Zinc Transfer from China to Europe via Trade, ca. 1600–1800

A Transnational Perspective

BY CHEN HAILIAN

Abstract
Previous studies of zinc in China and Europe have largely concentrated on issues of the origin of zinc in a specific place but have not addressed the connections and relationships produced and used between China and Europe because of zinc. This paper is the first attempt to approach the history of zinc transfer from China to Europe from a transnational perspective.[1] My narrative of this zinc transfer goes beyond a classical comparison of two trading patterns modelled on the major factors of transfer. Instead, by viewing trade as a vehicle for moving commodities and transmitting ideas, knowledge and technology, I interpret the transfer of zinc from China to Europe chronologically on two levels: both the physical movement or flow of zinc as an object or commodity that was being incorporated into producing a series of new goods, especially in such as imitating golden decorations; and the technology for producing the metal.

In order to examine both aspects, I discuss Chinese zinc and European inventions within their larger technological, economic, political, social and cultural contexts and address the following questions: why did the large-scale use of zinc emerge in China? How did Chinese zinc arrive in Europe and how was zinc adopted as a new raw material? Why and how was zinc discovered and produced in Europe?

As my findings suggest, the arrival of Chinese zinc in Europe a ballast item led to its adoption in the production of new goods in Europe, for instance being used to produce imitation gold ornaments and toys. This use of Chinese

1 Acknowledgements: I would like to thank the German Research Foundation (Deutsche Forschungsgemeinschaft) for supporting my zinc research project under project leader Prof. Hans Ulrich Vogel at the University of Tübingen, and the Organising Committee of the German Society for the History of Technology (Gesellschaft für Technikgeschichte) for inviting me to participate in their annual conference in 2011. I am truly indebted to Prof. George Souza for sharing his invaluable knowledge and insights and to Prof. Dagmar Schäfer for calling my attention towards a transnational approach and for her helpful comments on the earlier drafts of this article, particularly with improving my English. Thanks are also due to Dr. Marcus Popplow, Prof. Constantin Canavas and the anonymous reviewers for their invaluable suggestions for revision and improvement.

zinc to create new consumer products in Europe then stimulated a race for ways to devise European zinc production, although this took a long time to master, and led to competition between inventors, in commerce and with traditional uses of other metals. Equally significantly, connection and exchange via trade within European countries as well as China facilitated the spread of new goods and led to innovative uses of zinc in Europe.

Überblick

Bereits vorliegende Studien über Zink in China und Europa haben sich weitgehend auf die Frage der Herkunft des Metalls konzentriert. Bislang unberücksichtigt blieben die durch den Zink-Transfer entstandenen Verbindungen und gegenseitigen Beziehungen zwischen China und Europa. Dieser Artikel versucht erstmals, die Geschichte des Zink-Transfers von China nach Europa aus transnationaler Perspektive zu betrachten. Ausgehend von der Annahme, dass durch die Handelsbeziehungen nicht nur Güter, sondern auch Ideen, Wissen und Technologien ausgetauscht wurden, wird der Transfer von Zink aus China nach Europa chronologisch auf zwei Ebenen analysiert: Zum einen wird der Transport von Zink als Gegenstand bzw. Rohstoff zur Produktion neuer Güter (insbesondere solcher, die goldene Dekorationen imitierten), zum anderen das Verfahren zur Gewinnung des Metalls betrachtet.

Im Anschluss werden das chinesische Zink und damit verbundene europäische Innovationen in einem breiteren technologischen, ökonomischen, politischen, sozialen und kulturellen Kontext auf folgende Fragen hin untersucht: Warum begann die Verwendung von Zink in großem Maßstab in China? Wie kam chinesisches Zink nach Europa und wie wurde es als neuer Rohstoff verwendet? Warum und mittels welcher Verfahren wurde Zink in Europa entdeckt und gewonnen?

Die Ergebnisse legen den Schluss nahe, dass durch das chinesische Zink, das als Ballastgut in Handelsschiffen nach Europa kam, die Herstellung neuer Waren wie beispielsweise Imitate von Goldornamenten und Spielzeug angeregt wurde. Diese Verwendung des chinesischen Zinks für neue Konsumgüter hatte zur Folge, dass man in Europa bald nach einer Methode zur Zinkproduktion suchte. Bis zur Beherrschung der Zinkherstellung war es jedoch ein langer und mühsamer Weg, der vom Wettbewerb zwischen Erfindern und Händlern geprägt war. Festzuhalten bleibt, dass die Handelsverbindungen und der Austausch zwischen den europäischen Ländern und China die Verbreitung neuer Waren erleichterten und zu innovativen Nutzungen von Zink in Europa führten.

Introduction

Zinc is a conventional non-ferrous metal which is widely used today for industrial purposes. Prior to the nineteenth century, zinc was always associated with making copper-based alloys such as brass. Zinc does not occur naturally in its metallic state, however, the element zinc (Zn) is commonly found in six ores in the earth's crust,[2] and primarily in ores, such as sphalerite or blende, which contain zinc sulphide (ZnS). Calamine—the ore containing zinc carbonate ($ZnCO_3$) which is usually found at a very shallow depth in the earth—was widely exploited and used to obtain the metal before the nineteenth century, particularly in China, possibly due to its ease of access and the technical limitations of the contemporary smelting method.[3]

The origins of zinc are mysterious. It is not clear when, where, how or by whom metallic zinc first was obtained from zinc-bearing ores. While Johann Beckmann suggested in around 1800 that zinc was the eighth metal to be produced and used by humankind, many scholars were puzzled about how to produce, or even to identify, this metal.[4] This was because the temperature needed to reduce zinc-bearing ore is at least 1000°C, while the boiling or evaporation point for zinc is about 907°C, which means that the reduced zinc would escape unless professionally captured.[5] Even if zinc was accidentally obtained as a by-product of other production, it was difficult to recognize and hence to be utilized as a metal.

Eastern civilisations were the first to employ a distillation technique in the zinc smelting process, which was a major technical breakthrough. Considerable historical and archaeological research has been directed towards discovering the "earliest" zinc, and various indications have been found. For instance, P.T. Craddock suggests that India had solved the distilling problem as early as the seventh century.[6] Chinese debates mainly centred on dating this development, suggesting that China had mastered the smelting technology needed to produce zinc by the 1580s (or, at least, no later than 1600).[7]

Cultures in the Western hemisphere discovered and isolated zinc from ores much later. According to Ingalls, "in the sixteenth century zinc was brought to Europe from China and the East Indies under the name of *tutanego*

2 1) Sphalerite (blende) (ZnS); 2) Zincite (ZnO); 3) Franklinite [(Fe, Zn, Mn) $(Fe, Mn)_2O_4$]; 4) Smithsonite [calamine] ($ZnCO_3$); 5) Hydrozincite [$Zn_5(CO_3)_2(OH)_6$ or Zn_2SiO_4] and 6) Hemimorphite [$Zn_4(OH)_2Si_2O_7 H_2O$). See V. Anthony Cammarota, Jr., "Production and Uses of Zinc," in *Zinc in the Environment, Part I: Ecological Cycling*, ed. Jerome O. Nriagu (New York, 1980), 8.

3 Cf. Hailian Chen and George Bryan Souza, "Zinc in Ming and Early Qing China, ca. 1400 – ca. 1680s," in *Sino-Japanese Trade, Commodity Chains, Regional Economies and the Environment in China and East Asia*, ed. Ulrich Theobald and Hans-Ulrich Vogel (Leiden, forthcoming).

4 The seven metals are: copper, iron, gold, silver, lead, quicksilver/mercury and tin. See Johann Beckmann, *Beiträge zur Geschichte der Erfindungen* (original published between 1786–1805), trans. William Johnston, english title: *A History of Inventions, Discoveries, and Origins*, 4th ed., vol. 2 (London, 1846), 31.

5 Joan Day, "Copper, Zinc and Brass Production," in *The Industrial Revolution in Metals*, ed. Joan Day and R. F. Tylecote (London, 1991), 179–180.

6 P. T. Craddock et al., "Zinc in India," in *2000 Years of Zinc and Brass*, ed. P. T. Craddock (London, 1990), 28.

7 For more on this debate, refer to Chen and Souza, "Zinc in Ming and Early Qing China".

[*tutenag*]."[8] During the seventeenth and eighteenth centuries, the East India Company shipped a commodity named *tutenag*, or *spelter* from the East to the West which researchers have identified as metallic zinc. Torbern Bergman (1735-1784), a Swedish chemist and mineralogist, reported that an Englishman travelling to China had learnt the "secret" of zinc distillation *per descensum* in the 1730s or so, but deliberately concealed the art.[9] It was not until the 1780s that innovations in zinc production occurred in European countries such as Britain, Germany and Belgium. By the middle of the nineteenth century, the zinc industry "began to be established on a sure footing in Europe".[10]

There is less academic agreement regarding the discovery and dating of the earliest zinc in Europe. Issues of multiple origins and inventions notwithstanding, Chinese zinc (and/or Indian zinc)[11] substantially influenced the receipt and processing of zinc in Europe. In spite of a large existing body of literature on the analysis of zinc's origins in China, India and Europe, very little attention has been paid to the early production of zinc in China and Europe in a global context, especially the impact of imported Chinese zinc upon European production. In other words, little is known about the political, economic, social and cultural contexts of historical zinc production and usage. Metallurgists, chemists, artisans or merchants referred to zinc in diverse ways, substantially obscuring its origin, in both the East and the West. Historical studies have also frequently taken a philological approach to their research into zinc origin and usage and thus concentrated on one linguistic group. This has resulted in the findings being isolated from each other on account of their geographical context. For example, European and British narratives of zinc in Britain, more often than not, include only a few lines of description about Chinese (and/or Indian) zinc, whereas Chinese and Western studies of Chinese (and/or Indian) zinc seldom refer to the history of the metal in the West. Generally though, from the eighteenth century onwards, Western language literature on zinc suggests a "transfer" from the East to the West. The results of my preliminary research into the history of zinc industries, particularly in China in the early modern period (ca. 1500–1800), reveal the possibility of examining this zinc transfer process by viewing the zinc trade as a means of moving commodities and transmitting ideas, knowledge and technology around the world.[12]

8 Walter Renton Ingalls, *Production and Properties of Zinc* (New York and London: The Engineering and Mining Journal, 1902), 2.

9 Torbern Bergman, *Physical and Chemical Essays*, trans. Edmund Cullen, vol. 2 (London, 1784), 311–348.

10 Ernest A. Smith, *The Zinc Industry* (London and New York, 1918), 14.

11 In India, the scale of zinc production before the nineteenth century is not clear. The country was able to produce zinc quite early. Much literature suggests that zinc was carried by the East India Company's ships that came from China.

12 My recent doctoral research focuses on zinc's commodity chain in China in the early modern period.

From the perspective of viewing trade as a vehicle for moving zinc from China to Europe this paper interprets the transfer of zinc chronologically on two levels: 1) the physical movement or flow of zinc as an object or commodity (i.e. the metal as a raw material) that was being incorporated into producing a series of new goods, especially in imitating golden decorations, and 2) the basis for developing technology to produce the metal.

The first level of transfer is a basic reflection on cross-cultural commercial exchanges and communications in the early modern period. It relates closely to knowledge and information sharing and transfer regarding metal products and consumer markets among various material cultures. As my analysis will show, the knowledge and technology needed to produce zinc had been key factors as well as the demand for the metal which stimulated the emergence of zinc in China. However, as a raw metal material, the commodity of zinc could not be directly consumed like other goods (such as tea and porcelain) in foreign cultures, because the metallurgical knowledge and practices were determining factors of using or consuming the metal. Not surprisingly, this Chinese (and/or Indian) zinc commodity was treated as an unfamiliar sort of metal material in Europe for centuries, so it is worth asking how and why zinc was traded to European merchants and adopted into Western material culture. In this light, the cross-cultural zinc trade and its role in connecting various traditions through the flow of commodities are central to our understanding of knowledge and information transfer in the early modern world.

The second level of transfer is conceptualised in the wider domain of technology transfer, by asking why and how zinc in Europe was discovered and produced. It is important to determine if there was a genuine technological transfer from China or the East to Europe, since attempts had been made by the Europeans to produce zinc metal independently. Therefore, there is a need to further clarify the concept of technology transfer. However, it is difficult to find one commonly accepted definition of technology, which affects our discussion of "technology transfer." As broadly defined, technology consists of both "hardware" (things which are made, e.g. material artefacts and tools) and "software" (how things are made, e.g. skills, practices, know-how or knowledge, as well as management of the production processes).[13] The concept of technology transfer has also been interpreted in diverse ways by different academic disciplines. As the basic meaning of the word transfer indicates, "to move from one place to another,"[14] the transfer of technology emphasizes the spatial flows of technology from one region to another, and

13 On definitions of technology, see Arnulf Grübler, *Technology and Global Change* (Cambridge, 2003), 19–20; Andrew Murphie and John Potts, *Culture and Technology* (New York, 2003), 3–6; Ernes Braun, *Technology in Context: Technology Assessment for Managers* (London, 1998), 8–13.

14 http://oxforddictionaries.com/definition/english/transfer?q=transfer.

in particular from one country to another.[15] In broad terms of the transfer of technology, the flow of zinc from China to Europe consisted of knowledge and information flows on metallurgical uses of the metal, which in essence was already a technological transfer process on the first level of transfer. For clarity, I use "zinc transfer" as a general term to describe the whole process, including both the physical flow of the metal and its technological aspects, and I explore in detail how attempts at technological transfer on the second level encountered obstacles and failure.

Methodologically, in this paper I develop a transnational perspective on the history of transferring zinc from China to Europe during the period ca. 1600–1800. Transnational approaches have received increasing attention, for instance, in American, European and Australian historical scholarship, and there are a number of definitions of transnational history. Ann Curthoys and Marilyn Lake, for instance, define transnational history as a field that "seeks to understand ideas, things, people, and practices which have crossed national boundaries."[16] Although there are disputes about the benefits and limitations of a transnational approach, the emergence of transnational processes unquestionably provides a broader framework of analysis. Erik van der Vleuten points out that a transnational angle on the history of technology enables researchers to "spotlight and investigate important topics previously neglected, underestimated, or inadequately conceptualized" and "furnish a new and more accurate perspective on existing themes in historical scholarship, a novel understanding not only of global or regional integration issues, but also of national and local history."[17] The transfer of zinc involved China and several European countries, especially in Western Europe. Connections and exchanges via trade and the migration of craftsmen,[18] for example, were particularly important in the transfer processes. Therefore, in writing about the transfer history of zinc from a transnational perspective, I attempt to gain a new understanding of the global and local dimension of zinc—as a commodity and a representative of a technical process.

15 Maja Naur, "Transfer of Technology—A Structural Analysis," *Journal of Peace Research* 17, No. 3 (1980): 247–259; Robert P. Morgan, "Transfer of Technology," *Proceedings of the Academy of Political Science* 30, No. 4 (1972): 141–152.

16 Ann Curthoys and Marilyn Lake, "Introduction," in *Connected Worlds: History in Transnational Perspective*, ed. Ann Curthoys and Marilyn Lake (Canberra, 2005), 5.

17 Erik van der Vleuten, "Toward a Transnational History of Technology: Meanings, Promises, Pitfalls," *Technology and Culture* 49, No. 4 (2008): 974–994.

18 For a discussion of the role that the migration of craftsmen played in the transfer of know-how and technology, see the example of "Gesellenwanderung" discussed in Reinhold Reith, "Know-How, Technologietransfer und die Arcana Artis im Mitteleuropa der Frühen Neuzeit," *Early Science and Medicine* 10, No. 3 (2005): 349–377. For a critical comment on the role of migration in the transfer of knowledge, see Rainer S. Elkar, "Lernen durch Wandern? Einige kritische Anmerkungen zum Thema ‚Wissenstransfer durch Migration'" in *Handwerk in Europa: Vom Spätmittelalter bis zur Frühen Neuzeit*, ed. Knut Schulz and Elisabeth Müller-Luckner (München, 1999), 213–232.

My narrative of the zinc transfer goes beyond a bilateral comparison of two patterns modelled on some major factors of transfer, such as technological, organisational and environmental characteristics in China and Europe. Similarities and differences between factors in the transfer process between China and Europe may be demonstrated by establishing a zinc transfer model, but it is more significant to connect those factors and to analyse any changes arising or relationships developing over time and space. In other words, my goal is to examine the early history of zinc in both China and Europe, to identify the development path(s) of zinc (proto-)industries in China and Europe in their technological, economic, political, social and cultural contexts and to explore what part the transfer played in connecting the locations involved.

The paper begins with an overview of the use of zinc and the increasing demand for zinc in China. The second section then examines the transfer on the first level, i.e. the reception of Chinese zinc as a commodity that enabled new goods to be manufactured in the West. The third section discusses the transfer on the second level—technology transfer (including the transmission of ideas and knowledge in a broader definition)—and analyses the influential factors that made the invention of zinc production in Europe both necessary and possible. The last section examines European inventions in the post-invention phase—including obstacles and innovations—and explores the interrelation between Chinese and English zinc, including competition between imports and domestically-produced zinc.

Zinc: an emerging "useless" metal and its increasing early use in China

As noted above, the method of zinc extraction was discovered rather late and so it was one of the later metals to be produced and used. Techniques for producing metallic zinc emerged in close relationship to earlier uses of zinc alloys and ore. Prior to the nineteenth century, metallic zinc was found mostly, if not only, in the manufacture of alloys, along with copper. One striking example of this is brass (whose primary base metals are copper and zinc). Chinese and German sources literally named it *yellow copper*,[19] as it appears gold-like, with a concentration of 30–50% of zinc. Favoured as a decorative alloy, brass is superior to the older bronze alloy (whose primary base metals are copper and tin; or, occasionally, copper and lead), because bronze is friable and breaks easily, whereas brass can not only be cast, but also wrought.[20] In addition, its brilliant gold-like colour and polished surface make brass more attractive than bronze.[21] Zinc can also be found in another alloy called *paktong*

19 Chinese: *Huangtong*, and German: *Gelbkupfer*, see Hermann P. Lockner, *Messing: Ein Handbuch über Messinggerät des 15.–17. Jahrhunderts* (München, 1982), 10–11.

20 Rupert Gentle and Rachael Feild, *English Domestic Brass, 1680–1810, and the History of its Origins* (London, 1975), 2.

21 Lockner, *Messing*, 9.

or white copper (whose primary base metals are copper, zinc and nickel) in China, which is named according to its silver-like appearance.[22]

Both Eastern and Western civilisations were familiar with using calamine, which is mentioned in Western literature such as *Lapis Calaminaris*. It is an ore containing zinc (or zinc carbonate) which was employed in smelting zinc prior to the early nineteenth century. Calamine was used before metallic zinc, and was used together with copper to make brass, known as cementation brass in both Eastern and Western civilisations. Early brass production in the East and the West probably dated back to the beginning of the Christian era.[23] By the beginning of the second millennium, brass had become a popular material in China for statues or bells, especially in Buddhist temples and palace decorations, where it was used as a substitute for gilt copper. The brass made in China at this time contained 10–20% zinc.[24] By the fourteenth century, several Western countries, such as Austria, Germany and France, had developed flourishing brass industries, but brass was not produced in Britain until the end of the sixteenth century. Brass was used to make household utensils and ornaments, or the numerous monuments which were placed in cathedrals and churches in Europe. Famous brass foundries had been established earlier on in Dinant on the Meuse near Liège, and later at Aachen, Stolberg and Nuremberg in Germany. In continental Europe, brass production centres endured throughout the seventeenth and eighteenth centuries, and the British brass industry grew quickly after the late seventeenth century.[25]

On the face of it, metallic zinc was not necessarily extracted from its ores, since the zinc element remained in the alloy form (especially in brass), no matter how the zinc-bearing ore or metal was used. Official documents of Qing China (1644–1911) from the early eighteenth century reveal this insight when reporting that zinc was a "useless" metal except for making brass and coins.[26] The reason why the Qing governors considered zinc to be useless was because there was a ban on private trade of copper and because copper alloys were not used much in the private sphere. In many earlier dynasties before the Qing, such as the Tang, Song and Ming, governors had prohibited

22 Keith Pinn, *Paktong: The Chinese Alloy in Europe, 1680–1820* (Woodbridge, 1999).

23 Joseph Needham and Gwei-Djen Lu, *Science and Civilisation in China,* vol. 5 *Chemistry and Chemical Technology*, part 2 *Spagyrical Discovery and Invention: Magisteries of Gold and Immortality* (Cambridge, 1974), 195–199. For an analysis of calamine and its uses, see Chen and Souza, "Zinc in Ming and Early Qing China".

24 Ibid.

25 Gentle and Feild, *English Domestic Brass*, 1–3. According to Anton Becker, "*Die Stolberger Messingindustrie und ihre Entwicklung*" (PhD Diss., Rheinische Friedrich-Wilhelm-Universität zu Bonn, 1913), Stolberg was already an important brass manufacturing centre by around 1500, although it was not mentioned in *English Domestic Brass.*

26 Memorial by Chen Hongmou (1741), in *Gongzhong dang zhupi zouzhe, Caizheng lei* (Palace Memorials with Imperial Vermilion Prescripts: Financial Administration Category), document number 1232–007, kept in the Zhongguo Diyi lishi dang'an guan (the First Historical Archives of China), in Beijing.

the private trade of copper and copper alloys (such as bronze and brass), in order to monopolize the copper sources and to supply sufficient copper for the state minting of bronze coins (and brass coins in the late Ming period). This ban on the private trade of copper and copper alloys still continued in the early Qing period. Therefore, the Qing governors at that time agreed that abundant zinc was available for state minting, and that there was no need to worry about a shortage of the metal, because zinc was only useful for making brass and brass coins.[27] It was in the late Ming period that brass coins began to be issued by the state, in order to solve the fiscal crisis in the economy which was partly caused by the counterfeiting of bronze coins. Followed the Ming era, the Qing rulers continued to issue brass coins. From the 1620s until the end of the nineteenth century, late Ming and Qing Empires developed their zinc industries to mint brass coins in order to stabilise the Chinese economy. Thus, zinc became a primary minting metal, fuelled by the monetary policy of both the late Ming and Qing dynasties.[28] Two fundamental reasons why these states chose to use metallic zinc, instead of calamine, as their minting material, and shifted to producing brass coins were transport costs and quality control.

In the mid-sixteenth century, the mints of Yunnan province in south-west China used calamine to mint brass coins (as a substitute for bronze coins) (see Fig. 1). The Beijing mints also intended to mint coins using calamine and copper. However, the cost of transporting calamine over a distance of some 4,000 km from the mines in the south-west to Beijing in the north, was prohibitively high, hindering the process and inducing officials to make efforts to find and open new calamine mines in the north of China.[29]

The second issue was, quality control. Technically speaking, cementation brass smelted from calamine and copper cannot really contain more than 30% of zinc element.[30] However, it is impossible to make the alloy with consistent quantities of zinc and copper because the proportion of zinc in calamine varies. A numismatic analysis of late Ming Chinese coins shows variable proportions of the zinc element, and this irregularity is explained by the use of calamine instead of metallic zinc in minting. Therefore, it was difficult for officials to assay the components and to evaluate the quality of these coins. The relatively constant (although not identical) zinc component in coins from the 1620s onward suggests the exclusive use of metallic zinc in minting. From the late seventeenth century until the mid-nineteenth century, the zinc used in most Chinese mints, including the largest Beijing mints, was smelted from calamine from the Guizhou province in the remote south-west of China (see Fig. 1). To

27 Memorial by Chen Hongmou (1741).

28 See Chen and Souza, "Zinc in Ming and Early Qing China," for Chinese approaches to brass and bronze and their role in economic and political contexts.

29 Ibid.

30 Lockner, *Messing*, 9.

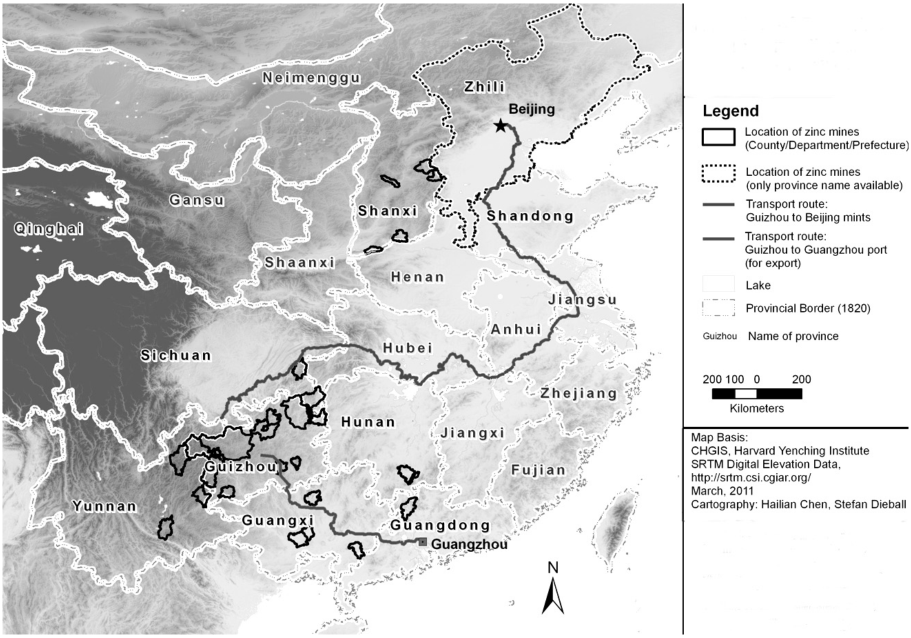

Fig. 1: Location of Zinc Mines in Qing China, c. 1700–1835. Source: Hailian Chen and Stefan Dieball

obtain one part of metallic zinc, about five parts of calamine were required.[31] So transporting metallic zinc instead of calamine was a way to reduce costs.

We can hence see that, while the technology for smelting zinc had existed in China well before the 1580s, the mints' demand for zinc grew exponentially at that time because the governors' monetary policy turned a "useless" metal into one of two key raw materials (along with copper) within a large-scale production process. Based upon my survey of archival sources, Qing China between 1720–1820 procured an average of 5,000 (imperial or long) tons[32] of zinc per annum with peaks of output exceeding 12,000 tons. Most of this, about 2,600–4,600 tons per annum, was consumed in Chinese mints producing brass coins.[33] At the same time, metallic zinc started to be substituted for

31 Routine Memorials of the Qing Dynasty kept in the Zhongguo Diyi lishi dang'an guan (the First Historical Archives of China), in Beijing, document numbers: 02–01–04–15812–004 and 02–01–04–16225–010; *Ming Qing Dang'an* (The Archives of Ming and Qing), edited by Zhang Weiren et al. (Taibei: Zhongyang yanjiuyuan lishi yuyan yanjiusuo, 1987–1995), A151–115.

32 For the convenience of converting historical weight records, in particular in the European context, the imperial ton (1 imperial ton = 1016 kg), i.e. a long ton, is adopted as a unit of weight in this article.

33 The statistics are based upon my survey of Routine Memorials of the Qing Dynasty and were presented at the international workshop of the research group *Monies, Markets, and*

calamine in everyday brass objects in China. Brass became more popular and was used in household utensils and palace construction, for statue casting, bell casting or decorations. Qing China also exported zinc to Japan, South-East and South Asia (e.g. India[34]), and Europe.[35] As Souza suggests, there is a wealth of information about Chinese zinc in Western trade records that has not yet been studied. In the following section, I attempt to explore the processes of transferring zinc to Europe.

Chinese zinc in Europe: terminological confusion and new methods of manufacture

As mentioned earlier, zinc transfer from China to Europe can be chronologically distinguished into two different periods spanning over two centuries. These two periods are also characterized by substantial divergent implications: in phase one new goods were imported, whereas the second era is marked by attempts to produce the goods independently. While this paper considers both the transfer of the metal itself as a commodity and the transfer of the technology required for processing the metal, this section focuses, first, on the reception of Chinese zinc—a commodity (i.e. raw material) that resulted in the manufacturing of new goods in the West.

How did Chinese zinc arrive in Europe? Why was the foreign metal adopted as a raw material in Europe since, probably, artisans or metalworkers in the West had no previous knowledge of zinc? Those are difficult questions to solve, due to a lack of sufficient information. In contrast to other trade commodities such as tea, silk or porcelain, which could be consumed almost directly in a foreign culture, zinc—a raw metal material—had to be re-processed along with other metals (such as copper) to create final consumable products. Therefore, the knowledge of metallurgical practices regarding zinc was particularly important, in order for the commodity to become turned into consumer goods. Earlier interactions between the East and the West had created various channels of communication, including the diffusion or transmission of knowledge. Knowledge about other parts of the world, whether held by Europeans or Asians, had been increasing over time, especially in the age of global integration from ca. 1400 onwards. Trade acted as one extremely important way to strengthen commercial exchanges and communications between

Finance in China and East Asia, 1600–1900 (MMF) in April 2010, at Tuebingen University, Germany.

34 Trade records suggest that Chinese zinc went into Indian markets, and that possibly most, if not all, of the zinc imported by Europe was originally from China.

35 George Bryan Souza, "Ballast Goods: Chinese Maritime Trade in Zinc and Sugar in the Seventeenth and Eighteenth Centuries," in *Emporia, Commodities and Entrepreneurs in Asian Maritime Trade, c. 1400–1750*, ed. Roderich Ptak and Dietmar Rothermund (Stuttgart, 1991), 291–315.

different countries.[36] The Indian Ocean and the South China Sea witnessed the intensive maritime activities and trade between Asian and European countries in the early modern period. Merchants, principally European merchants, were cross-cultural brokers,[37] being mobile and intensely involved in the geographical expansion of trade (including inter-Asian and Eurasian trade). They had access to both Chinese and European metal markets,[38] so probably observed the use of zinc in China and found a way to start trading zinc as a commodity. Chinese zinc occasionally arrived in Europe in the early seventeenth century as ballast goods in Portuguese ships travelling from Asia;[39] In addition, other European companies from The Netherlands, Sweden or Britain loaded zinc at the coastal port of Guangzhou (see Fig. 1) where zinc was cheap and easily available and then journeyed home via Japan, India, and the African coast.[40] The official documents refer to zinc by various names, like contemporary Western scholarly literature of that time. Terms such as *tutenag* (with many similar spellings, such as *tutentag*, *tutanego*, *tutancg* and *tuttanego*), or *spelter* (or *speautre*, *spiauter*, *speauter*, *spialter*, *speltrum*, etc.), however, were mainly used by merchants and importers.[41] The exact nature of the "metal" or commodity is also hard to define, because scholars of that and earlier times had increasingly confused the issue in their attempts to solve it.

Assumptions about the components of metals or metallurgical objects before the mid-eighteenth century differ substantially from our modern perspective. The physical similarities of many kinds of alloys or metals meant that appearance alone could not be used to identify a single metal object. For example, tin, lead and zinc, together or mingled with copper, can be manufactured into several alloys that look very similar to the naked eye. Historical records aimed to differentiate between them, describing the whitish zinc (under the names of *tutenag* and *spelter*) in many ways, likening it to tin and lead, as "a sort of tin" (in 1699), or "a metal unknown in Europe, Africa or America and peculiar to China only […] between tin and lead" (in 1728), or "a metal very like tin" (in 1751).[42]

36 Kevin Reilly, "The Making of Market Conventions," in *The World That Trade Created: Society, Culture, and the World Economy, 1400–the Present*, ed. Kenneth Pomeranz and Steven Topik (Armonk, New York, 1999), 41–43.

37 Philip D. Curtin, *Cross-Cultural Trade in World History* (Cambridge and New York, 1984), 11–12.

38 George Bryan Souza, *The Survival of Empire: Portuguese Trade and Society in China and the South China Sea, 1630–1754* (Cambridge, 1986), 1–7.

39 Johann Beckmann, *Beiträge zur Geschichte der Erfindungen*, vol. 3 (Leipzig, 1791), 408–409.

40 Souza, "Ballast Goods", 293–298.

41 Beckmann, *Beiträge*, 440–441; Bergman, *Physical and Chemical Essays*, 311.

42 Alfred Bonnin, *Tutenag and Paktong; with Notes on other Alloys in Domestic Use during the 18th Century* (Oxford, 1924), 4–7.

Chinese zinc (i.e. *tutenag* or *spelter*) further confused the Western view of metals because some people likened it to *paktong* or *white copper*. Alfred Bonnin, in his book *Tutenag and Paktong*, quotes from Western records to examine zinc and white copper in historical contexts.[43] A degree of uncertainty remains over whether or not the commodity shipped to the West was actually zinc, as the name was mistaken or misused in different contexts. However, examples of zinc have been identified: ingots salvaged in around 1872 in Gothenburg in Sweden have been proven to have a 98.99% zinc purity, and they were in a vessel consigned from Guangzhou to Sweden in 1745.[44]

Despite the confusion and chaos arising from encounters with Chinese zinc in the West, metalworks, especially brass foundries, adopted the new "metal" into their different metallurgical procedures without being aware of the fact that the commodity was a metal smelted from calamine. Interestingly, the zinc was also combined with copper. In this respect, the part that merchants played in this cross-cultural trade can shed light on our understanding of the transfer puzzle. Merchants' choices of commodity compositions for long-distance trade and transport were constrained by the characteristics of individual commodities, for example, whether they were categorised as "rich" or "coarse" goods, having a high value or high volume, being perishable or indestructible. Zinc was one of the preferred low-cost ballast goods used by the East India Company. Moreover, changing trends in consumer taste, along with the emergence of a consumer society (or consuming revolution)[45] in the European economies and societies from 1600 created new fashions or demands for luxury or exotic goods from the Orient, such as textiles, beverages (e.g. coffee and tea) and porcelain.[46] The foreign zinc which became a staple commodity in European markets was ideally tailored for a specific taste in metalware that emerged in the period of globalisation. It is very unlikely that merchants transferring the raw metal material from China to the West would have had much know-how about the practical metallurgical process of using zinc, but they would have become acquainted with the market potential of zinc, for example, selling zinc to brass foundries. The information and knowledge about using zinc which the merchants shared with European artisans or craftsmen directly oriented local

43 Bonnin, *Tutenag and Paktong*.

44 Needham and Lu, *Science and Civilisation in China,* vol. 5, part 2, 212.

45 Wolfgang König, *Kleine Geschichte der Konsumgesellschaft: Konsum als Lebensform der Moderne* (Stuttgart, 2008), 22–26.

46 K.N. Chaudburi, *The Trading World of Asia and the English East India Company, 1660–1760* (Cambridge, first published 1978, paperback edition 2006), 15, 204–206; Beverly Lemire and Giorgio Riello, "East & West: Textiles and Fashion in Early Modern Europe," *Journal of Social History* 41, No. 4 (2008): 887–916; Robert Batchelor, "On the Movement of Porcelains: Rethinking the Birth of the Consumer Society as Interactions of Exchange Networks, China and Britain, 1600–1750," in *Consuming Cultures, Global Perspectives: Historical Trajectories, Transnational Exchanges*, ed. John Brewer and Frank Trentmann (Oxford and New York, 2006), 95–121.

practices of consuming the zinc commodity in metalworks. Without doubt, the metallurgical tradition of making cementation brass in Europe facilitated the relatively easy technical adoption of this foreign metal, although the nature of zinc commodity as a metal was not fully understood.

Under the name *spelter*, the official documents mention one use of zinc mixing it with copper to make *cement* or *solder*, which was harder and cheaper than that made from silver and brass.[47] They also recorded that metallic zinc[48] was used in the manufacture of gilding metals, such as *tombac*, *Mannheim gold* or *Dutch gold*, *similor*, *tinsel*, *Prince Rupert's metal* (or *Prince's metal*), or *Pinchbeck*, all of which consist of zinc mixed with different proportions of copper.[49] The more zinc is used, the paler the alloy appears, and if less zinc is used, the alloy appears reddish—close to the colour of copper.[50] Frederic C. Gren described the alloy's colour changes from palest to reddest in the following order: *Prince's metal*, *Pinchbeck*, *tombac*, *similor*.

Prince's metal was obtained by smelting five or six parts of copper with one part zinc, and was reportedly invented by Prince Rupert (1619–1682), an English Admiral. *Prince's metal* was sometimes also called *Rupert's metal*, or *bath metal*.[51] Prince Rupert's early stay in The Netherlands and an interest in metallurgy acquired in Bristol, where brass was commonly traded, might have stimulated his discovery of the new fashionable material, although he kept the production technique secret.[52] J. A. Cramer, in *Elements of the Art of Assaying Metals* (published in 1741), noted that *Prince's metal* or the famous *bath metal*, "resembling gold to the eye," "became a more modern metal at present, in great use for cane-heads, buckles, and other toys."[53] Having similar components to *Prince's metal*, *Pinchbeck* bears the name of its inventor Christopher Pinchbeck (c. 1670–1732), an English clock-maker and toy-maker; and was used to make imitation gold watches[54] and inferior jewellery.[55] *Dutch gold* is recorded as "copper-leaf coloured by the fumes of zinc. It is much cheaper than true leaf-gold, and is very useful where large quantities

47 John Webster, *Metallographia, or, A History of Metals* (1671), 399; John T. Desaguliers, *A Course of Experimental Philosophy*, vol. 2 (1744), 366, 467.

48 Joan Day, *Bristol Brass: A History of the Industry* (Newton Abbot, Devon, 1973), 123.

49 William Nicholson, *The British Encyclopedia, or Dictionary of Arts and Sciences*, vol. 2 (1809); Frederic Charles Gren, *Principles of Modern Chemistry*, vol. 1 (1800), 383–384.

50 Lockner, *Messing*, 12–13.

51 Johann A. Cramer, *Elements of the Art of Assaying Metals* (London, 1741), 25, 166.

52 Gentle and Feild, *English Domestic Brass*, 22.

53 Cramer, *Elements*, 166.

54 Houghton Mifflin Company, *The Houghton Mifflin Dictionary of Biography* (Boston, 2003), 1210; http://www.britannica.com/EBchecked/topic/512900/Prince-Rupert; also see Bonnin, *Tutenag and Paktong*, 85.

55 Colin MacKenzie, *One Thousand Experiments in Chemistry: With Illustrations of Natural Phenomena and Practical Observations on Manufacturing and Chemical Processes* (London, 1821), 2.

of gilding are wanted."[56] According to commercial handbooks from around 1800, the name *Dutch gold* (or *Dutch leaf*, *Dutch metal*) reflects its origin from The Netherlands, where the product was abundant. Similarly, the designation of *Mannheim gold* is derived from its place of manufacture—Mannheim (a German town), where vast quantities of the product were manufactured.[57] *Similor* was suggested as a different name for *Mannheim gold* or *Dutch gold*,[58] and in essence it resembled *Pinchbeck*,[59] which was "used in England for philosophical purposes, for gilding the leaves, etc. of low-priced books, for coarse gilding of picture-frames, for covering gingerbread, cockades, etc."[60]

European books provided background information on the use of Chinese zinc, explaining who could use it, when, where and for which purposes. Metallic zinc was used to make new alloys, based upon instructions for the precise processing of alloys. The new alloys emerged in Europe in the mid-seventeenth century, when China began to mine and produce zinc on a large scale. As these examples show, before the 1730s, zinc was used in the West to create new goods for the European markets, which ushered in a new consumer culture. The main appeal of zinc was that it could be used to give a golden shine to metals used in making toys, small articles such as buttons or buckles and less expensive kinds of jewellery.[61]

So, when sources mention the Dutch East India Company's trades with *Dutch gold*, they may, in fact, be referring to Chinese zinc. Whether this is also true for Mannheim gold requires further research. However, situated at the confluence of two navigable rivers—the Rhine and the Neckar—Mannheim was a hub of trade within Europe from the early seventeenth century onwards.[62] Mannheim had particularly close connections with The Netherlands, not only because of the excellent transport links provided by the most important waterway in Europe—the River Rhine, but also due to the many Dutch immigrants who were attracted to Mannheim in the seventeenth and eighteenth centuries.[63] There were probably extensive commercial and technical exchanges between The Netherlands and Mannheim, which may mean that *Dutch gold* equates

56 John Imison, *Elements of Science and Art, a Familiar Introduction to Natural Philosophy and Chemistry* (London, 1803), 526.

57 Thomas Mortimer and William Dickinson, *A General Commercial Dictionary: Comprehending Trade, Manufactures, and Navigation* (London, 1819), 680–681.

58 Bonnin, *Tutenag and Paktong*, 85–86.

59 Anthony F. M. Willich, *The Domestic Encyclopaedia*, vol. 5 (Philadelphia, 1804), 475.

60 Mortimer and Dickinson, *A General Commercial Dictionary*, 681.

61 Day, *Bristol Brass*, 73–74, 123.

62 Cornelis Disco, "Taming the Rhine: Economic Connection and Urban Competition," in *Urban Machinery: Inside Modern European Cities*, ed. Mikael Hård and Thomas J. Misa (Cambridge, Mass., 2008), 29.

63 Elisée Reclus, et al., *The Universal Geography: The Earth and Its Inhabitants,* vol. 3 *Austria-Hungary, Germany, Belgium and The Netherlands* (London, 1876), 199–200; Henry W. Lawrence, *City Trees: A Historical Geography from the Renaissance through the Nineteenth Century* (Charlottesville, 2008), 73–74.

to *Mannheim gold* in this context. *Dutch gold*, *Mannheim gold* and possibly also other materials made from adopting metallic zinc into their production methods were widely traded in Europe and then employed and processed into new goods and redistributed again. Although the sudden appearance of significant quantities of Chinese zinc in European markets enabled the local metal manufacturers to adopt a series of new procedures, this foreign-sourced material was sold at very high prices. As I will discuss later, although the cost of Chinese zinc production and the zinc export price at Chinese ports was low, around £22 to £39 per ton, the market price of imported zinc in Europe was much higher—for instance, zinc was priced at £260 per ton in Britain in 1731.[64] It is difficult to estimate the quantities of the new goods that were transported, but it was probably undertaken on a limited scale, because the average per annum export figure for Chinese zinc was an estimated 200 tons in total during the seventeenth century.[65]

The European invention of zinc production

The flow of Chinese zinc into European markets rapidly developed new consumer goods in the local markets. However, it was more than a century from the time that Europeans started importing the raw material to the point where they had developed the technology to produce the metal in Europe. Naturally, this questions whether a technology transfer actually occurred or if new technological innovations were attempted by the Europeans, in order to produce zinc metal independently. For the purpose of exploring the transfer of zinc production at the technical level, I analyse the technological, economic, social, political and cultural preconditions that made zinc production in Europe necessary and possible.

Before that, I shall briefly outline the history of early discoveries of zinc in the West, based primarily upon the historical chemistry records of the eighteenth century and some secondary literature on this issue. As mentioned earlier, there are divergent views on who first invented zinc in Europe. Torbern Bergman, a source from the early 1780s who provides a short review of the history of zinc, suggested that a German scholar, Henckel,[66] might have obtained zinc from *lapis calaminaris* by means of phlogiston. Henckel gave an account of zinc extraction in 1721, but he did not reveal his method. In 1742 the Swedish chemist Anthony von Swab extracted zinc from ores by distillation at Westerwick, but he failed in further industrial development. Von Swab's method seems not to have been known to Margraf, who obtained zinc from calamine in 1746. Bergman was, in fact, one of the sources who introduced the myth that English zinc production technology was based on Chinese origins:

64 Day, *Bristol Brass*, 123.
65 Souza, "Ballast Goods", 302–304.
66 No more detailed information is available about Henckel.

> "A certain Englishman, who several years ago took a voyage to that country [China] for the purpose of learning the art, returned safely home, and indeed he appears to have been sufficiently instructed in the secret, but he carefully concealed it."

Bergman did not reveal the Englishman's identity, if he knew it, but he mentioned that a process of zinc smelter by distillation *per descensum* had been established in Bristol afterwards.[67]

Bergman's contemporary Bishop Richard Watson (1737–1816), argues in his *Chemical Essays* that a Scotsman, Dr. Isaac Lawson, was the second European, after Henckel, to invent zinc production, in 1741. Bergman had omitted this from his account. Watson speculated that Lawson might have been the Englishman who travelled to China that Bergman was referring to. Watson also specified that the exact date when the first zinc smelter started production near Bristol was 1743, and mentioned that Henckel's dissertation on the observation of discovering zinc was published in 1737.[68]

Other stories were told, such as the notion that William Champion had learnt about zinc from visits to continental metallurgical enterprises in 1730, or that William's brother, John Champion, had actually discovered the secrets of *spelter* and brass making while visiting The Netherlands and that John, rather than William, had brought Dutch workers back to England.[69] Later studies suggest otherwise though—that Dr. Isaac Lawson had been the visitor to China and that he had instructed Champion in how to develop a zinc smelting industry.[70]

There is no record of the zinc production procedures or technologies used by any of these early inventors, as metallurgists and chemists did not publish their discoveries. Secrecy was an issue. Some individuals such as William Champion, did, however, apply for patents. Champion was granted his patent in 1738 for the, then, usual term of 14 years.[71] About 20 years later, around 1766, Watson mentioned his visit to Champion's metalworks, at which time the process was still kept a secret.

Joan Day suggests that the early zinc smelters might have looked similar to those described in 1825 by Mosselman, who established zinc smelters in Belgium after a visit to England.[72] The early zinc smelters in England were structurally different from those in China or in India. In Asia, the retorts or pots containing zinc ores were placed vertically in the furnace, while Mossmann describes a horizontal arrangement in England. The basic ideas and theory of

67 Bergman, *Physical and Chemical Essays*, vol. 2, 313–314.
68 Richard Watson, *Chemical Essays*, vol. 4 (London, 1786), 33–38.
69 Day, *Bristol Brass*, 82–83.
70 H.O. Hofman, *Metallurgy of Zinc and Cadmium* (New York, 1922), 3.
71 Henry Hamilton, *The English Brass and Copper Industries to 1800* (London, second edition 1967), 154.
72 Day, *Bristol Brass*, 76.

distillation were similar, though, in the East and the West. Joan Day asserts that Champion derived his design from the Indian process, perhaps being influenced by the Indian ceramic process.[73]

Based upon the smelters' technical differences, E. J. Cocks and B. Walters suggest that there is no evidence to support Bergman's report that an Englishman learned the process in China. They also dispute the idea that Dr. Lawson had been instrumental in introducing zinc smelting to England, or that Champion had learned the technique from a sailor who had been to China. They consider the method that Champion invented as an English process, i.e. an independent system entirely different from the Eastern ones.[74]

With so many conflicting references on this topic, it is impossible to determine whether the English invention originated from the Chinese method or was entirely re-designed. Clearly the Chinese, English and Indian methods of zinc smelting had basic similarities, yet they also showed subtle variations. It is also evident that the Europeans only had limited access to Chinese technology, which hindered the technological exchange. The German chemist J. A. Cramer mentioned that his contemporaries (ca. 1730s) knew nothing about where or how Chinese zinc was made, since "no European is granted the liberty of entering into those countries."[75] As a vehicle for transmitting ideas and fashions, the zinc trade between China and Europe stimulated attention and thus contributed to the dissemination of zinc smelting technology. The legend about the Englishman reveals the desire of contemporary inventors to discover the origins of zinc manufacturing, whilst giving it an exotic tint through its identification with China.

Zinc illustrates the significant impact that Chinese trade had on Europe's consumer culture and its technical development, which was apparent in metallurgists' eagerness to invent their own zinc. As Bergman indicates, a number of countries in Europe, such as Germany, Britain and Sweden finally succeed in the early eighteenth century (1720–1740s). This period before the industrial revolution witnessed many rapid changes in the world. In Europe, commercialization accelerated, affecting politics, society and popular culture.[76] One characteristic of this consumerism was its close linkage to a global trade culture.[77] Maxine Berg has highlighted how Asian luxury goods swamped British markets under the import substitution policy (i.e. replacing the imported goods with domestic production, for instance, by promoting imitation and product innovation), and how this stimulated innovations in Britain. This argument can also be extended to industrial products such as

73 Day, "Copper, Zinc and Brass Production", 181.
74 E.J. Cocks and B. Walters, *A History of the Zinc Smelting Industry in Britain* (London, 1968), 7–8.
75 Cramer, *Elements*, 167.
76 Peter N. Stearns, *Western Civilization in World History* (London, New York, 2003), 69–82.
77 Peter N. Stearns, *Globalization in World History* (London, New York, 2010), 83–88.

zinc. Just as Europeans had no access to porcelain technology, they were also unable to gain knowledge of Chinese (and Indian) technology. As a transfer of technology did not happen, Britain excelled in imitating the Chinese zinc, by designing a new technical procedure. This was common to many commodities that were initially imported from the East but eventually produced in Britain.[78] Although the transfer at a technical level was impossible in many cases, the local "copy" of "original" products from the East could hardly be seen as an entirely endogenous invention. Certainly, the success of such imitation was underpinned by the solid local technological traditions. The imitating process itself was, nevertheless, an extension and development of a knowledge and information transfer built upon the first level of transfer—the physical flow of commodities—which served as the direct stimulus for the second level.

This development seems even more surprising when it is considered that Europeans had originally only brought Chinese zinc into Europe as ballast. As artisans realized that zinc could be used to gild metals and imitate gold, this ballast, however, turned into a valuable commodity. The West Midlands in England, for instance, specialised in toy-making, an industry subject to fashions, and most of the toys were exported to France. Between the 1710s–1740s, the business grew rapidly, closely because of the rapid growth of copper and brass manufacture in England and Wales during 1690–1720,[79] along with the increase in copper mining outputs. The Midlands' demand for zinc accelerated even more with a growing middle class who appreciated imitations of gold and silver as cheap substitutes for the real thing. Zinc became the gold of ordinary people. The new metals could be easily shaped and decorated by pressing, stamping and moulding, which was suitable for producing goods on a large scale.

The growth of English brass output was not unique in the European context. Stolberg in Germany increased its brass output from 1,400 tons in 1691 to 3,000 tons in 1726, exporting most of the brass to Belgium, France, The Netherlands, Spain and Portugal. An overall increase in brass consumption was apparent in the first quarter of the eighteenth century all over Europe. At that time, most brass industries did not yet use zinc, which was reportedly an expensive commodity, with a peak price of £260 per ton in 1731.[80] Even though China opened several new mints during 1720–1730 (mainly because of an internal demand as detailed above), the export price of zinc was raised

78 Maxine Berg, "In Pursuit of Luxury: Global History and British Consumer Goods in the Eighteenth Century," *Past and Present*, 182 (2004): 85–142; Maxine Berg, "From Imitation to Invention: Creating Commodities in Eighteenth Century Britain," *The Economic History Review*, n.s., 55, No. 1 (2002): 1–30; Lemire and Riello, "East & West: Textiles and Fashion in Early Modern Europe", 893–894.

79 Marie B. Rowlands, *Masters and Men in the West Midland Metalware Trades Before the Industrial Revolution* (Manchester, 1975), 134–135, 141.

80 Hamilton, *English Brass*, 154.

by 25%.[81] European countries in the eighteenth century increasingly pursued a mercantilist approach, including enacting import substitution policies and promoting local production, so they competed in quantities of brass production rather than quality. Using zinc in brass making gave a competitive edge to those producers, and thereby stimulated different inventors in several countries to pursue creating their own processes.

As well as this external stimulus, the development of zinc production processes had its roots in Europe's metallurgical tradition. As mentioned above, brass industries on the continent were already prospering by the fourteenth century. The Harz Mountain region in northern Germany was particularly famous for its metallurgical practices. George Agricola, in his renowned work *De Re Metallica* (1556), describes "*Ofenbruch*" (furnace calamine) from Goslar near Harz Mountain, which was thought to refer to zinc (*Conterfey*). However, Goslar's furnace chose not to use zinc for brass production because it had sufficient calamine. In essence, the nature of Chinese zinc was poorly understood for a long time in Europe. The metallurgists did not know which ore zinc could be extracted from until in the 1740s, when Cramer published a book in which he explained that zinc was connected with calamine, based upon his practical experiences in Goslar.[82] At that time, Cramer was not aware that Henckel or Champion had managed to obtain zinc from calamine, since their methods were kept secret by the inventors. While secrecy thus resulted in multiple variations in zinc production, cross-border trades and migrations of people such as the Champion brothers within Europe at the same time provided a good basis for transnational technology exchanges.

The long road to mastery: English zinc struggling for existence and innovations

Although zinc smelters had been built in Bristol by 1743, the road to mastering large-scale zinc production in Britain and Europe was still long and full of pitfalls. Global competition was a major incentive in the post-invention phase yet, as this section will discuss, Great Britain and other European states still had to overcome many obstacles before they managed to establish a genuine zinc production industry of their own.

The primary challenge to English zinc produced by the Bristol method came from Chinese zinc entering British markets. At that time, production costs such as raw material and labour mainly determined market prices. Despite an experimental success, Bristol was still a long way from commercial large-scale production. Raw material and labour costs was £40 per ton,[83] which did not include capital investments for plant construction, transportation costs, etc.

81 See Souza, "Ballast Goods", 314.
82 Cramer, *Elements*, 163–167.
83 Day, *Bristol Brass*, 123.

According to Watson, Bristol could only produce 200 tons of zinc annually,[84] and not over extended periods. In contrast, Chinese zinc during the eighteenth century was sold at zinc mines, for example, in Guizhou province, for about £8 to £12 per ton;[85] reaching an export price at Guangzhou of £22 to £39 per ton. Before the English succeeded in zinc production, they often purchased Chinese zinc at much higher prices, up to a maximum of £260 per ton. But once English zinc came on the market in the 1740s, merchants lowered the Chinese zinc price to £48 per ton in an attempt to force English zinc producers out of business. English merchants were losing some £22 to £25 per ton when transportation costs were included.[86] But, spurred on by a boom in Chinese zinc production from 1745 onwards, they were assured of an unlimited supply. Based on an initial survey, Souza suggests, European ships imported some 660 tons of zinc per year in the 1730s, and over 2,400 tons per year in the 1790s.[87] Although it is not clear how much zinc was consumed in Europe, imports were clearly on an upward trend during the eighteenth century. Hence, the development of the European zinc industry was impeded from the very beginning by an effective commercial monopoly over Chinese zinc. Chinese zinc continued to swamp British markets for some years, substantially hampering further technical developments.

Another competitor to both English and Chinese zinc in the European markets was the brass being produced in the traditional cementation manner. As mentioned above, brass output in Britain and Germany grew rapidly in the first quarter of the eighteenth century, making brass more widely available. Unlike the large quantities of Chinese brass which were required for coin minting, brass in Europe had little connection with monetary functions, since silver and gold had been the predominant currencies for several centuries, especially during 1500–1800.[88] The reasons for changes in Chinese brass production, from using calamine to zinc, such as the calamine transport costs and brass quality control, as analyzed above, were not relevant to brass processing in Europe. The traditional cementation process of brass-making, by melting copper and calamine, still predominated in European brass markets, although Chinese zinc had been adopted in the new brass-making method. Metallic zinc costing around £40 per ton could be used to produce common brass, in order to remain competitive with traditional brass making.[89] The issue of price probably limited the application of both Chinese and local zinc in

84 Watson, *Chemical Essays*, vol. 4, 38.

85 Zinc prices, or official cost prices, at mines are documented in many kinds of official documents in the Qing dynasty, such as the Routine Memorials.

86 Day, *Bristol Brass*, 77.

87 Souza, "Ballast Goods", 306–307.

88 Pierre Vilar, *A History of Gold and Money, 1450–1920*, trans. Judith White (London, 1976), 193–203.

89 Day, *Bristol Brass*, 123.

common brass production in the West, however traditional brass makers and merchants claimed that new brass which contained metallic zinc was inferior.[90]

Likewise, the technological monopoly which China maintained handicapped the development of the earlier inventions to some extent. Champion had his invention of zinc smelting technology patented for 14 years and even proposed another 14 years' extension. Although various beneficial exchanges of technology and commerce did exist within Europe, individual inventions were not widely disseminated at first. Bergman noted that all of the earlier zinc inventors kept their production methods secret, increasing commercial competition between the inventors and craftsmen themselves. English zinc was struggling for survival throughout the second half of the eighteenth century.

Innovations in the zinc smelting process resulted in an upsurge in favour of the European zinc industry from the 1780s onwards. All of the rivalry in which inventors, merchants and craftsmen were involved had one single aim: reducing costs whilst maintaining or enhancing quality. The factors that impacted on the cost and quality of zinc were calamine and coal fuel, as well as minor quantities of fireclay, mud and other construction materials, all of which were required for Chinese zinc production. The ratio of coal consumed to metallic zinc obtained was about 9:1. Coal fuel was extraordinarily crucial for the operation of Chinese traditional zinc industries. Guizhou province's successes in the development of zinc industries throughout the eighteenth century were caused by the availability and adequate quality of both calamine and coal.[91]

European zinc production was equally driven by fuel considerations. Coal was central to J. Emerson's patent for producing zinc in 1781, which aimed to increase zinc production to an industrial scale. On the continent, engineers were also attempting to solve the fuel efficiency problem and find other ways of reducing production costs (see Fig. 2). For example, J. C. Ruberg reduced the ratio of coal to zinc from 20:1 to 17:1 in 1799 in Silesia (Germany), by adopting and improving the Bristol method. Much later, in Swansea (Wales), the ratio was reduced to 11.5:1. By the turn of the nineteenth century, J. D. Dony established the zinc industry in Liège (Belgium, 1806–1807), having also, reportedly, learned the Bristol method.[92] The success of those zinc industries by 1800 was built upon former brass industries. Importantly, the European innovations must be seen as being interconnected with each other rather than as singularly national events. As these exchanges occurred throughout the period in which Europeans gained wider knowledge of China.

90 Smith, *Zinc Industry*, 13.

91 Refer to my research results presented in the internal and international workshops of the MMF research group at Tuebingen University in 2009 and 2011, which will be expanded upon in my dissertation.

92 Day, "Copper, Zinc and Brass Production", 184–189; Smith, *Zinc Industry*, 11–13.

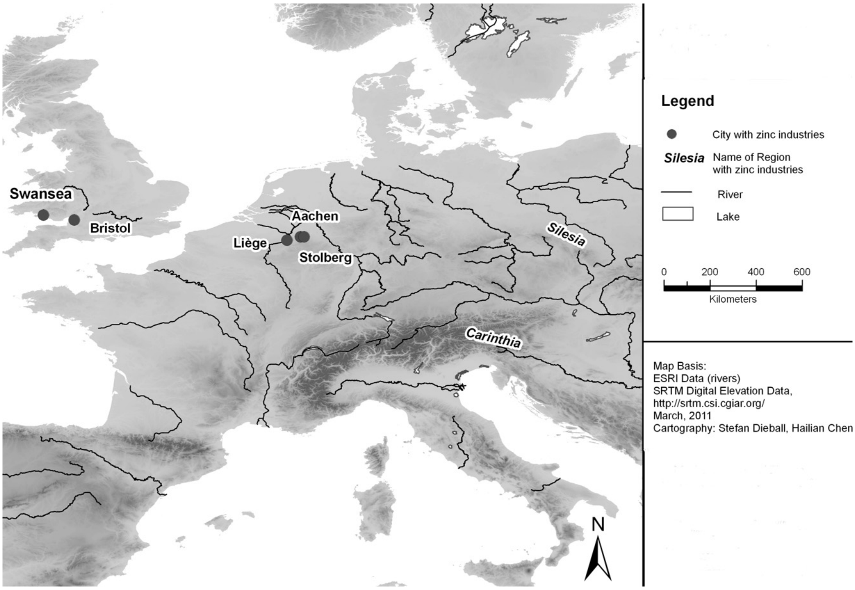

Fig. 2: Location of zinc industries in Europe around 1800. Source: Hailian Chen and Stefan Dieball.

Conclusion

In this paper, I have examined the connections between Chinese zinc and European inventions in their larger technological, economic, political, social and cultural contexts, employing a transnational perspective on the history of the transfer of zinc from China to Europe in the early modern period. It was not inevitable that zinc would be used for brass production in either China or Europe, but the emergence of zinc production on a large scale made brass (in the broader definition which includes brass coins and gilding metals) better and cheaper and enabled it to be used in new applications. A growing Chinese demand for the metal as a minting material stimulated zinc production in China from the early seventeenth century onward. Almost simultaneously, global trade links brought zinc to the West. As reviewed above, the specialisation of using zinc in brass-making in Europe was substantially affected by transnational trade and transfer processes. The foreign metallic zinc slowly changed brass metallurgical practices in Europe, as it had also done in China. The transferring processes can be divided chronologically into two quite distinct phases.

In the first phase, Chinese zinc as a commodity was transferred to Europe and a series of new goods was produced, many of which were concerned with gilding metals to imitate gold. At this level of transfer, the role of cross-cultural commercial exchanges and communications in the early modern period is central to our understanding: since zinc was a raw material and the European artisans or craftsmen probably had no experience of the practical application of zinc, why and how was the foreign zinc metal sold and adopted in the continent? As transfer agents, merchants from the East India Company, who were intensively involved in cross-cultural trade (including inter-Asian and Eurasian trade) around the Indian Ocean and the South China Sea, played a significant role in the transfer of knowledge and information regarding metal products and consumer markets within various material cultures.

The second phase began in the first quarter of the eighteenth century, and was characterised by attempts to produce zinc in Europe. There are many divergent views on the origins of European zinc production, which agree that Chinese zinc acted as a stimulus. In particular, the legend that an Englishman learned how to smelt zinc in China has aroused a great deal of scholarly interest in investigating the transfer of technology, which formed the starting point for my discussion of the second level of zinc transfer. In general, the technological transfer from the East to the West (in particular to Britain) during the seventeenth and eighteenth centuries faced many obstacles, since access to Eastern technology practices was restricted or impossible. However, an increasing consumer culture, along with growing global trade from Europe in the early modern period, stimulated the quest to devise European versions of many oriental commodities. Consequently, despite the obstacles to technological transfer, many oriental commodities could be locally produced in Europe, supported by solid local technological traditions. This was also the case for zinc. Nevertheless, the European process was not an entirely endogenous invention, but rather an extension and development of the knowledge and information transfer which had been built upon the physical flow of commodities. As a commodity, Chinese zinc had a great impact upon European industrial invention, especially in the post-invention phase, when cheap Chinese zinc competed with the first patented European zinc production (known as English zinc). All this competition between inventors within commerce and traditional enterprise reflects an intricate and complicated course of technology transfer. Equally significantly, connections and exchanges via trade within European countries such as Britain, Germany, Sweden, The Netherlands and France, as well as China, facilitated the spread of new goods and led to innovations in zinc production and consumption.

Author: Hailian Chen, AOI, Abteilung für Sinologie und Koreanistik, Universität Tübingen, Wilhelmstr. 133, 72074 Tübingen.