new institutions were established which were organised along new educational lines, where mathematics formed the backbone of technical education. In my opinion, this new educational organisation was absolutely necessary to make mathematical sciences 'useful' in a narrower sense, that is, practicable in everyday life. From around the middle of the century, new institutions called 'academies' were created.

2.1. Cameralism and the Rise of a New Academic Model

It may be useful to track the rise of the 'academic model' in studying the cameralists' writing. The cameralist movement, which has recently been the subject of several studies, was the science of administration.[15] The word 'cameralism' comes from the German '*Kammer*', which was a chamber

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[14] Johann Peter Eberhard, *Gedanken vom Nutzen der Mathematik und ihrem Einflus in den Staat: Nebst einer Nachricht von seinen Vorlesungen* (Halle, 1769), Vorbericht.

[15] About the cameralist movement, see for example Pascale Laborier et al. (eds.), *Sciences camérales. Activités pratiques et histoire des dispositifs publics* (Paris, 2011).

or board of people who worked with kings to develop the German states in the eighteenth century. I am not certain if the cameralists inspired the academies or, as seems more likely, they accompanied and documented ongoing developments. In any case, their numerous books and writings on this topic provide a clear record of its evolution.

The most famous academies were the scientific academies, which were established around the middle of the century in Berlin, Munich, Göttingen and other state capitals.[16] They are usually discussed today in relation to the important philosophical questions they examined, the prizes they awarded and their prestigious members. But it should be recognised that these institutions also played an important role in making science useful for the state, sometimes bypassing the universities. Their function was to write reports and provide expertise, and sometimes even to teach university students. Because of this, they were in a very good position to test out the usefulness of mathematics, as Georg Grünberger (1749–1820) explained in a lecture to the Academy of Science in Munich in 1784,. Grünberger was a mathematician and scholar who taught at both the military academy and the forest school in Munich, and he also wrote about insurance calculations. The topic of his talk might appear surprising, considering that he was addressing an Academy of Science, to celebrate the birthday of the Elector of Bavaria Karl Theodor. His lecture was called: *Discourse on the Multiple Usefulness* [Brauchbarkeit] *of Mathematical Knowledge, and of the Use* [Nutzen] *of Broad Teaching in this Science.*[17]

The fact that he spoke about mathematics is not, in itself, surprising, because it was considered an important science in eighteenth-century Germany. However, Grünberger did not focus on contemporary significant questions in higher mathematics, such as celestial mechanics, or on university teaching. Instead, he apologised for choosing a topic that was neither "new" nor "erudite" but, rather, "of public utility" (*gemeinnützig*). He was concerned with "what is the most useful for anyone in public life".[18] Describing at length the uses of probability, arithmetic and geometry in building machines for hydraulics, mills, ships, or for war, he discussed the ways that mathematics could be used in mining and subterranean geometry, quoting the French *Encyclopédie*: "*Le règne des mots et des termes est passé, on veut des choses*".[19] He also stressed the importance of mathematics education, congratulating the Elector of Bavaria at length for introducing mathematics in elementary schools.

The academies were therefore, at least as far as mathematics was concerned, not only a place for scholars (*Gelehrte*) like the universities, but also a place for experts and cameralists, that is, people concerned with the development of state, schools and industry. This paper does not aim to define a dichotomy between research and teaching or application. Not only was such a dichotomy meaningless at the time, but the point is that academies were discernibly useful for the state, both for acquiring new knowledge and for solving specific problems. This was a clear consequence of their institutional context. These institutions were directly controlled by the states, which funded them, in contrast to universities which were entirely independent. This point was commented on at the time by authors writing on the topic.[20] The states' rulers would often ask very practical

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[16] The academy in Berlin was founded in 1700 but didn't work fully until its re-foundation in 1740, Göttingen academy was founded in 1751, Erfurt in 1754 and Munich in 1759. A similar institution was created in Saxony in 1769, the Jablonowski Society.

[17] It was printed the same year as Georg Grünberger, *Rede von der mannichfaltigen Brauchbarkeit mathematischer Kenntnisse* (München, 1784).

[18] Grünberger, *Rede von der mannichfaltigen Brauchbarkeit*, 6.

[19] Grünberger, *Rede von der mannichfaltigen Brauchbarkeit*, 30: " The reign of words and terms is past, we want things".

[20] Carl Friedrich Zimmermann, *Ober-Sächsische Berg-Academie, in welcher die Bergwercks-Wissenschaften nach ihren Grund-Wahrheiten untersuchet, und nach ihrem Zusammenhange entworffen werden, 3 Stücke*

questions, especially about public finances, and they had power to award academies prizes and control their funding. The academics therefore focused on a small range of public utility topics, unlike the universities where professors taught more erudite subjects such as Greek, poetry or the history of Roman law. The academies were therefore 'useful' in a new, more direct and practical sense than the universities.

2.2. A New Role for Mathematics in the Mining States

These observations about scientific academies were also applicable to the newly-created technical academies. This paper only discusses mining academies, but they were similar in many ways to the military, art or even farming academies that were created in the second half of the eighteenth century. The academies, and more specifically the mining academies, represented a new kind of institution, based on a model with several features – that will be described later in this paper – that made them especially well-suited to teach practical mathematics. This was the reason why some people in the mining states (*Bergstaaten*) thought that mining academies were necessary.

One well-known proponent of this was Carl Friedrich Zimmermann (1713–1747), who wrote a book in 1746 called *A Saxon Mining Academy.*[21] This work provides useful insights, showing how he distinguished academies from the university model, and proposing a new role for mathematics. He asserted that Germans were traditionally good at mining, but should be encouraging the industry through institutions. He stated this was the only way to perfect the sciences, and that this was the reason "one has built academies of sciences, in which mathematics and natural sciences are taught, why such academies exist to improve astronomy and navigation, why one has built military academies, navy schools, drawing, painting, sculpture and construction academies".[22]

In the context of eighteenth-century central Europe, mining academies were therefore seen as a way to stimulate the German states' economies. In this regard, they were a characteristic product of both the cameralist spirit and the new absolutism of the many states. It was no coincidence that numerous academies of art, commerce, science and mining sciences were created shortly after the Seven Years' War (1756–1763), when there was a need for economic improvement and deep political reforms. These academies were established to play a dual political and scientific role, both of which were interconnected and necessary in order to create a new political framework in which the sciences and technologies would bloom, as C.F. Zimmermann explained:

> Mining is a national business, but it would be better if it were a national study. Mining sciences are used by some isolated individuals, but these efforts would be much more useful if they were united together.[23]

This was, indeed, what happened shortly after the Seven Years' War ended. In 1765, the Kingdom of Saxony established the Freiberg *Bergakademie*, followed by the Habsburg Monarchy who founded the Schemnitz *Bergakademie* in 1770, while the Kingdom of Hanover opened a Mining School in 1775.[24] Before moving on to the next section, which describes the content and

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(Dresden und Leipzig, 1746), 15, describes at length the european academies, mentioning Colbert and Louis XIV in France. He adds that most private institutions quickly disappears.

[21] Zimmermann, *Ober-Sächsische Berg-Academie*.

[22] Zimmermann, *Ober-Sächsische Berg-Academie*, 15.

[23] Zimmermann, *Ober-Sächsische Berg-Academie*, 19.

[24] Not mentioning the pseudo-mining school created in Berlin in 1770 (see Ursula Klein, 'Ein Bergrat, zwei

organisation of mathematics teaching in academies, it is important to recognise that these institutions were not only new, but had been created in a completely different context to the universities. In contrast with the universities, which were still mostly independent, the academies were created by, and for, the states. They worked in constant cooperation with the *Kammer*—the highest administration—and, at least in Saxony and Austria-Hungary, professors were also members of the mining administration.

In each mining academy or school, the principal position was the professorship of mathematics and mechanics, which acted in a radical new way. Whereas university professors were learned scholars who were members of the Republic of Letters and most were active at a German-wide or European level, they did not generally cooperate with school teachers or mathematical practitioners working in the same region. In the following decades, Wilhelm von Humboldt would famously speak of the *Einsamkeit und Freiheit*— the solitude and freedom of the ideal university lecturer.

In contrast, mathematics professors in German mining academies at the end of the eighteenth-century had a great deal of contact with the outside world. At the Freiberg *Bergakademie*, mathematics teachers merely provided the final stage of a coordinated local education system. Pupils in this system first studied at a local school, before attending a mining school and, finally, the mining academy. The mathematics professors often taught at both the school and the academy, so textbooks were produced to suit both institutions.[25] This meant that the pupils received mathematics tuition from the earliest stage of their education which was oriented towards a certain application, and was therefore 'useful' in the narrower sense of 'practicable'.

There is a second very important point to note: these institutions had to provide mathematical knowledge for a specific audience. While universities were training future lawyers, doctors, theologians and senior public servants, the mining academies only trained mining officials and scientists. These students did not need a general mathematics education to understand the general rules of reasoning, but they required specific mathematics skills. They had to understand enough methods and principles to solve the types of problems they would encounter in the mines. This narrow audience facilitated much more efficient teaching. Suddenly, mathematics ceased to be 'useful' in a general sense, that is to train the mind, but became more focused and more tangible: helpful for managing mining operations.

In the same way that scientists in the science academies were occasionally asked to solve specific problems for the kings—for example, Leonard Euler designed a lottery system for the king of Prussia—mathematicians in the mining academies were also required to perform specific tasks which would solve the problems frequently encountered in mining, whilst helping engineers to improve existing operational conditions. Mathematics teachers and mathematically-trained engineers could then fulfil an innovative, more defined role, solving problems using mechanics and mathematics. As C.F. Zimmermann stated in 1746, they had made the "national business" a "national study" by using mathematics and natural sciences.

Minister und sechs Lehrende, Versuche zur Gründung einer Bergakademie in Berlin um 1770', *NTM*, 18/4 (2010)) and schools in other parts of Europe. I won't speak here of the several mining schools created in the first half of the eighteenth century, for their organization was very different from the modern academies, especially in relation with the use of mathematics.

[25] See for example the arithmetical textbook written by Johann Friedrich Lempe, *Bergmännisches Rechenbuch* (Freiberg, 1787).

3. Teaching Mathematics as a Useful Knowledge

3.1. Teaching Practical Mathematics in a Coherent Curriculum: the Freiberg Mining Academy

The most innovative feature of the way mathematics was taught in the mining academies was that all the academy's courses were coordinated. This had two very important positive consequences. Firstly, it allowed students to overcome any deficiencies in their secondary education by giving them all a solid education in geometry and arithmetic. Secondly, the existence of a coherent curriculum enabled each course to be clearly differentiated and, if a course was made mandatory, it became possible for its content to be used, possibly with the addition of advanced or higher mathematics, in subsequent courses.

In Freiberg, a mining academy was established in 1765 and a mining school was added in 1776. At the end of the eighteenth century, students enrolling in the academy were required to have studied at the mining school or be able to prove their mathematical knowledge. They therefore joined the academy with a background including what was called *mathesin pura*, that is, elementary mathematics. This might seem obvious to modern readers but, as the first section of this paper showed, most university courses in mathematics at that time were focused on this very topic. The academies thus improved the overall quality of local mathematics teaching. This is a distinct step forward from the beginning of the eighteenth century, when manuscripts about subterranean geometry used in the mountains still included instructions on how to perform addition, or on the rules of three.[26]

The year 1799 provides a good example of mathematics teachers at the Freiberg mining academy. In that year, five of the most important courses were taught by the professor of mathematics and physics, Johann Friedrich Lempe (1757–1801): pure mathematics, physics, applied mathematics, theory of mining machines and theoretical subterranean geometry. In addition, lessons on technical drawings and map drawing were given by J.S.B. Sieghard (n.d.), along with a practical course about subterranean geometry led by the *Markscheider* C.F. Freiesleben (1747–1801).

There are a number of different aspects relating to mathematics teaching, and the academy's archives contain many more details about this. One such example is the table below which, following the model of cameralist and mercantilist thought, shows how various information about mathematics disciplines was brought together and explained by Lempe himself. This panoptic view of mathematics teaching was developed further in comprehensive reports, but this table provides some interesting insights. The columns show when each course took place, for how many hours every week, why they were offered, and which textbooks or manuscripts were used. Since Lempe taught most of the courses, he was able to design them. In his description, he explained that "all the programmes [of the mathematics courses] complement one another, just as one of these sciences follows the others".[27]

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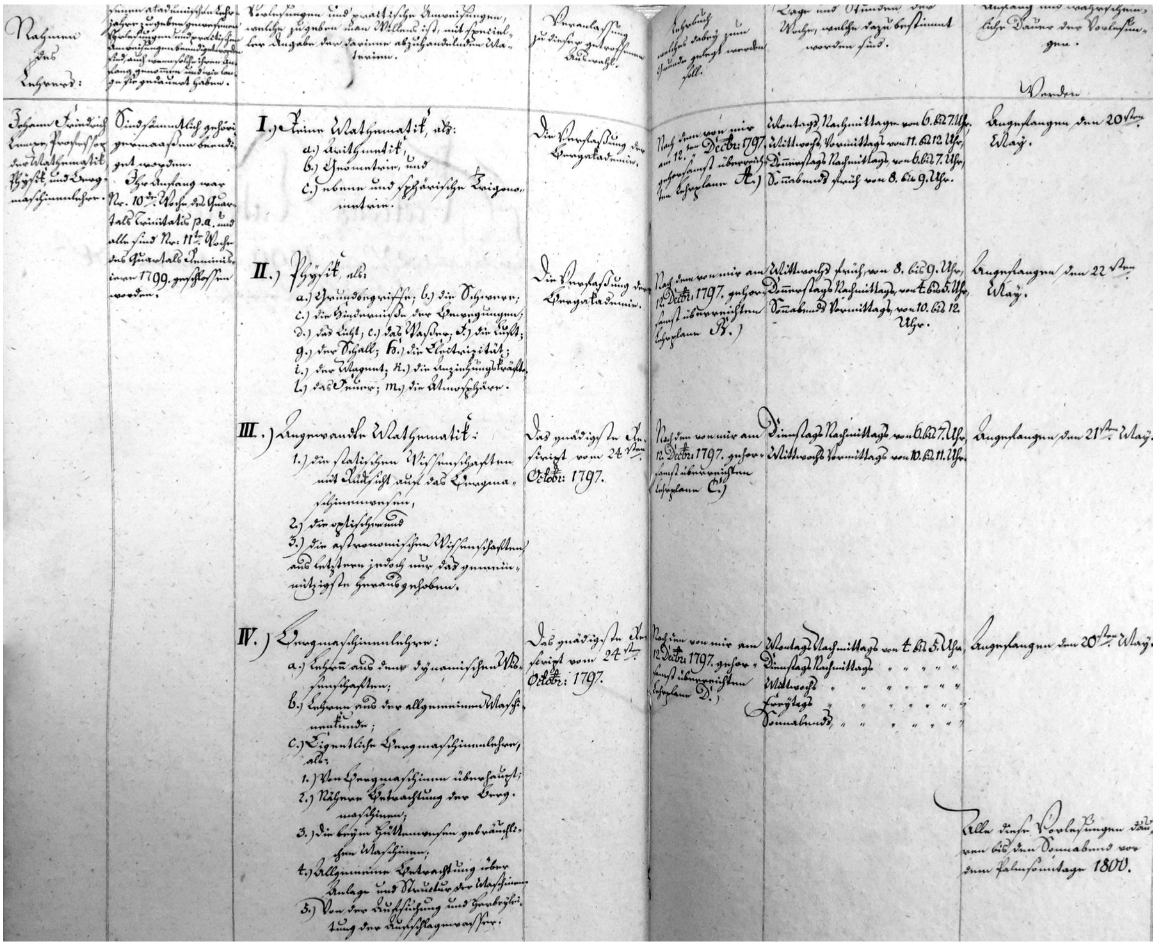
[26] As an example, we can consider the *Geometria Subterranea*, whose manuscript version had been written in 1708 by August Beyer (Archiv Technische Universität Bergakademie Freiberg – Universitätsbibliothek XVII 12), ff. 26r–34v.

[27] Universitätsarchiv Freiberg – OBA 12, f. 21v : "Da aber die reine elementare Mathematik die Grundlage von alle den obgenannten Wissenschaften und selbst bey sehr vielen physikalischen Experimenten unentbehrlich ist, so steht hier, ihr Plan zuerst: und alle Pläne folgen so aufeinander, wie eine von diesen Wissenschaften der andern die Hand bittet."



Annual report (1799) for the mathematical courses of the Bergakademie Freiberg. Source : UAF - OBA 258, Jahresbericht 1799, ff. 32v-33r.

Each individual course was thus designed as a component of the programme, whose goal was clear: to make mathematics useful—practicable—in the mines of Saxony.[28] Overall programme organisation was often discussed and modified, in cooperation with the administrators and other professors, to meet the ever-changing needs of the local mining industry.[29] During the three or more years of their training, students therefore gradually gained an advanced mathematics education, and they subsequently put this knowledge into practice in the related fields of physics, the theory of machines and, later on, crystallography and chemistry. Because of this, most of the courses were based on textbooks which the professors themselves had written for the Freiberg academy.

This gives a completely different meaning to the concept of 'useful' knowledge, in the case of 'useful mathematics'. In universities at the time, mathematical sciences were considered 'useful' in general, and were taught as a foundation for further study in completely different subjects. In the mining academies, the calculations, theories and methods learnt were immediately put into

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[28] See for example the inspection report made by the administration in year 1770 in Thomas Morel, *Mathématiques et politiques scientifiques en Saxe (1765–1851). Institutions, Acteurs et Enseignements* (Thèse de doctorat, Université Bordeaux 1, 2013), 159–60.

[29] Morel, *Mathématiques et politiques scientifiques en Saxe*, 172–73.

practice on other courses, while the academy's overall programme was conceived as one single entity.

3.2. Teaching Mathematics in a Practical Context: the Schemnitz Mining Academy

Another innovative feature of academy training was that its mathematics teaching took place within a practical context. The list of courses provided by universities at the time ostensibly appear to include some involving practical mathematics, such as land surveying or astronomy. But most of these courses were not delivered in the field or in an observatory, so were merely discursive, whereby a university professor read a book out to their students. A good case study which shows how mining academies changed the way mathematics was taught is to examine how another major mining academy, the Schemitz *Bergakademie* in Austria-Hungary, taught practical geometry.

The location where mathematics teaching took place is highly significant. Some lessons were held at the academy, in the town of Schemnitz. However, practical courses, including subterranean geometry, map drawing and land surveying took place in a neighbouring mining town called Windschacht, where the *Markscheiderey* was located. This building was the headquarters of the subterranean geometers, where all the maps were drawn, instruments stored and practical matters discussed. In 1778, the mining administration asked for a progress report on practical geometry teaching. The update was written by Lorenz Siegl, who was not a professor but a subterranean geometer, that is a mining official—a *Markscheider*. His report explained that the students were taken down in the mines and out into the fields, where they learnt how to use instruments, collect data and draw maps. They were required to learn how to solve practical problems, and accounts written by students are preserved in the archives, annotated with Siegl's comments. To give one simple and tangible example, the twelfth problem students faced on his course was how to calculate the depth of a mineshaft based on the water level. A diagram depicting the solution was produced by student Anton Wagner, and Siegl had written on the back: "I hereby certify that the present problem has been collected [that is, data] and drawn in my presence".[30]

Johann Möhling's career is another instructive example of the tangible aspect of mathematics teaching. Möhling moved from Bohemia and obtained a grant to study at Schemnitz mining academy in 1782, eventually becoming a subterranean geometer in the same town. At the end of 1788, he was paid by the mining administration to give drawing lessons in the *Markscheiderey*, probably still as a geometer.[31] He therefore became a drawing teacher. In 1791 he asked the government for authorisation to publish a textbook about subterranean geometry. This was a way for him to work towards the vacant position of mathematics professor. The academy's professors reviewed the book and considered it fit to print, so a publishing deal was concluded. Two years later, the government paid to publish it and bought two hundred copies for distribution in all the mining regions of the Habsburg monarchy. Eager to show his competence as a practical mathematician, Möhling also drew several wonderful maps which helped to solve some very complex mathematical-juridical issues about property boundaries in the mines (see the picture below). When the chair of mathematics finally became vacant in 1798, J. Möhling was the best-placed candidate for the role, so was appointed as the mining academy's new professor for mathematics and physics.

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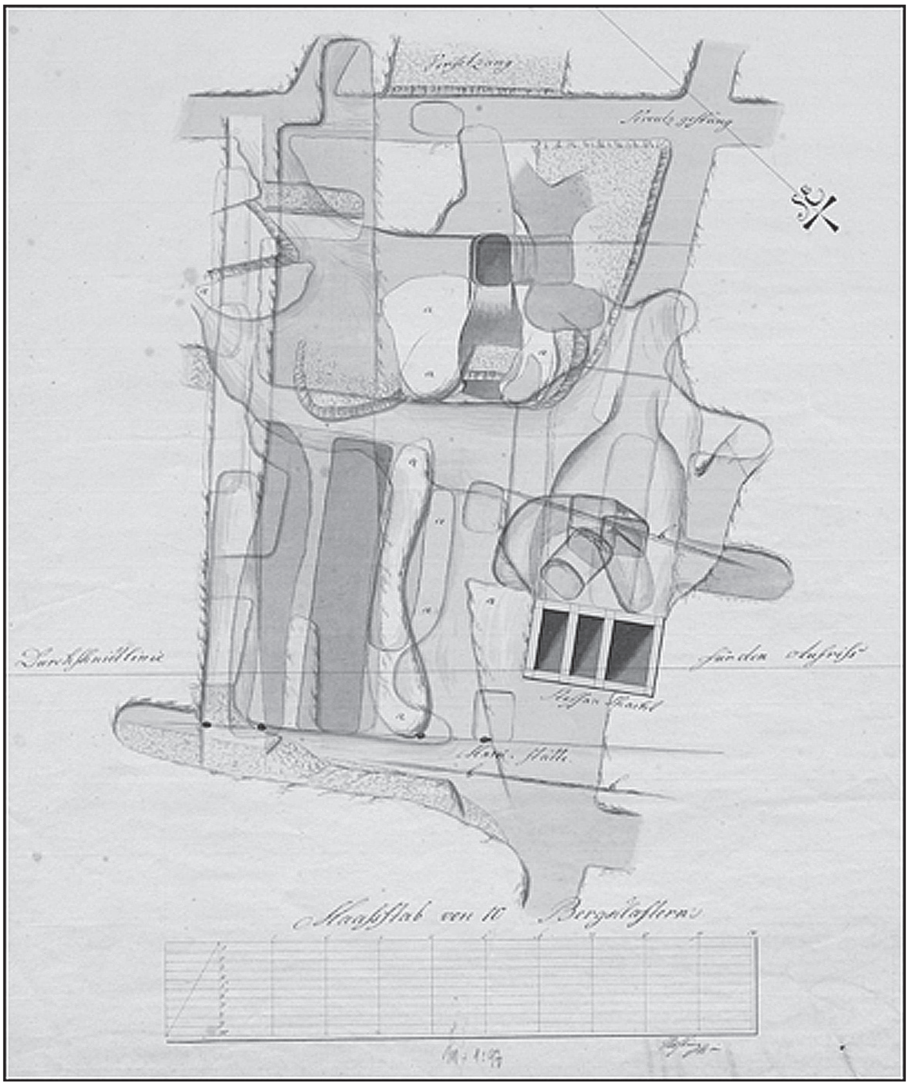
[30] Banska Stiavnica, Oberkammergrafenamt (hereafter HKG) VI, 376 front and back.

[31] Banska Stiavnica, HKG I, Agenda 1788, Sign. 3706.



Mining map drawn by J. Möhling to resolve some legal issues in the Friedenfelder Grube (1794, detail). Source: Banska Stiavnica, HKG III 6720

As this example show, a professorship of mathematics in a mining academy was a completely different job than in a university. Almost all professors of mathematics in the mining academies had either studied in mining academies themselves, or had at least been mathematical practitioners. Saying that mathematics was taught in a practical context means that professors were going into the mines with students, and the teaching included collecting data, drawing maps and solving concrete problems, for example in hydrodynamics or legal issues. They were working closely with the administration, the engineers, the geometers and the machine masters. I gave here the example of Schemnitz, but the situation was very similar in Freiberg. Let's see how the position of professor of mathematics at the mining academy of Freiberg was described in 1801:

> He [the professor of mathematics] has to be in constant contact and maintain good relations with the masters of arts and the machine supervisors working in Freiberg's mines and the other mining regions, to help them with their current concerns and to ask their advice

> regarding possible improvements, and also to take part as often as possible in inspections of, and visits to, the mines.[32]

Conclusion

In this paper, I have shown how the type of mathematics taught in eighteenth-century German mining academies was completely different from that in the universities of the time. As a result of political and economic developments during that period, a new ideal institutional model was proposed by many philosophers and theorists, which eventually became a genuine alternative to universities. This paper has focused on the mining academies, but all of the academies had a new goal: to make mathematics practicable, to provide a tool for solving problems frequently encountered in mining.

This led to a novel, more specific concept of the 'usefulness' of mathematics. This new mathematics was not only useful in the old meaning of the word *nützlich*, but also in a much more focused way. By the end of the eighteenth century, the mathematics taught in academies was useful in the sense of *brauchbar* – that is, according to the dictionaries of the time – not only 'useful' but also 'effective' and 'practicable' in everyday life, the *bürgerliches Leben*.[33] This aim was clearly stated by both Freiberg and Schemnitz mining academies, as evidenced in the archives: "to train useful [*brauchbar*] mining officials". 34

This paper has therefore shown how these mining academies were one of the sites where the figure of the modern specialised *ingénieur* was created. Teaching and using mathematics became a much more precise and tangible endeavour. The academies' main innovations were: firstly, they introduced a rational curriculum, which coordinated each course with the others and which aimed to teach specific skills. Secondly, they changed the nature of teaching: their courses could take place outside, or even underground, demonstrating how theoretical or academic knowledge could be directly applied in a mining context. The gulf between scholars and practitioners was thus bridged by a constant collaboration, as the biographies of most of the mathematicians active in the mining regions of central Europe during that period reveal.

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[32] Universitätsarchiv Freiberg – OBA 62, p. 46r.

[33] See Nathan Bailey, Johann Anton Fahrenkrüger and Theodor Arnold (eds.), *Dictionary English-German And German-English*, vol. 1 (Leipzig, 1796), 229 (effective), 590 (practicable), 903 (useful).

[34] See Banska Stiavnica, HKG I, Agenda 26.09.1809, "*brauchbaren montanistischen Beamten bilden zu lassen*".

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FARMING, METEOROLOGY AND FIELD EXPERIMENTS: USING STATISTICS TO IMPROVE AGRICULTURAL PRACTICES

Giuditta Parolini

‘Useful knowledge’ is a protean concept. It defies any clear-cut definition, has to be renegotiated for every age and context, and can be approached from multiple perspectives, thus representing a conundrum for disciplinary experts. Yet, any discourse on science, technology, and human development is compelled to touch upon the practical dimension of knowledge, when knowledge is accepted as a resource that can generate material benefits.[1]

In historical accounts of the twentieth century, the intertwining of knowledge and material welfare is almost always taken for granted. Terms such as ‘knowledge economy’ and ‘knowledge society’ have been coined to bring this notion to the fore. However, research on this topic has mainly focused on urban development and industrial organisation, whilst neglecting rural and artisanal context.[2] Investigating the tools, practices and stakeholders that have emerged in these underexplored fields therefore provides an opportunity to understand more about how useful knowledge is produced and its inner mechanisms.

Agricultural science offers a case in point. This discipline aims to improve the cultivation of crops and horticultural products and the rearing of farm animals. In so doing, it brings together science, technology and human economic activities, providing a suitable case study for the investigation of useful knowledge. It touches upon food production and the management of natural resources, relies on laboratory and field research, requires networks of communication which are able to transfer the knowledge acquired in scientific institutions into farming communities, and it challenges traditional attempts to demarcate practical from fundamental research. Above all, it forces us to question our understanding of the role and impact of technologies in agriculture, not only in relation to controversial issues such as biotech crops but, more broadly, in relation to the wide array of tools and techniques that have contributed towards improving farming practices over the centuries. As well as plant and animal breeding or the chemical synthesis of artificial fertilisers, these also include elements that are less obviously associated with agricultural research, such as mathematical reasoning or information technologies.[3] In the past few decades, in fact, these tools have become an integral part of agricultural science, as proved by the publication of journals like *Computers and Electronics in Agriculture*, the existence of practices such as ‘computational cattle breeding’, and the organisation of international congresses for computer technology in agriculture.

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[1] For a discussion of how useful knowledge can be considered as practical knowledge with an impact on material welfare, see Fritz Machlup, *Knowledge: Its Creation, Distribution and Economic Significance. Vol. 2: The Branches of Learning* (Princeton, 1982), 8–11.

[2] On the notions of ‘knowledge economy’ and ‘knowledge society’ see, respectively Joel Mokyr, *The Gifts of Athena: Historical Origins of the Knowledge Economy* (Princeton and Oxford, 2005); and Dominique Pestre, *Science, Society, and Politics: Knowledge Societies from an Historical Perspective*. Report to the Science, Economy and Society Directorate, European Commission (Luxembourg, 2007).

[3] Apart from some rare exceptions – for instance, D.A. Grier’s work on the Iowa State Statistical Computing Service: David Grier, ‘Agricultural Computing and the Context for John Atanasoff’, *IEEE Annals of the History of Computing*, 22/1 (2000); David Grier, *When Computers Were Human* (Princeton, 2007), 159–69 – mathematical reasoning, data management and computing in agricultural research have been neglected by historians.

These developments are the result of a longer process that has been bringing mathematical knowledge and computing tools into agricultural research since the early decades of the twentieth century. Farming has benefited from these developments by gaining improved advice on agricultural practices, new tools, and a greater awareness of the influence of environmental factors on human activities. Useful or practical knowledge is evidently a critical part of this process, and warrants further investigation.

This paper focuses on the contribution of inferential statistics to the increased profitability of farming. Since the 1920s inferential statistics has transformed twentieth-century agricultural research, by systematically redefining the techniques used for designing and analysing field and laboratory experiments, and helping to unravel the complex factors involved in agricultural meteorology.

I trace the impact of inferential statistics on agricultural practices during the 1920s and 1930s, by considering the activities promoted by Rothamsted Experimental Station – a British agricultural institution. In particular, I investigate the experiments which the Rothamsted staff carried out in the fields of private farms and the role that the station's statistics department played in the British Ministry of Agriculture and Fisheries' Crop-Weather Scheme. I analyse the boundary between statisticians' technical expertise and the practical knowledge available to farmers; I investigate whether inferential statistics is a science or technology, when it is assessed for its impact on cultivation practices; I examine the networks that created connections between scientific and practical knowledge in British farming during the first half of the twentieth century. In conclusion, I will use the issues raised by the case study to make a few general remarks on useful knowledge.

Between Farming and Scientific Research

Agricultural science is an imprecise term, as the British agricultural historian Paul Brassley has noted.[4] At the beginning of the twentieth century, this label encompassed organisations devoted to farmers' education and the dissemination of best practice for crop cultivation and animal breeding, as well as institutions engaged in furthering scientific knowledge on agricultural matters. Brassley suggests that only "professional and disinterested" enterprises concerned with "*explaining* why the best practice [in agriculture] was so, or in finding out how things worked in order to produce *better* practice" should qualify as agricultural science.[5]

The research produced by the institutions devoted to agricultural science, however, was not solely intended for the scientific community. Even those institutions engaged in fundamental research maintained close contacts with farmers, although their survival in Britain did not depend on financial support from the farming community.[6] Their investigations in experimental fields and scientific laboratories were, in fact, inspired by the practical problems encountered while growing crops or rearing animals, so farmers' practical knowledge was extremely useful for their scientific research. Disseminating the findings was also recognised as an integral part of agricultural science, which again brought farmers and scientists into contact with each other.

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[4] Paul Brassley, 'Agricultural Research in Britain, 1850–1914: Failure, Success and Development', *Annals of Science*, 52 (1995), 466.

[5] Brassley, 'Agricultural Research in Britain', 467.

[6] In the first half of the twentieth century, the main funding bodies for British agriculture were the Development Commission and the Agricultural Research Council (ARC). Both were more interested in supporting the basic sciences that were useful for agriculture, rather than practically-oriented work (Jonathan Harwood, *Technology's Dilemma. Agricultural Colleges between Science and Practice in Germany, 1860–1934* (Bern, 2005), 224–227). Therefore, the institutions which focused on fundamental research like Rothamsted received the most funding.

Rothamsted Experimental Station was representative of this trend. It was established in the mid-nineteenth century by John Bennet Lawes, a landowner and businessman working in the fertiliser industry.[7] In association with the chemist Joseph Henry Gilbert, a former pupil of the agricultural chemist Justus von Liebig, Lawes set up a series of long-term experiments on crops and fertilisers on his family estate, Rothamsted.[8]

Despite its commitment to fundamental research, Rothamsted Experimental Station was well aware of farmers' needs. When they began their field experiments, the station's founding fathers, Lawes and Gilbert, wanted to benefit the farming community.[9] Indeed, the aim "to develop an agricultural science that experts and teachers could use in their daily work and that would stimulate good farmers to think and so to devise new and better methods of agricultural practice" was still recognised as "Rothamsted's chief claim to distinction" during the station's centenary celebrations in 1943.[10]

This engagement with the farming community and the dissemination of scientific results were achieved through lectures, visits to the station's experimental fields and laboratories, publications for farmers, and joint research schemes. "Farmers and agricultural students" were "cordially invited to Rothamsted at any time convenient to themselves. May and June [were] good months for seeing the grass plots, July for the cereals, and September and October for the mangolds and potatoes".[11]

From the early 1920s on, a 'guide demonstrator' was hired to facilitate the dissemination of the institution's scientific research. The demonstrator's salary was initially funded by private sponsors, such as the Fertiliser Manufacturers' Association and Imperial Chemical Industries.[12] In spring, summer and autumn, the demonstrator's tasks mainly consisted of showing visitors around Rothamsted's experimental plots and describing the field trials. During the winter, the demonstrator, along with the farm manager and other members of Rothamsted's scientific staff, gave free lectures to farmers' clubs, Chambers of Agriculture and Horticulture, and other agricultural associations. Topics ranged from the best use of manures, lime and fertilisers, to basic notions on entomology and on animal pests – all areas connected to Rothamsted's research activities and with potential implications for farming.[13]

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[7] Thompson, F. M. L., 'Lawes, Sir John Bennet, First Baronet (1814–1900)', in: *Oxford Dictionary of National Biography* (Oxford, 2004).

[8] On Gilbert, see Clarke, Ernest [rev. Johnston, A. E.], 'Gilbert, Sir Joseph Henry (1817–1901)', in: *Oxford Dictionary of National Biography* (Oxford, 2004). On Rothamsted, see John E. Russell, A History of Agricultural Science in Great Britain, 1620–1954 (London, 1966), 88–109. Lawes and Gilbert managed the agricultural institution until their deaths, at the beginning of the twentieth century. At that stage, Rothamsted only employed a handful of people, had limited laboratory facilities and was mainly concerned with the chemical analysis of soil and crop samples taken from the station's experiments (Rothamsted Experimental Station (hereafter RES), Report 1918–1920. With the Supplement to the 'Guide to Experimental Plots' (Harpenden, 1921), 7). The sustained growth of the institution only began in 1911, when funding provided by the Development Commission became available (Robert Olby, 'Social Imperialism and State Support for Agricultural Research in Edwardian Britain', Annals of Science, 48/6 (1991); Brassley, 'Agricultural research in Britain').

[9] Brassley, 'Agricultural Research in Britain, 1850–1914', 497.

[10] RES, *Rothamsted Experimental Station Centenary Celebrations, 1843–1943* (St Albans, 1943), 2.

[11] RES, *Report 1921–22. With the Supplement to the 'Guide to Experimental Plots'* (Harpenden, 1923), 28.

[12] RES, *Report 1921–22*, 10; RES, *Report 1925–26. With the Supplement to the 'Guide to Experimental Plots'* (Harpenden, 1927), 14; RES, *Report for 1934* (St. Albans, 1935), 16.

[13] Anonymous, 'Rothamsted Lecturers: A List of Subjects on Which Addresses May be Had by Societies', *The Farmer & Stockbreeder*, 6 September (1926).

The guide demonstrator at Rothamsted was also a regular contributor to the *Journal of the Ministry of Agriculture*, a publication aimed at progressive farmers. In the 1920s, monthly notes on the best use of manures were written by the first demonstrator, H.V. Garner.[14] Based on the experimental research undertaken in Rothamsted's fields, these notes suggested suitable arrangements for manuring different types of crops, focusing on striking a balance between the cost of the manures and the expected increase in yield that they would produce.[15]

Collaboration between Rothamsted and the farming community was not limited just to disseminating research findings. Farmers and their representative organisations were also included as partners and sponsors in certain research projects. Examples of this include: an investigation into brood diseases in bees, co-sponsored by the British Beekeepers Association and the Agricultural Research Council; support provided by the Cotton Growing Corporation for research into soil physics and the cooperative scheme which Rothamsted developed with the Institute of Brewing in order to provide higher-quality barley for malting.[16]

The contiguity between agricultural science and farming is relevant to any exploration of what comprises useful knowledge. When faced with the question: "useful to whom and for what?" – which Machlup considers to be the first question in any debate about useful knowledge – it is easy to give an unambiguous answer for agricultural science.[17] The declared beneficiaries of Rothamsted's research were the farmers and the acknowledged aim, even of fundamental research, was to increase farming profits by reducing expenses, reorganising cultivation practices, and adopting new tools and methods.

However, there was no standard way of producing this useful knowledge or deciding who should contribute to it.[18] Agricultural scientists, farmers and extension officers all participated in the process, but their respective merits (and shortcomings) were viewed variously by different groups of stakeholders. For instance, the British farming journal *Farmer and Stockbreeder* was always keen to remind agricultural scientists that they should not overlook the practical experience which farmers possessed. The journal claimed that the "considerable breach between science and the practical man" could not be attributed to farmers alone. In fact, their experience "counselled caution, for much has masqueraded as science that might be called by another name".[19] The position of extension officers, and teachers in rural schools and agricultural colleges, was also controversial, and they often faced accusations that they were either too scientific or, conversely, too practical in their work.

It is therefore interesting to understand how inferential statistics became practical knowledge, even though it had no obvious connection with agriculture. Numbers and formulae were hard to

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[14] H.V. Garner, 'Notes on Manures for December', *The Journal of the Ministry of Agriculture* (Dec. 1923); H.V. Garner, 'Notes on Manures for January', *The Journal of the Ministry of Agriculture* (Jan. 1924); H.V. Garner, 'Manures for February', *The Journal of the Ministry of Agriculture* (Feb. 1924); H.V. Garner, 'Manures for March', *The Journal of the Ministry of Agriculture* (Mar. 1924); H.V. Garner, 'Manures for April', *The Journal of the Ministry of Agriculture* (Apr. 1924); H.V. Garner, 'Manures for May', *The Journal of the Ministry of Agriculture* (May 1924); H.V. Garner, 'Manures for October', *The Journal of the Ministry of Agriculture* (Oct. 1924); H.V. Garner, 'Manures for November', *The Journal of the Ministry of Agriculture* (Nov. 1924).

[15] Garner, 'Manures for February', 1061.

[16] For bees see RES, *Report for 1934*, 34; for cotton see RES, *Report 1925–26*, 15; for barley see RES, *Report 1925–26*, 15.

[17] Machlup, *Knowledge*, 8. [Vol. 2]

[18] Jonathan Harwood has discussed, for instance, the academic drift of German agricultural colleges between the nineteenth and twentieth centuries, see Harwood, *Technology's Dilemma*.

[19] Anonymous, 'The Farmer and Research', *The Farmer & Stockbreeder*, 1 November (1926).

grasp even for the agronomists, who often only had a basic grounding in mathematics. Moreover, they could not be directly linked to everyday farming practice, as information on fertilisers, crop varieties, animal breeds or tools could be. So, how was the 'usefulness' of the figures produced by inferential statistics to be measured?

Farmers, Agricultural Scientists, and Statistics

Statistics is a tool for making sense of figures. Census returns, laboratory tests or marketing survey results are all suitable datasets for statistical examination. However, while a census return includes the entire population of a country, the results of laboratory tests and marketing surveys only relate to a limited sample. In such a case, statistical inference can be used to gather knowledge about the scientific phenomenon under investigation or about consumer choices.

Inferential statistics is, in fact, used to draw inferences from the data collected from a limited, but representative, sample of the population being studied.[20] In agricultural research these mathematical techniques offer effective tools for determining whether the changeable results of agricultural trials, in particular field trials, should be attributed to the intrinsic variability of the objects under investigation or are caused by a specific factor, for instance a fertiliser involved in the experiment. Inferential statistics enables users to estimate the error associated with the experiment, and to apply mathematical tests, called 'tests of significance', to check whether the experimental data proved a certain scientific hypothesis or not.

At the beginning of the twentieth century, the opportunity to use both the experimental error as a benchmark of an experiment's reliability and to rule out, through tests of significance, that the variations observed were due to mere chance, represented a notable step forward in agricultural research, especially in relation to field experiments. Previously, in fact, an experimental error was rarely associated with the results of agricultural trials.[21] And even when such experimental error was provided, its reliability was considered controversial. The statistical methods used to calculate it, in fact, had been borrowed from astronomy and were inaccurate when applied to the analysis of agricultural experiments.[22] Moreover, the only available tools for analysing time series, as in the case of long-term field experiments, were restricted to calculating averages. There was no follow up investigation into the factors which contributed to the fluctuations of the yields.

Rothamsted Experimental Station played a crucial role in the emergence of inferential statistics and its application to agricultural research. During the 1920s, the statistical methods of analysis of variance and experimental design were developed at Rothamsted, and its statistics department remained a reference point for statistics and computing in Britain and the British Empire for decades.[23] At Rothamsted, mathematical reasoning, computing and information management became a core part of experimental research, and a new expert group of consulting statisticians supported the agricultural scientists working at the station.

Even so, did inferential statistics have any impact on the value of agricultural research for farming? As mentioned before, the aim of agricultural experiments is to suggest more efficient and economic methods for growing crops and rearing animals. Practical returns from research

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[20] Gerd Gigerenzer et al., *The Empire of Chance* (Cambridge, MA, 1989), chapter 3.

[21] A.D. Hall, 'The Experimental Error in Field Trials', *The Journal of the Board of Agriculture* (Aug. 1909).

[22] Zeno Swijtink, 'Probability and Statistics in Agronomy', in: I. Grattan-Guinness (ed.), *Companion Encyclopedia of the History and Philosophy of the Mathematical Sciences*, vol. 2 (London and New York, 1994).

[23] Giuditta Parolini, 'The Emergence of Modern Statistics in Agricultural Science: Analysis of Variance, Experimental Design and the Reshaping of Research at Rothamsted Experimental Station, 1919–1933', *Journal of the History of Biology*, DOI: 10.1007/s10739-014-9394-z.9-526 (2014), printed in vol. 48/2 (2015).

are only possible if the experimental results are reliable – that is, if they are known with their related error and if these errors are small enough not to invalidate a potential economic advantage.

The Rothamsted reports of the 1920s constantly emphasised how a 5% difference in gross yield "could make the whole difference between profitable and unprofitable farming".[24] They also pointed out that the modern research techniques might increase reliability in agricultural experiments – in particular the field experiments where multiple environmental factors such as soil and climate were at stake. The same reports emphasised how this result was achieved through statistical inference, a tool that made it possible to determine the experimental error and test the effect of each factor on the results. Inferential statistics, therefore, was accepted as part of the institution's research activity, and was also displayed as useful knowledge in the station's official reports. These publications were distributed to other agricultural establishments, policy circles, and farming associations.

It is not surprising, then, to find these new techniques of statistical experimentation mentioned in journals which were read by the farming community, and by agricultural organisers and educators. In these publications, the corpus of statistical knowledge deployed in agricultural experimentation was regarded as a technical and 'dry' subject and its complexity was openly acknowledged.[25] Nonetheless, it was also clearly stated that, "in order to demonstrate a yield difference of the order of 10 per cent. due to the employment of a certain variety, manuring, or cultivation a rather elaborate technique in the field, coupled with suitable statistical analysis in the laboratory, is required".[26] Inferential statistics was therefore acknowledged as necessary to achieve the economic results that agricultural research, a costly activity, aimed for. Both agricultural scientists and farmers agreed on this point.

This approach was not only successful in Britain. As Harro Maat argues, statistical inference also became an essential tool for improving agricultural productivity in the Netherlands and the Dutch East Indies, and the relationship between agricultural advisers, agricultural scientists, political institutions and farmers was reshaped by the emergence of experimentation techniques based on statistical inference.[27]

It is important to stress, however, that the usefulness of inferential statistics was not directly linked to the corpus of mathematical knowledge imbued in the discipline neither for agricultural scientists nor farmers. The usefulness resided, instead, in the fact that people could use the statistical methods based on inference even without any detailed understanding of them.[28]

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[24] RES, *Report 1923–24 With the Supplement to the 'Guide to Experimental Plots'* (Harpenden, 1925), 38.

[25] A.B.B., 'Experimental Error', *Agricultural Progress*, 8 (1926).

[26] H.V. Garner, 'Rothamsted Conferences', *Agricultural Progress*, 9 (1932), 164.

[27] Harro Maat, 'Statistics and Field Experiments in Agriculture. The Emerging Discipline of Inferential Statistics', in: I. H. Stamhuis, P. M. M. Klep and J. G. S. J. van Maarseveen (eds.), *The Statistical Mind in Modern Society: The Netherlands 1850–1940. Vol. II: Statistics and Scientific Work* (Amsterdam, 2008). The vision of field experimentation as a statistical endeavour which was promoted by Rothamsted Experimental Station was successful, but not uncontroversial. See Giuditta Parolini, 'In Pursuit of a Science of Agriculture: the Role of Statistics in Field Experiments', *History and Philosophy of the Life Sciences* (2015).

[28] This is not particular to agriculture. Methods based on statistical inference were used also in serology from the 1920s on, with statisticians working in close contact with laboratory researchers and hospital physicians. It was certainly appreciated that the study of blood groups required statistics, but the methods were "most fortunately simple to apply" and demanded "no understanding of their subtlety", Robert Race and Ruth Sanger, *Blood Groups in Man* (Oxford, 1954), 8. On statistics in serology, see chapter 3 in Giuditta Parolini, *"Making Sense of Figures": Statistics, Computing and Information Technologies in Agriculture and Biology in Britain, 1920s–1960s* (Ph.D. Thesis, University of Bologna, 2013: chapter 3).

Percentages and results of significance tests remained valuable tools even when the rationale behind them was considered too technical or complex to be explored. They enabled even inexperienced users – albeit at the risk of some misuse – to make sense of the results of agricultural experiments in a standardised form.[29]

In his book *The Gifts of Athena*, Joel Mokyr divides useful knowledge into *propositional knowledge* ("what") and *prescriptive knowledge* ("how").[30] According to Mokyr's classification, mathematics is a form of propositional knowledge, "insofar as mathematics is used to describe and analyse the regularities and orderliness of nature".[31] It follows that inferential statistics should be considered a form of propositional knowledge. However, in the case examined, statistics was more akin to Mokyr's *prescriptive knowledge* ("the sets of executable instructions or recipes for how to manipulate nature"), because experimental scientists were not interested in the 'beliefs' that underpin statistical methods, but solely in their practical use.[32] Statisticians themselves have stressed their role as technicians and the practical value of the mathematical methods they have developed.[33]

Mokyr's choice to split the *what* from the *how* does not suit inferential statistics, either for agricultural science or for the many other contexts in which statistical inference has been applied to solve real problems. In fact, Mokyr's categorisation disregards the constant interplay between propositional and prescriptive knowledge that arises when a common goal brings several scientific and non-scientific actors together.

I claim that statistical inference became useful knowledge in agriculture precisely because the *what* and the *how* could not be fully demarcated. This enabled different agendas to be brought together (the agricultural institutions' scientific agenda and the farming community's business-oriented agenda), along with social actors (statisticians, agronomists and farmers), and skills (linked to mathematics, experimentation and farming). To support this claim, I discuss two different areas in which statistical inference became useful knowledge for farming: field experimentation on commercial farms and agricultural meteorology.

Farming and Field Experiments

The history of field trials is as long as the history of agricultural science itself. They are one of the main forms of experimental activity in agriculture, as they can be used for several aims, for instance to investigate the effects of fertilisers, soil conditions, husbandry methods, agricultural tools, and cultivation practices on the growth of crops. In my examination of inferential statistics as useful knowledge for farming, they represent a particularly valuable case study because field experimentation was the first context in which the techniques of inferential statistics were applied to agricultural research.[34]

Field experimentation was by no means only undertaken by agricultural institutions.[35] Scientists, extension services, and private farmers all contributed to trials conducted in the fields

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[29] Maat, 'Statistics and Field Experiments in Agriculture'.

[30] Mokyr, *The Gifts of Athena*.

[31] Mokyr, *The Gifts of Athena*, 3.

[32] Mokyr, *The Gifts of Athena*, 10.

[33] Michael Healy, 'Is Statistics a Science?', *Journal of the Royal Statistical Society A*, 141/3 (1978).

[34] Parolini, 'The Emergence of Modern Statistics in Agricultural Science'.

[35] As Harro Maat argues, "[i]n agriculture, science-based experimenting was preceded by (and ran in parallel with) practical, farm-based experimenting": season after season farmers' experiments built up an in-depth knowledge of the local quality of soils and crops, and the influence of environmental factors, such as rainfall": Maat, 'Statistics and Field Experiments in Agriculture', 96.

of research institutions, rural colleges, and private farms. However, the experiments carried out on private farms were usually ‘demonstrations’ rather than proper scientific trials, as they disregarded even the basic principle of agricultural experimentation – the replication of treatments on different plots.[36] Rather than attempting to prove any scientific hypothesis, they were used to provide an easy-to-understand display of certain properties of a crop variety or the efficacy of a fertiliser. Paradoxically, the experiments which were carried out in accordance with the best practices suggested by inferential statistics, such as randomisation, “looked untidy and were less effective as demonstrations”.[37] Despite their scientific biases, demonstrations were popular because they offered farmers hands-on experience of agricultural experiments and brought them into closer contact with extension services, as the local agricultural organisers were usually in charge of these trials.

During the 1920s and 1930s, Rothamsted Experimental Station actively promoted experiments on commercial farms. These experiments were designed and analysed in line with the methods of statistical inference. They were planned using Latin squares and randomised blocks, the two schemes for statistical experimentation that had been developed at Rothamsted. These ensured that the basic requirements of experimentation imposed by statistics – replication and randomisation – were satisfied.

The trials which Rothamsted set up on private land concerned the institution’s core research area – the efficacy of fertilisers on crop growth.[38] The questions tested were the effect of slag on hay, arable and root crops, of superphosphate on potato growth, and of nitrogenous fertilisers on the growth of sugar beets.[39]

Experimenting on private farms required a constant compromise between scientific principles and farmers’ needs. Field trials on commercial farms needed “sufficient practical bearing to appeal to the farmer, while also providing information on more general questions”.[40] Without this practical bearing, it would have been impossible to gain the full cooperation of the farmer. Cooperation that was essential for successfully carrying out an experiment. Unlike the Rothamsted experimental fields, whose history was known in detail and for which accurate records existed, the soil on private farms was totally unfamiliar. Only the farmer knew which crops had previously been planted there, which manure had been applied, and any other unusual features of the soil.

Farmers were asked to collaborate further, by monitoring the crops’ growth, and taking notes that could be used afterwards while analysing the experimental data. The farm owners were also responsible for carrying out everyday field operations on the experimental land, and alerting the Rothamsted staff when they were about to start the harvest. Each experimental plot had to be harvested separately and its produce weighed and recorded. The data was then examined using inferential statistics, and the results of the statistical analysis determined whether the experiment had been successful or not and to what degree. For the farmers who let their land be used for research, these results directly translated into recommendations for achieving more profitable

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[36] “[T]he results of such experiments [demonstrations], even when not mutually contradictory, are so lacking in precision as to be of little value, and [...] the time and money spent thereon are often wasted.” J. Wishart and H.J.G. Hines, ‘Fertiliser Trials on the Ordinary Farm’, *The Journal of the Ministry of Agriculture* (Sept. 1929), 524.

[37] Russell, *A History of Agricultural Science in Great Britain*, 328.

[38] John Bennet Lawes funded the scientific research at Rothamsted Experimental Station using the money he had earned as an entrepreneur in the fertiliser business, manufacturing superphosphate.

[39] Wishart and Hines, ‘Fertiliser Trials’.

[40] H. V. Garner, ‘Practical Details of Experimentation on Ordinary Commercial Farms’, in: Rothamsted Experimental Station, *The Technique of Field Experiments* [Rothamsted Conferences XIII] (Harpenden, 1931), 49.

crop cultivation, as "the farmer has the advantage of the only fertiliser experiments which he can interpret with confidence, namely those carried out on his own soil".[41]

The modern techniques of field experimentation offered an economic advantage to farmers. No matter how abstract in principle, the tools provided by statistical inference could lead to a return on investment for the trials completed on private farms. It was not necessary to have an in-depth understanding of the concept of statistical significance to grasp that a big enough difference in the trial results could mean savings.[42] To highlight this, the field demonstrator at Rothamsted, H.V. Garner, reviewed the results of Rothamsted experiments on private land, attributing a precise cash value to each significant difference, and pointing out that these were not just a matter for academic discussion, but that the "detectable differences" fully justified the costs of purchasing the manures used in the trials.[43]

The Rothamsted staff were satisfied by the activity on commercial farms, although it was not possible to achieve the same level of accuracy on private land as in a scientific institution, where the layout of field trials included more replications and where trials could be constantly monitored. Nonetheless, the sharing of scientific research and practical knowledge had a positive economic impact on farming, whilst also proving that it was worthwhile and valid for scientific institutions to carry out field investigations on commercial farms. Inferential statistics was therefore able to produce useful knowledge, because it could reveal the connections between the fundamental research undertaken by Rothamsted and the needs of commercial farmers.

The Crop-Weather Scheme

Weather conditions deserve special attention when considering the environmental factors that have the most significant effect on the outcome of agriculture. During the twentieth century, the discipline of agricultural meteorology was created to investigate weather conditions "with the ultimate end in view that the farmer and the horticulturalist may be better armed to prevent injury from, or take advantage of, the vagaries of climate".[44]

The British Ministry of Agriculture and Fisheries sponsored research on agricultural meteorology from the early 1920s on and, in 1924, the Ministry set up a Permanent Committee on the subject. In particular, the Committee took charge of the scheme of crop and weather observations which were collected at about thirty British experimental stations. This scheme aimed to find correlations between weather and crop growth. Rothamsted was one of the stations chosen, and each of them took and recorded daily meteorological observations, together with notes on various local crops. Within this crop-weather scheme, selected institutions also agreed to collect more detailed observations on wheat and apples, based on sampling procedures, which were called 'precision observations'.

Rothamsted Experimental Station was one of the scheme's key participants. It was responsible for statistical analysis of the precision observations on wheat, and the members of its statistics department were actively involved in the Committee's work as consultants.[45] Ronald Fisher, chief statistician at Rothamsted during the 1920s, was co-opted onto the committee from its inception

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[41] Garner, 'Practical Details of Experimentation', 49.

[42] According to the convention used in the Rothamsted reports a difference of three times the standard error was considered significant.

[43] Garner, 'Practical Details of Experimentation', 53.

[44] Agricultural Meteorology, Report, The UK National Archives, MAF 33/679.

[45] A detailed description of the precision observations on wheat carried on at Rothamsted is in Joseph Irwin, 'Crop Estimation and Its Relation to Agricultural Meteorology', *Supplement to the Journal of the Royal Statistical Society*, 5/1 (1938), 10.

in 1924. In the same year, Fisher published a paper on the correlation of wheat growth and rainfall in the Royal Society's journal *Philosophical Transactions*. The paper was based on his re-examination of the data from Rothamsted's long-term experiments.[46]

This interest in crop and weather data remained a long-lasting feature of research in the Rothamsted's statistics department even after Fisher relinquished his position there in the early 1930s, and many more scientific contributions on the correlation of weather and crop data were published by the department in the following years. Rothamsted also hosted the statistician Joseph Oscar Irwin, who was hired by the Committee to advise them on the crop-weather scheme and "make recommendations for its improvement".[47]

Irwin worked closely with Fisher and other members of the statistics department. Using the tools provided by statistical inference, they extracted information from the crop and weather figures. In particular, the analysis of variance – developed at Rothamsted to examine experimental results – was used to study the correlation between crop growth and weather data and to analyse the precision observations on wheat.[48]

Once again, methods based on statistical inference made a crucial contribution to agricultural research. Above all, as Irwin pointed out, they made it possible to associate an error with the crop observations made in the field, making these data reliable.[49] Irwin, therefore, suggested that the same model should be used, with a few modifications, for all crop observations.

Reliable crop data was not an end in itself, but a necessary step towards obtaining reliable crop-weather correlations which could be used "for forecasting or estimating in advance the acreage, yield or quality of crops", which Irwin considered the main practical impact of agricultural meteorology.[50] These correlations could then be used to plan future cultivation, determining the best time for marketing crops, or working out schemes for crop insurance.

Thus, statistical inference provided suitable tools for use in agricultural science to increase farming profitability. However, in contrast to field experiments, where the impact of inferential statistics was felt immediately, things were not so straightforward in agricultural meteorology. In the 1930s, agricultural meteorology was still a novel subject and the British crop-weather scheme rather experimental. Even Fisher's method for correlating yield and rainfall was not considered uncontroversial.[51] The main limitation was the lack of sufficient long-term data on crops and weather which could be used to reliably identify trends. In their absence, forecasts based on weather data only had a limited value. Agricultural meteorology as useful knowledge remained a work in progress.

Conclusion

Since it was first used in agricultural research at the beginning of the twentieth century, inferential statistics has proved to be a useful tool, not only for improving agricultural experimentation, but

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[46] For instance, see Ronald Aylmer Fisher, 'The Influence of Rainfall on the Yield of Wheat at Rothamsted', *Philosophical Transactions of the Royal Society of London*, series B (1924), 213.

[47] Irwin, 'Crop Estimation'.

[48] Irwin, 'Crop Estimation', 9.

[49] Irwin, 'Crop Estimation', 9.

[50] Irwin, 'Crop Estimation', 1.

[51] When William Cochran, appointed to work in the Rothamsted statistics department during the 1930s, applied Fisher's method to the data gathered at Woburn Experimental Station, he could not find any significant impact of rainfall on yields, as Fisher had argued, see John Russell and J. A. Voelcker, *Fifty Years of Field Experiments at the Woburn Experimental Station* (London, 1936).

also for increasing farming profitability. As this paper shows, the methods of inferential statistics had an impact – actual or potential – on cultivation practices.

However, the relevance of inferential statistics for farming is not limited to the specific cases examined. Experimentation, in particular field experimentation, is a constant requisite of practical agriculture, as well as agricultural research, and statistical methods remain essential to make sense of it.[52] Unsurprisingly, inferential statistics has also formed part of the initiatives promoted by the Food and Agricultural Organisation (FAO), whose mission is to improve nutrition and agricultural productivity, especially in developing countries, rather than to undertake fundamental research. For instance, John Wishart – Ronald Fisher's former assistant at Rothamsted and later a statistician at the Cambridge School of Agriculture – wrote manuals on statistical methods for FAO training centres and was a long-term collaborator of this organisation in promoting the knowledge of inferential statistics in agricultural research.

I want to conclude with a few general remarks on useful knowledge. The impact of inferential statistics on farming suggests that the making of useful knowledge can be associated with tools, in this case statistical methods, which may appear to be distant from practical applications. It is therefore important that any investigation into the intertwining of knowledge and material welfare should cast a wide net, including less obvious elements.

In relation to tools and their use, it is also crucial to note that this is a complex process involving multiple elements (such as science, technology, practices and social structures). Therefore, I have questioned the feasibility of the distinction, suggested by Joel Mokyr, between prescriptive and propositional knowledge in the case of inferential statistics. I believe Mokyr's approach is too reliant on a stereotypical model of innovation, mostly based on industrial innovation and engineering processes. This is unsuitable for agriculture and, more generally, whenever the connections between the *what* and the *how* are non-linear and involve several stakeholders.

My last comment concerns the relevance of networks of knowledge exchange in promoting useful knowledge. Describing how the numbers and formulae of inferential statistics became part of the economic process of farming, I had to take into account researchers and their institutions, farmers and their associations, rules for experimentation and cultivation practices, publications and other dissemination strategies adopted in agriculture. Any investigation into the making of useful knowledge, therefore, should not only identify the potential beneficiaries of the knowledge at stake, but should also address how actors belonging to different social worlds, possessing different skills and accepting different, and sometimes contrasting, evaluation criteria, can find common ground to share such knowledge and make the most out of its potential economic impact.

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[52] Harro Maat and Dominic Glover, 'Alternative Configurations of Agronomic Experimentation', in: J. Sumbaer and J. Thompson (eds.), *Contested Agronomy* (New York and London, 2012), 132.

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REPORTING USEFUL EXPERIMENTS: COST ACCOUNTING AND EARLY MODERN TECHNICAL EXPERIMENTATION

Cesare Pastorino

Financial accounting was a widespread practice in the early modern period, undertaken not only by professionals and merchants, but also by individuals for their own private records.[1] Accordingly, the early modern age saw a great diffusion of handbooks and manuals on accounting, detailing the practices and techniques of mercantile bookkeeping. These texts were widely printed and reprinted from the sixteenth century on. They were modelled on the famous work by Luca Pacioli (1446–1517): *Summa de arithmetica, geometria, proportioni et proportionalita* (1494). In this treatise, Pacioli formalised the rules of double-entry bookkeeping, based on the notion of describing commercial activities by reporting the debit and credit of each transaction. As Richard Yeo summarises, the use of Pacioli's method:

> required the provision of considerable circumstantial detail, such as the name of the person [involved in the transaction], the date, hour, and place of transaction, the quantity and prices of goods or loans. Moreover, after an inventory had been compiled, the entries were made in *three* notebooks: the memorandum, […] the journal […], and the ledger […]. Daily transactions were entered in the memorandum (also called a day or waste book) as they occurred. […] Transactions in the day book were later summarised and entered in the journal. This information could then be properly rendered as either debit or credit in the ledger.[2]

Thus, double-entry bookkeeping and, more generally, mercantile accounting established a formalised system of specific and standardised practices and procedures for recording financial transactions.

The question of what role such practices and procedures played in the rise and development of early modern science has not been fully investigated. There have been a few significant but specific studies, often related to the role of accounting in natural history. This chapter, however, focuses on a subject that has not yet been explored—the role of accounting techniques as templates and standards for recording experimental practice—and proposes an original hypothesis: the notion that mercantile accounting, mediated through its industrial and institutional forms, provided a model for the establishment of techniques and practices of experimental reporting.

Several authors have shown how mercantile accounting embodied sets of social and epistemic values. For instance, Mary Poovey has explained that:

> *as a system of writing*, double-entry bookkeeping produced effects that exceeded transcription and calculation. One of its *social* effects was to proclaim the honesty of merchants as a group. One of its *epistemological* effects was to make the formal precision of the double-entry system […] *seem* to guarantee the accuracy of the details it recorded.[3]

Accuracy, precision and trustworthiness all had an obvious role to play in commercial and industrial spheres. However, this paper will consider the possibility that these values and qualities

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[1] Adam Smyth, *Autobiography in Early Modern England* (Cambridge, 2010), chapter 2, 'Financial Accounting'.

[2] Richard Yeo, *Notebooks, English Virtuosi, and Early Modern Science* (Chicago, 2014), 18–19.

[3] Mary Poovey, *A History of the Modern Fact* (Chicago, 1998), 30.

could also make accounting an appealing template for early modern experimenters. In this sense, the case of accounting and experimentation acquires a different significance, as it provides an example of how 'useful' knowledge and expertise was transferred between apparently distant areas and disciplines—in particular, from economic to scholarly and philosophical domains.

Cost Accounting in the Early Modern Period

This analysis focuses on one specific type of accounting practice: what would be called 'cost accounting' or 'management accounting' today.[4] Boyns and Edwards define management accounting generally as 'the use of accounting information for the purpose of assisting management in carrying out its numerous functions'.[5] Cost accounting is included in this definition, because in this case the notion of accounting means reviewing the costs and charges involved in a process or production, in order to reduce such costs, maximise profit, or alter the process or procedure in other ways.

Management accounting is quite a sophisticated use of accounting and, in the past, was thought to be a recent development. For instance, the early accounting historian A.C. Littleton thought that 'cost calculation practice' had emerged as late as the industrial revolution:

> [c]ost accounting […] in the last analysis, represents the influence of the industrial revolution upon double-entry bookkeeping; it is an important element in marking the expansion of bookkeeping (a record) into accounting (a managerial instrument of precision).[6]

However, several accounting historians suggest that management accounting was already beginning to evolve in earlier times. In general, they agree that cost calculation was developed in some way through the 'replacement of the domestic system by capitalist processes of production'.[7] They identify three main industries where this form of accounting emerged early on: mining, textiles and iron manufacture;

> additional accounting problems were encountered by businesses operating in these sectors as increasing amounts of capital had to be invested in mines, ore processing equipment, and manufacturing plants such as textile mills, blast furnaces and rolling and slitting mills.[8]

Interestingly, cost and management accounting techniques are never described in the popular early modern genre of accounting handbooks and manuals. It is also difficult to find any early modern literature which discusses or describes the existence of anything analogous to cost and management accounting. It seems probable that this specific type of accounting activity was widely used, but not yet formalised. In the case of the mining industry, Vannoccio Biringuccio is clearly referring to this type of accounting in the 'Preface' to Book I of his *Pirotechnia*:

> [s]uppose that by signs or other method you have found the mountains and by knowledge have also found the ore without being certain of its particular type, in order to make sure what kind of metal the ore contains, what its quantity, what its companions, and what its purity or impurity, it is necessary before any expenditure is made to assay it one or more

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[4] The difference between these two terms in accounting literature is not well defined. See, for instance, Trevor Boyns and John Edwards, *A History of Management Accounting: The British Experience* (New York, 2013).

[5] Boyns and Edwards, *A History of Management Accounting*, 2.

[6] Ananias Littleton, *Accounting Evolution to 1900* (New York, 1933), 360, quoted in Boyns and Edwards, *A History of Management Accounting*, 97.

[7] Boyns and Edwards, *A History of Management Accounting*, 97–8. See also S. Paul Garner, *Evolution of Cost Accounting to 1925* (Montgomery, Al, 1954), 3.

[8] Boyns and Edwards, *A History of Management Accounting*, 98.

> times […]. When it is known that there is an ore and what quantity of what metal it contains, and it is found by calculation [*e trovando per il calcolo*] that you will recover enough value in it to justify the expense, I exhort you to begin courageously and continue the undertaking with every care, and to start mining.[9]

Here, Biringuccio describes a common occurrence at the start of important mining enterprises: large-scale assaying projects were developed in order to provide evidence for potential investors so that economic profit could be realised from mineral exploitation schemes. Analogous cases were common for voyages of exploration, and for the testing of rocks and ores discovered during such ventures.

A Textual Genre: the Cost Estimate

Biringuccio used the interesting words 'found by calculation' [*trovando per il calcolo*]. This expression probably refers to a cost estimate, which would have been drawn up according to accounting techniques. In the case described by Biringuccio, a cost estimate was equivalent to an assaying trial report.

Here are two examples of early modern English assaying trial reports:

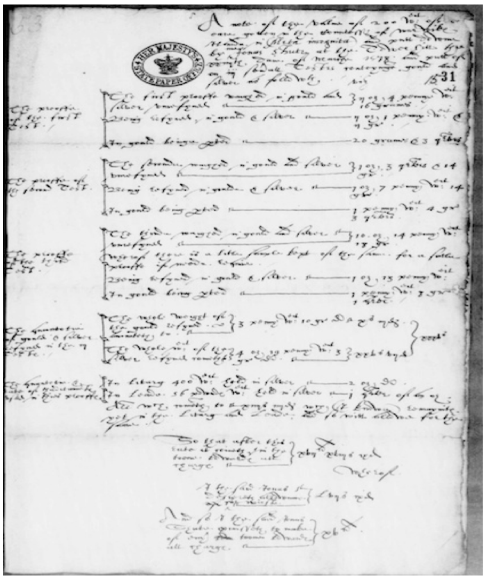

Fig. 1. Assaying trial report by Jonas Schutz, 24 March 1579 (State Papers Domestic, SP 12/130). The National Archives. Crown Copyright.

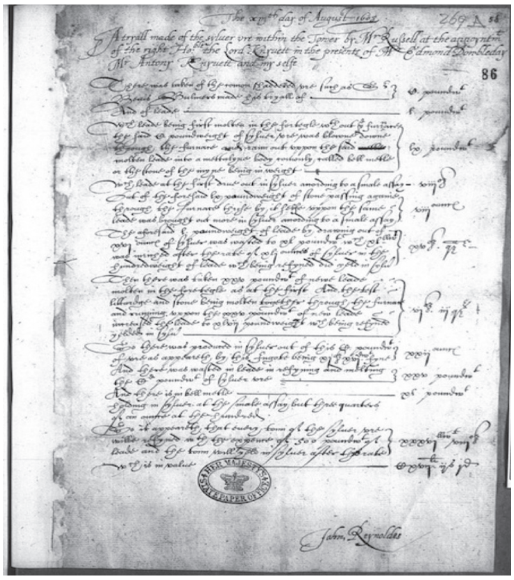

Fig. 2. Assaying trial report by Thomas Russell, 13 August, 1608 (State Papers Domestic, SP 14/35). The National Archives. Crown Copyright.

The first one refers to a trial conducted on ores from Martin Frobisher's expedition in 1579, the second to a trial in relation to a Scottish mining enterprise in 1608.

It is interesting to consider what information is included in these accounts. The second cost estimate reports that the assayer obtained silver weighing thirty-six pounds and eight ounces for every 'ton' of ore (or 2,240 pound weights). The results of the test, particularly the proportion of noble metal present in the mineral ore, were clearly the fundamental component of assaying

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[9] Martha Gnudi and Cyril Smith (eds.), The Pirotechnia of Vannoccio Biringuccio (New York, 1990), 16–17. Analogous considerations can be found in Georg Agricola's De re metallica. See Georgius Agricola, *De Re Metallica*, Herbert Clark Hoover and Lou Henry Hoover eds., translated from the First Latin Edition of 1556 (New York, 1950), 219–21.

reports. However, such reports were also documents through which an assayer would detail the expenses incurred in the course of the testing process. It was vital to include an exact description of every single cost, because the trial was usually conducted for an employer, or a potential employer. These documents did not just detail the quantity of precious metals found in an ore, but also the costs of the refining process. These costs had to be subtracted from the metal's market value to obtain the estimated net profit. In this respect, an assay report was a commercial document, and the merchant-like style and organisation of the information in the text suggest that these documents actually evolved out of the mercantile tradition of accounting. Moreover, the documents' layout reveals that, in England at least, the format and structure of these assaying reports remained relatively unchanged over time. It appears that there was already a specific textual genre, which had well-defined characteristics and was easy to distinguish from other documents such as, for instance, technical guidelines or how-to manuals.

Technical Experimentation and Experimental Philosophy

As shown above, cost accounting entailed the use of a specific, quantitative model for reporting on technical experimentation processes. This raises the following questions. Was accounting expertise transferred from the area of economic usefulness to other domains and, in particular, did it become linked with more philosophical and scholarly forms of experimentation in the seventeenth century? Are there are any examples of reporting in the domain of experimental philosophy that derive from cost accounting and cost estimates?

In an initial general survey of authors who wrote explicitly about the best ways to report experimental practice, three prominent examples come to mind: Francis Bacon (1564–1626), Robert Hooke (1635–1703), and Johann Joachim Becher (1635–1682).

Francis Bacon

Suggestions derived from accounting are evident in Baconian forms of experimental reporting. Under the heading of 'literate experience', Bacon devised a complex system of reporting, which had as one of its major goals the idea of the full, quantitative account: 'every thing to do with natural phenomena, be they bodies or virtues, should (as far as possible) be set down, counted, weighed, measured, and defined. For we are after works, not speculations'.[10] This is very much the mindset of a merchant, an engineer or a state officer: the notion that data of experimental practice are like valuable 'commodities' that need to be fully accounted for. Bacon stressed similar ideas elsewhere in his work. For instance, in an early text, *Valerius Terminus* (c. 1603), Bacon used accounting as a metaphor for the work of a philosopher, who had to initially provide and produce a 'Kalendar or Inventory of the wealth, furniture, or means of man according to his present estate'.[11] It is always important to differentiate between simple accounting metaphors and the actual, intended use of accounting templates; however, Bacon's metaphor seems to have been meant quite literally, as it required the philosopher 'to distinguish and present, as it were in several columns, what is extant and already found, and what is defective and further to be provided'.[12] Interestingly, Gottfried Leibniz captured Bacon's accounting metaphor in his *Project of a General Science*, by mentioning the production of 'a precise INVENTORY of all the available but dispersed and ill-ordered pieces of knowledge'. He asserted that 'General Science' must start from this 'good

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[10] Francis Bacon, *The Instauratio Magna Part II: Novum Organum and Associated Texts,* ed. Graham Rees with Maria Wakely, *The Oxford Francis Bacon*, vol. 11 (Oxford: Clarendon, 2004), *Parasceve*, 465.

[11] Francis Bacon, *Works*, eds. James Spedding, Robert Leslie Ellis, and Douglas Denon Heath (London, 1857–1874), vol. 3, 233.

[12] Bacon, *Works*, vol. 3.

inventory', because it is 'for the particular sciences what the science of accounting is for a merchant or a man in charge of finances, it is with it that one must certainly begin';[13] a statement with which Bacon would certainly have agreed. As a matter of fact, Bacon's Experimental Histories, and particularly the Mechanical Histories, or histories of experiments in the mechanical arts, required a rigorous recording in line with precise tenets:

> the places or thinges to be inquyred are; first the materialls, and their quantities and proportions; Next the Instrumts and Engins requesite; then the use and adoperation of every Instrumt; then the woork it self and all the processe thereof wth the tymes and seasons of doing every part thereof.[14]

These rules of composition were, in fact, quite similar to those used to produce costings in the commercial sector. It is interesting to note that, while he was formulating these rules and tenets, Bacon was in close contact with the assayer Thomas Russell, who very probably gave him some reports and cost estimates of assaying trials.[15]

Robert Hooke

The Royal Society paid great attention to the rhetorical aspects of communication, which Sprat called 'the manner of Discourse' in his history of the Society. The Society forbade the use of ornate speech, the 'easy vanity of fine speaking' and the 'vicious abundance of Phrase, this trick of Metaphors, this volubility of Tongue'. It advocated the 'constant Resolution, to reject all the amplifications, digressions, and swellings of style'. Instead, the members of the Society resolved to:

> bringing all things as near the Mathematical plainness, as they can: and preferring the language of Artisans, Countrymen, and Merchants, before that of Wits or Scholars.[16]

It is fair to say that Robert Hooke was very receptive to this notion. In his long *Method of Improving Natural Philosophy*, he covered many subjects regarding how to improve experimentation, including a comprehensive section on what he called the 'manner of Registering' experiments.[17] His approach builds upon and develops Sprat's statements about mercantile plainness. For example, Hooke recommended experimenters record their activities in two stages. Initially, they should make their notes:

> as fast as the Experiment is made, and as soon as the Observations or Circumstances occur, because of the Frailty of the Memory, and the great Significancy there may be in some of the meanest and smallest Circumstances.

Then, this initial record should be improved. In the second phase, accounts of experiments:

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[13] Gottfried Wilhelm Leibniz, *The Art of Controversies,* ed. Marcelo Dascal (Dordrecht, 2006), 235.

[14] Bacon, *Works*, vol. 11, *Commentarius solutus*, 65– 66. See also Cesare Pastorino, 'Weighing experience: Experimental histories and Francis Bacon's quantitative program', *Early Science and Medicine*, 16/6 (2011), 542–70.

[15] See Cesare Pastorino, 'The Mine and the Furnace: Francis Bacon, Thomas Russell and Early Stuart Mining Culture', *Early Science and Medicine,* 14/5 (2009), 630–60.

[16] Thomas Sprat, *History of the Royal Society* (London, 1667), 13.

[17] This text can be found in Robert Hooke, *A General Scheme, or Idea of the Present State of Natural Philosophy, and Hhow its Defects may be Remedied by a Methodical Proceeding in the Mmaking of Experiments and Collecting Observations. Whereby to Compile a Natural History, as the Solid Basis for the Superstructure of True Philosophy,* (in Richard Waller (ed.), *Posthumous Works of Robert Hooke* (London, 1705)).

> ought […] to be several times reviewed and examin'd, and rang'd into a better Method, and abbreviated in the manner of Description; so that as nothing be wanting in the History, so nothing also be superfluous in words.

Hooke commented on the choice of words and terminology:

> there ought to be great Care and Circumspection, that they be such as are shortest and express the Matter with the least Ambiguity, and the great Plainness and Significancy, not augmenting the Matter by Superlatives , nor abating it by Diminutives, not inclining it to this or that Hypothesis, or accommodating it to this or that Author's Opinion; avoiding all kind of Rhetorical Flourishes, or Oratorial Garnishes, and all sorts of Periphrases or Circumlocutions, omitting the Citations of Authors, or the Recital of Opinions, and Sayings, or the like.

He envisioned that the second phase of writing would include a stylistic revision to the record:

> in the second Review and Writing […] 'twill not be amiss to write it in a very fine piece of Paper, and to enter it in the most compendious manner of writing that the Historian is acquainted with, such as some very good Short hand or Abbreviation, whereby the whole History may be contracted into as little Space as possible.[18]

What counts here is the fact that these principles reveal several similarities with the techniques used in commercial records, regarding different types of log books. An early eighteenth-century handbook, Mair's *Book-keeping Methodiz'd*, provides a clear description of this:

> [t]he *Waste-book* is written in *a plain and simple style*; and ought to be so: for this book being nothing but a bare history of facts and occurrences of trade, containing the matter and substance of accompts, without any thing of that artificial dress which they assume in the other books, the style should be suited to the nature of a narrative, that is, easy, simple, plain, and perspicuous; and the more it so, it is the more like what is should be, answers its design the better, and the book will be the more perfect.[19]

Mair's handbook echoes rules which were frequently reiterated in English bookkeeping manuals from the seventeenth century and even earlier. The material recorded in the 'wastebook' then had to be summarised and sent on to the 'Journal'. According to the *Briefe Instruction* of 1588:

> the parcels of the Journall ought to bee written, ordered and indited in shorter sentence, without superfluous words, than be the parcels in ye Inventory or Memorial as hereafter you shal by divers examples have information.[20]

These texts establish an analogy between annotations of mercantile transactions and of experimental practices according to Hooke's rules: from a more general 'waste-book' or 'memorial', where everything was written down to be recollected and kept, to a more formal 'journal', which only included certain excerpts and was edited in a specific order, with summaries and abridged material. Thus, the principles of clarity, brevity and stylistic decorum were emphasised in both the commercial and philosophical contexts.

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[18] Waller, *The Posthumous Works of Robert Hooke*, 63–64.

[19] John Mair, *Book-keeping Methodiz'd: or A Methodical Treatise of Merchant-accompts, According to the Italian Form* (Edinburgh, 1736), 6.

[20] John Mellis, *A Briefe Instruction and Maner how to Keepe Bookes of Accompts After the Order of Debitor and Creditor* (London, 1588), B8r.

Johann Joachim Becher

Johann Joachim Becher (1635–1682) provides a significant, and different, example. He was a natural philosopher, physician, alchemist, entrepreneur and a court commercial adviser (first to the Elector of Bavaria and subsequently to the Emperor in Vienna). Pamela Smith has shown how motivations from both commerce and natural philosophy strongly influenced all of his diverse projects.[21]

Becher was certainly familiar with the idea of reporting on his projects and experiments in a formal way. In 1676, Becher wrote a 'Referat', or report, for the Emperor Leopold I about an alchemical manufactory (*Kunst- und Werckhaus*).[22] Becher's stated aim was to inform 'the emperor about progress on the construction of the buildings, as well as to seek funds for its completion and for hiring workers'.[23] This document shows that Becher was familiar with the concept of cost accounting on a technical experimental process. In fact, Becher's plans included a worker who was, precisely, responsible for recording and evaluating the experimental practices taking place in the laboratory.

The report describes the structure of Becher's laboratory in detail. The facility was managed by a *Consiliarius Laboratorii*, who was 'directly responsible' to the prince.[24] The Consiliarius was tasked with collating recipes to be tested and deciding on which activities the workplace would undertake. However, as Smith relates:

> [t]he second class of worker in the laboratory was the *Dispensator Laboratorii*, who received instructions from the counselors for undertaking processes, based on the written *consilia*. Once the dispensators were given the process, they were not to 'tinker with it or add anything to it, but should perform it as it is written down and annotated in the *consilium*' […]. The real task of this second class of worker, as his title suggests, was to divide each process into its proper operations and delegate it to the different types of laborers beneath him. He was to report on the trials performed and write a report, which included quantitative information on the materials used and the outcomes achieved.[25]

Moreover,

> [t]he dispensator was required every quarter to make an inventory of his space and to keep orderly bookkeeping to ensure the honesty of the workers. The amounts of material taken from his shelves must be found to agree with the amounts used in the processes. The dispensator's stock of materials was to be ordered and inventoried as in the workshop of an artisan or the warehouse of a merchant.[26]

Becher's conception of the role of *Dispensator* was clearly inspired by the example of accountants calculating the costs of technical operations in a commercial context.[27]

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[21] Pamela H. Smith, *The Business of Alchemy: Science and Culture in the Holy Roman Empire* (Princeton, 1994).

[22] Johann Joachim Becher, *'Referat, oder gründliche Beschreibung was in dem Kunst- undt Werckhauß sambt beyliegenden Schmeltz- undt Glaßhütten, gethan und operirt wirdt, auch wie selbige angeordnet seyn'*, 19 March 1676, Hs. 8046, Handschriftenabteilung, Österreichische Nationalbibliothek, Vienna; see Smith, *The Business of Alchemy*, 190–96.

[23] Smith, *The Business of Alchemy*, 190.

[24] Smith, *The Business of Alchemy*, 231.

[25] Pamela Smith, 'Becher, Johann Joachim', in Charles Coulston Gillispie, Frederic Lawrence Holmes and Noretta Koertge (eds.), *Complete Dictionary of Scientific Biography*, vol. 19 (Detroit, 2008) 229–32. *Gale Virtual Reference Library.* Web. 23 June 2015.

[26] Smith, *The Business of Alchemy*, 237.

[27] On the figure of the *Dispensator*, see Smith, *The Business of Alchemy*, 236–38.

It is not known if Becher implemented the plans in the *Referat* and the figure of the *Dispensator* in his everyday experimental practice. However, there is further evidence of Becher's use of techniques of cost calculation. After his experience at the court of the Emperor, Becher moved to Holland, where he was involved in several technological schemes. In particular, Becher proposed a project for the extraction of gold from sand to the Dutch government. In order to prove the viability and profitability of such a scheme, Becher performed several quantitative tests, summarized in the form of cost estimates.[28] By this time cost accounting was firmly ingrained in Becher's practices of technical and experimental reporting.

Conclusion

The place of commercial accounting in early modern science still needs to be thoroughly investigated, although a few noteworthy studies have started to examine the issue. In a recent article, Deborah Harkness considers the accounting practices of three 'well-to-do Elizabethan merchants with an interest in the new science', showing how 'merchant bookkeeping practices, skills, and priorities could prove enormously beneficial to students of nature'.[29] Overall, Harkness refers to 'the evaluative and analytical skills required to keep a set of business books'. Such expertise 'made merchants […] ideally suited to the work of sifting and sorting through an increasingly large and daunting body of information about the natural world'.[30] Similarly, in an important study of the German scholar and physician Daniel Gottlieb Messerschmidt (1684–1735), Anke te Heesen shows that early eighteenth-century natural history relied on a set of commercial recording practices, 'already common among world travellers'. According to Heesen, 'in such recording practices, the connection between botany and commerce—even between botany and double entry bookkeeping—[was] obvious and concrete".[31] Both of these studies demonstrate the significant role that accounting played in early modern investigations into nature. They confirm that there was an overlap between dissimilar forms of expertise: useful knowledge created in economic and commercial contexts was merged and combined with practices not intrinsically related to those domains. In a process of transition and diffusion, tools which made knowledge useful in one specific area (commerce and industry) were adopted and replicated in different, unrelated contexts.

However, if the general significance of accounting is evident in these examples, the specific applications of accounting techniques for the purpose of 'accounting' and recording experimental practice are crucially under-investigated. This lack of analysis is connected to a more general underestimation of the role that technical experimentation played in narratives of the development of early modern experimentation.[32] Initially, this chapter put forward the working hypothesis that commercial accounting provided a model for practices of early modern experimental reporting, through its use in industrial and institutional contexts. If this was indeed the case, then particular

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[28] See the 'Computationes' and 'Rechnungen' described in Johann Joachim Becher, *Trifolium Becherianum Hollandicum* (Frankfurt, 1679) and *Experimentum novum ac curiosum* (Frankfurt, 1680).

[29] Deborah Harkness, 'Accounting for Science: How a Merchant Kept His Books in Elizabethan London', in: Margaret C. Jacob and Catherine Secretan (eds.), *The Self-Perception of Early Modern Capitalists* (Basingstoke, 2008), 215.

[30] Harkness, 'Accounting for Science', 222–23.

[31] Anke te Heesen, 'Accounting for the Natural World: Double-Entry Bookkeeping in the Field', in: Londa Schiebinger and Claudia Swan (eds.), *Colonial Botany: Science, Commerce, and Politics in the Early Modern World* (Philadelphia, 2005), 237–51. See especially the section on 'keeping accounts'.

[32] This is most clear in general presentations and encyclopaedia pieces. See for instance Peter Dear, 'The Meaning of Experience', *Cambridge History of Science*, vol. 3: Early Modern Science (Cambridge, 2006), 106–31.

attention should be paid to the role of early modern cost accounting, a genre which is naturally related to technical experimentation. A few features make cost accounting techniques distinctive within the history of experimental practices. A first important attribute is their quantitative character, derived from the commercial and industrial realms in order to assess and estimate manufacturing costs. A second, crucial characteristic is their inherently analytic quality. In order to evaluate costs, a specific process had to be examined and analysed by its constituent components (such as materials, instruments and by-products). In this way, cost assessments produced detailed, if idiosyncratic, records of technical experiments. It is then worth exploring the assertion that cost accounting reports paved the way for different, less inherently commercial forms of experimental reporting. The role of cost accounting in such an evolution should be investigated further.

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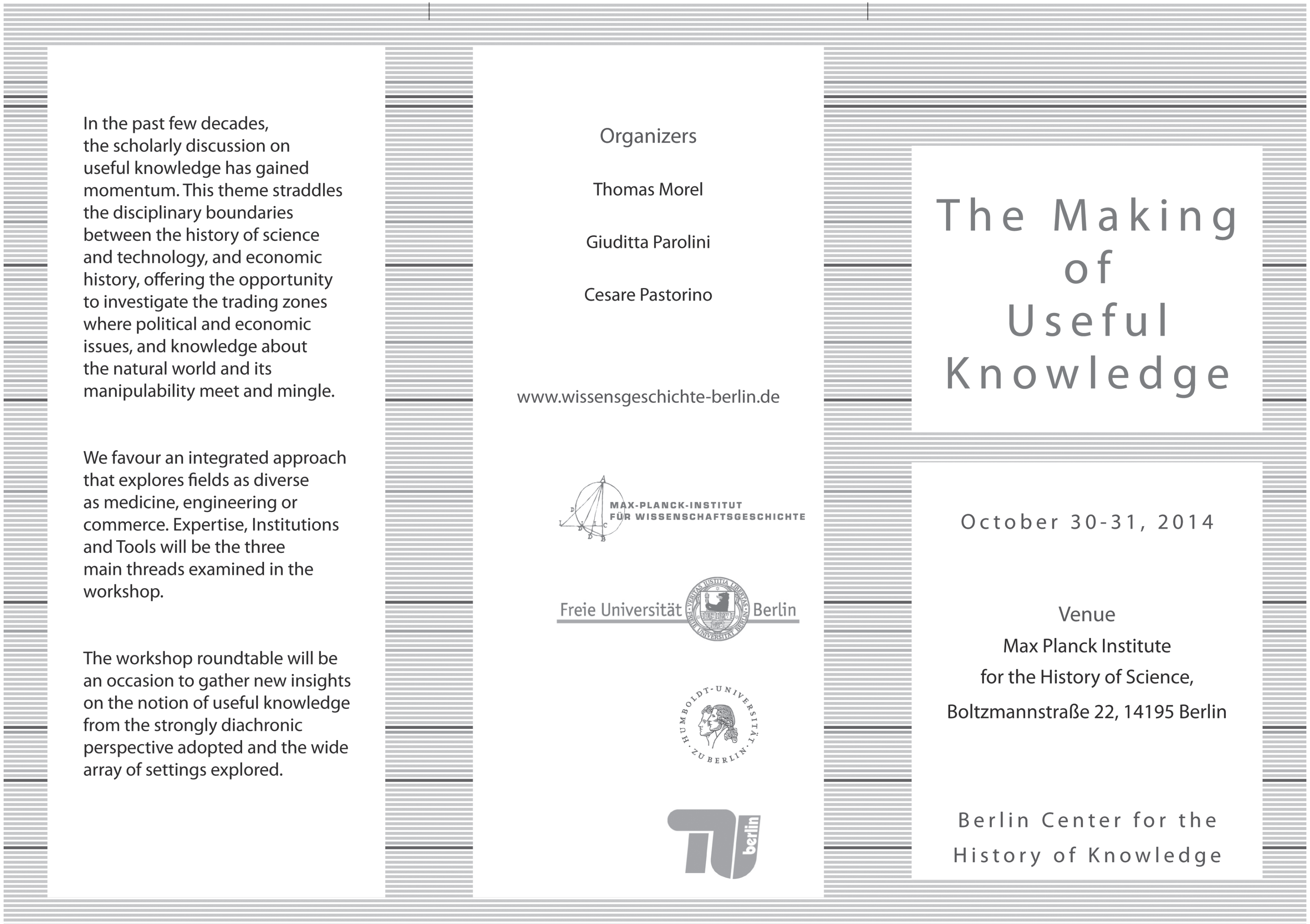

In the past few decades, the scholarly discussion on useful knowledge has gained momentum. This theme straddles the disciplinary boundaries between the history of science and technology, and economic history, offering the opportunity to investigate the trading zones where political and economic issues, and knowledge about the natural world and its manipulability meet and mingle.

We favour an integrated approach that explores fields as diverse as medicine, engineering or commerce. Expertise, Institutions and Tools will be the three main threads examined in the workshop.

The workshop roundtable will be an occasion to gather new insights on the notion of useful knowledge from the strongly diachronic perspective adopted and the wide array of settings explored.

Organizers

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The Making of Useful Knowledge

October 30-31, 2014

Venue
Max Planck Institute
for the History of Science,
Boltzmannstraße 22, 14195 Berlin

Berlin Center for the
History of Knowledge

Thursday, October 30

9:00-9:15 Welcome Coffee

9:15-9:30 Introduction

SESSION 1: EXPERTISE

Chair: Friedrich Steinle, *TU Berlin*

9:30-10:15 Simona Valeriani,
Victoria and Albert Museum, London
Objects and Spaces for the Production of Useful Knowledge in Early Modern Europe

10:15-11:00 Ursula Klein,
Max Planck Institute for the History of Science, Berlin
The 'Useful Sciences' in Prussia around 1800

11:00-11:15 Coffee Break

11:15-12:00 Cesare Pastorino,
TU Berlin/Berlin Center for the History of Knowledge
Reporting Useful Experiments: Cost Accounting and Early Modern Technical Experimentation

12:00-12:30 General Discussion

12:30-13:30 Lunch

Thursday, October 30

SESSION 2: INSTITUTIONS

Chair: Dagmar Schäfer,
Max Planck Institute for the History of Science Berlin

13:30-14:15 Jonathan Harwood,
University of Manchester
Useful Knowledge but for Whom? The Development of Appropriate Agricultural Technology in Southern Germany, 1890-1920

14:15-15:00 Thomas Morel,
TU Berlin/Berlin Center for the History of Knowledge
Usefulness and Practicability of Mathematics: The German Mining Academies in the 18th Century

15:00-15:30 Coffee Break

15:30-16:15 Karel Davids,
VU University, Amsterdam
Making 'Useful' Knowledge in the 18th Century: A Maritime Perspective

16:15-17:15 Roundtable chaired by Dagmar Schäfer,
Max Planck Institute for the History of Science Berlin

Friday, October 31

SESSION 3: TOOLS

Chair: Marcus Popplow, *TU Berlin*

9:30-10:15 Gerhard Rammer, *TU Berlin*
Practical Mathematics and the Waterwheels in the 18th Century

10:15-11:00 Stephen Johnston,
Museum for the History of Science, University Oxford
Utility, Commerce, Pleasure: London Scientific Instrument Workshops as Sites of Public Knowledge, 1550-1750

11:00-11:30 Coffee Break

11:30-12:15 Angela Creager,
Princeton University
Making Mutations Useful: The Development of In Vitro Tests for Carcinogens in the 1970s

12:15-13:00 Giuditta Parolini,
TU Berlin/Berlin Center for the History of Knowledge
Farming, Meteorology, and Field Experiments: Using Statistics to Improve Agricultural Practices

13:00-14:00 Lunch

14:00-15:00 General Discussion

15:00-16:00 Conclusions, Results and Prospects

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