The Great Divergence and the Economics of Printing

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Abstract

While China's invention of printing took place several centuries ahead of Europe's, it was in Europe where the more advanced printing technology of movable type took hold and where book production reached far higher levels. This paper explores to what extent China's complex logographic writing system explains these different outcomes. Using an economic analysis, I show how China's preference for block printing technology over movable type can be justified as the rational choice of commercial producers. In addition to this, model simulations also predict that movable type would be used in China under some specific circumstances which closely match the historical record. On the other hand, the use of block printing would not have led to larger printing costs in China, and as such should not be regarded as the reason behind China's modest level of book production when compared to Europe's.

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One of the finest paradoxes in global history is the statement by Francis Bacon, champion of empiricism and a major figure in Europe's intellectual ascendancy, about the importance of inventions in changing human lives. The three great inventions chosen by Bacon to make his case are printing, gunpowder, and the compass. All three were of Chinese origin.[2]

The failure of China to industrialize ahead of Europe, leading to what Kenneth Pomeranz termed "The Great Divergence", has puzzled scholars ever since China's prolific record of technological inventiveness was uncovered by the work of Joseph Needham.[3] China was richer than Europe in the centuries preceding the European Renaissance: the most recent set of estimates puts its income per head at between 1,200 and 1,500 US dollars during the 11th century, while England's figure at that time was a modest 750 US dollars per person.[4]

As is well known, the early modern period saw the rapid rise of Europe to global dominance. The change is perceptible not so much in figures of income per capita, which took a long time to rise beyond the wealthy regions of Holland and Northern Italy, but rather in the several intellectual and social revolutions that Europe was to experience from the 16th century onwards: the Scientific Revolution, the Enlightenment and the Industrial Revolution - together with the creation of history's first transoceanic empires by European powers. This apparent change of trend in European development beginning sometime around the year 1500 has led a number of scholars of the western tradition to look for an exogenous factor crashing into the European scene at this time and shifting the continent's trajectory towards faster accumulation of knowledge, 'modern' mindsets and, eventually, sustained economic growth. A favourite suspect for such a factor is the invention of printing.

[2] Bacon, *Novum Organum*, Book I, CXXIX.
[3] Needham, *Science and Civilization*; Pomeranz, *Great Divergence*.
[4] Broadberry et al., "China, Europe and the Great Divergence".

In the words of Myron Gilmore, printing "brought about the most radical transformation in the conditions of intellectual life in the history of western civilization".[5] Printing made existing knowledge far more accessible than it had been hitherto: Europe passed from producing 2.7 million books during the 14th century to 217 million books during the 16th century.[6] If we follow the endogenous growth literature and consider existing knowledge as the primal input in the production of new knowledge, the impact of printing seems evident and far-reaching.

Elizabeth Eisenstein, whose work on the consequences of printing on western civilization serves as the reference in the literature, illustrates this very well with the life of Nicolas Copernicus, the first major figure in Europe's Scientific Revolution. Copernicus' work presupposes a detailed knowledge of Greek astronomy and, in particular, of its greatest work, Ptolemy's *Almagest*. As Eisenstein describes it, "As a student at Cracow in the 1480s, the young Copernicus probably found it hard to get a look at a single copy of Ptolemy's Almagest - even in a corrupted medieval Latin form. Before he died, he had three different editions at hand".[7] Copernicus was fortunate enough to live through a period where the invention and rapid adoption of printing made owning a copy of a book like the *Almagest*, and carefully studying its every page, a realistic possibility. Equally important, the invention of printing not only meant that Copernicus was able to generate his revolutionary thesis - he was also able to disseminate it throughout the European ecumene by having it printed in *De revolutionibus orbium coelestium (1543)*.

Recent research in economics corroborates this view and makes the link to economic development. Dittmar shows how an early adoption of printing technology is associated with faster economic growth among European cities. Reverse causality does not seem to explain the trend as the early adopters of printing had no previous observable advantage. Along the same lines, Baten and van Zanden use country-level data covering the pre-industrial period to show how book

[5] Gilmore, *World of Humanism*, p. 186.
[6] Buringh and van Zanden, “Charting the Rise”.
[7] Eisenstein, *Printing Revolution*, p. 234.

production per capita during any given 50-year period is a good predictor of economic growth over the next 50-year period.[8]

While all of the above indicates that printing was of major importance in Europe's early modern ascendancy, it also puts the Chinese experience in even starker contrast. As we know well, China developed printing technology as much as seven centuries earlier than Europe. And while printing did spread and was eventually to exert an important influence on the Chinese civilization, it did not lead to anything as momentous as the transformation of thought and society that Europe was to experience over the early modern period.

Looking into the Chinese experience, it is apparent that printing did not enjoy the same level of success as it did in Europe. The most telling evidence of this is the number of book titles produced in each region: with a significantly smaller population, European book production was at least an order of magnitude larger than China's (see the next section for estimates). While Chinese printing output would have been initially restricted by the dominating role of the state, this was no longer the case by the early modern period, which this comparison refers to. Of potential relevance to this outcome is the fact that China never fully embraced the technology of movable type, relying instead on the method of block printing for the vast majority of its output.

Once the main characteristics of the Chinese printing experience are established, the central aim of this paper is to evaluate, from an economic perspective, a simple explanation for China's relative underperformance in the printing world: its hugely complex logographic writing system, as opposed to Europe's alphabetic ones. The explanation has been advanced by historians of printing when referring to the choice of printing technology in China.[9] Here I give this argument a formal structure by considering how cost functions for printing are affected by different writing systems, and

[8] Dittmar, "Information Technology"; Baten and van Zanden, "Book Production".
[9] See, for instance, Carter, *The invention of printing*, p. 242; McLuhan, *Gutenberg Galaxy*, p. 152; Febvre and Martin, *Coming of the Book*, p. 75; and Eisenstein, *The Printing Press*, p. 27, f. 65.

demonstrate its validity when it comes to explaining China's printing technology.[10] Once this is established, I consider whether the Chinese writing system may also explain China's restricted printing output via larger printing costs. My quantitative estimates suggest this was not the case, and thus that the reasons for China's limited printing output ought to be searched for elsewhere.

I

Two printing technologies were in place over the early modern period, and both of them make their first appearance in China during the European Middle Ages. The first one is xylography, commonly called block printing, where characters are carved onto a wooden block, which is then inked with the help of a brush, and impression are taken by laying a sheet of paper over the block and rubbing. Block printing was in place by the 8th century in China, and its invention has not been precisely dated. The technology was in use on a very large scale by the 10th century, for the printing of the entire canon of Confucian scriptures by the Chinese government.

Movable type technology differs from block printing in that each character is either carved or cast into a separate piece of wood, metal, or other material. The characters (or "types") are then assembled together into a "form", which is laid on a tablet and from which impressions can be taken as in block printing or, in the European case, with the help of a printing press. The form is disassembled after use, and the types stored for future usage. The invention of movable type is ascribed to a certain Pi Sheng sometime in the years 1040s - we have no surviving texts or types but know of his invention by the account of the renowned polymath Shen Kuo in his *Dream Pool Essays* of 1088.

Despite this early invention, a full four centuries in advance of Europe, movable type remained a marginal technology in China up until the late 19th century. China printed books in large quantities,

[10] For an earlier attempt along these lines see Heijdra, “Technology, Culture and Economics”.

but the vast majority of them were produced using block printing technology. Kai-Wing Chow tells us that we know of about 100 book titles printed using wooden movable type during the Ming dynasty which, when reported to the total number of titles printed during this period, would represent well below 1% of the total.[11]

Movable type was never forgotten, but its use was largely limited to two particular areas. First, large government projects such as the printing of Imperial Encyclopedias. As an example, consider the Grand Encyclopedia of Ancient and Modern Knowledge (*Gujin Tushu Jicheng*), presented to the Chinese Emperor around the year 1725 and comprising 5,020 volumes and 800,000 pages of text. Sixty-six copies of the full Encyclopaedia were produced using types made of copper.[12] Second, and perhaps somewhat surprisingly, movable type was often used by itinerant printers of family genealogies.[13] These were printing entrepreneurs travelling from province to province and offering to produce genealogies for the exclusive circulation among kin members. Their types were made of wood, a much cheaper alternative to the metal types often used by the government. Albeit movable type using wood made some inroads among regular commercial producers, the vast majority of them resorted to block printing up until the late 19th century.

Europe's experience with printing, as we know well, was very different. Block printing and movable type appear in Europe almost simultaneously during the middle of the 15th century but movable type rapidly becomes the technology of choice. Europeans printed their first book using movable type during the 1450s, yet the technology was in place in 110 towns and cities throughout Europe by 1480 and in as many as 236 places by the year 1500.[14] By the turn of the 16th century, block printing technology had disappeared as a method for producing text while printing shops using movable type were present from Portugal to Russia and far beyond the main cities.

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[11] Chow, *Publishing, Culture, and Power*, p. 68.
[12] Tsien, *Paper and Printing*, pp. 185 & 216.
[13] Heijdra "Technology, Culture and Economics", p. 227; Chow, *Publishing, Culture, and Power*, p. 68.
[14] Febvre and Martin, *Coming of the Book*, pp. 182 & 186.

The European adoption of printing was much faster than China's, and almost entirely led by the private sector. In comparison, the state was the major player in China from the invention of printing up until the middle of the 16th century, when the output of private firms finally becomes dominant.[15] It took Europeans about 50 years to set up more than 200 printing shops across the continent, whereas a similar number was reached in China only during the Southern Song dynasty, no less than 300 years after the invention of block printing during the Tang.[16] By the 16th century, however, the market structure of the printing world was quite similar in China and Europe, with most of the output coming from a large number of small private firms in competition with each other and producing books for a profit.[17]

Other than the choice of technology, the most remarkable difference between European and Chinese printing during the early modern period lies in the scale of their outputs. While it seems abundantly clear that European output was much larger, coming with a precise estimate of the difference is far more difficult, mainly because of uncertainty about the Chinese figures.

An adequate period for performing a comparison is the second half of China's Ming dynasty, roughly the years between 1522 and 1644. Printing had been fully adopted throughout Europe by the beginning of this period while, on the Chinese side, the development of a highly competitive private printing sector had seen printing output increase 10-fold between the first and second half of the Ming dynasty.[18] The comparison will be made in terms of number of titles produced, and not total books printed, and that for two reasons. First, from an analytical perspective, it is the number of titles that gives us a more accurate representation of the amount of knowledge being put in

[15] McDermott, *A Social History*, pp. 68-69.
[16] Chow, *Publishing, Culture, and Power*, p. 20.
[17] Meyer-Fong, "Printed World".
[18] Chia, "Mashaben".

circulation in printed form. Second, from a practical perspective, we seldom have information on print runs throughout this period in order to calculate total book production.[19]

The number of book titles produced in Europe during this period is known with a good degree of certitude thanks to the Universal Short Title Catalogue (USTC), an exhaustive list of all extant books printed in Europe between Gutenberg and the year 1600, and similar national catalogues for the years thereafter. As reported by Buringh and van Zanden, Europeans produced an average of 3,750 book titles per year between 1522 and 1644, for a total of 457,500 titles over this period.[20] This figure does not include titles for which no copies have survived to our days, but these would be few in number.

For China we have several estimates, none of them as comprehensive as the European one. A good place to start is Chia, who reports a total of 7,325 titles for the whole Ming dynasty (1368-1644), with 6,618 of them corresponding to the years 1506-1644. McDermott reports a higher figure for the first half of the Ming, 1,095 titles for the years 1368-1505, but his figures for the second half only cover the years 1506-1521. While both of these figures are carefully constructed using library catalogues and bibliographies, neither of them claims to be exhaustive and Chia clearly states her figure does not cover the output of government publishers and religious organizations.[21] The figures give us an order of magnitude, but they should be regarded as a lower bound. For higher values we may refer to Chow, who cites a total of 15,725 Ming dynasty titles as reported in a catalogue from China's Qing dynasty (1644-1911).[22] Finally, at least one Chinese source puts the total number of Ming titles at a considerably larger 35,000 titles – which we may regard as an upper bound.[23] If

[19] McDermott, *A Social History,* p. 43, tells us that we know the print run of less than 0.1 percent of all printed titles during the pre-modern period in China. We have more information for Europe, but still far from a full coverage.
[20] Buringh and van Zanden, "Charting the Rise".
[21] Chia, "Mashaben", p. 303; McDermott, *A Social History,* p. 81.
[22] Chow, *Publishing, Culture, and Power*, p. 22, f. 24.
[23] Miao, *Mingdai*. I thank Martin Heijdra for pointing this source to me.

Chia's findings about the growth in book production between the first and second half of the Ming dynasty apply, about 31,500 of these titles would correspond to the latter period.

As we see, while the total number of titles produced in China during this period is known only within a broad range, even the largest available figure suggest a ratio of 15 European titles for every Chinese one. The difference becomes even more remarkable when we consider that, around the year 1600, China's population was about 60% larger than Europe's. Europeans would then have produced at least 24 times the number of book titles per person being produced in China.[24]

Could such a large difference be explained by China's relative linguistic homogeneity as compared to Europe? European books were printed in a large variety of vernacular languages in addition to Latin and ancient Greek, whereas Chinese publications were, with some rare exceptions, all in Chinese. We may thus hypothesize that a large number of European titles would not have been produced if all Europeans had read the same language.

In order to assess the magnitude of this phenomenon we may subtract from the total number of European titles all translations of works originally published in another language. While detailed data for all European countries is not currently available, we do have data for the Netherlands revealing that 14.68% of all titles printed in this country during the period 1522-1644 were translations from languages other than Dutch.[25] Due to its size the Netherlands should be expected to have more translations than the European average, but even taking the Dutch figure as representative for Europe would still leave a 20-fold difference in titles per capita between China and Europe. I

[24] I note that this comparison is based on printed books, which somewhat understates Chinese book production as manuscripts continued to be produced in China throughout the early modern period. While counting manuscripts would enlarge Chinese figures to some extent, it is not clear how manuscript titles should be weighed against print titles. After all, a manuscript has a print run of 1, while printed books are produced in hundreds or thousands of copies. In any case, McDermott (*A Social History*, p. 54) suggests that by the late 16th century printed books were far more important than manuscripts.

[25] Short Title Catalogue for the Netherlands. For all books in the catalogue, covering the period 1451-1800, the share of translations is 11.20%.

conclude that the difference in title production between the two regions is largely unrelated to linguistic heterogeneity.[26]

The subsequent sections explore to what extent the different writing systems employed in China and Europe can explain these observed disparities in printing technology and level of output.

II

Scholars of the history of Chinese printing have long pointed at the complexity of China's logographic script as the main reason behind its failure to adopt movable type technology. As Denis Twitchett explains, "The basic problem of Chinese typography was, and still remains, the fact that the repertory of Chinese characters is virtually limitless. Even today, after decades of efforts at limiting the number of characters in use, a Chinese printer needs an active stock of more than 8'000 [distinct] characters".[27]

To be clear, the problem was not that Chinese printers needed to produce thousands of types in order to use movable type technology, for that was also the case in the West. Chow tells us that printers of family genealogies were able to operate with as little as 20,000 types[28], which is not more than what one would find in the West for any given letter font (and European printers would typically have several fonts available). Western alphabets reduced the number of distinct characters to around 30, but each character is repeated a large number of times within a given page. The problem, then, was not the total number of types needed but their structure. Europeans needed a

[26] I may add that, in the absence of linguistic differences, many of these translated titles would have been produced anyway, as reprints of the original title (which would often incorporate minor changes, and would count as a new title in any case). Indeed, high transportation costs meant that titles were often re-issued in cities far from the original place of publication in order to make them available there. Thus, subtracting all translations overestimates the effect of language heterogeneity.
[27] Twitchett, *Printing and Publishing*, p.76.
[28] Chow, *Publishing, Culture, and Power*, p. 68.

large number of copies of a reduced set of distinct characters, while the Chinese required a small number of copies of a very large set.[29]

These different structures in the set of types required resulted in very different production costs, as there are important economies of scale in the production of types. Indeed, the most important contribution of Europe to global printing technology was arguably not the invention of the printing press, which did little to reduce costs with respect to other forms of printing, but rather the development of the punch-matrix process for the production of types.[30] In this process, a punch is carved with the shape of a letter in a hard metal like steel, which is then used to strike a soft metal plate to create a matrix. The matrix can then be used to cast types by filling them with metal in liquid form. This represents one of the earliest instances of standardization in manufacturing, and greatly reduces the unit cost of producing types. The initial investment in punches and matrices pays off greatly, as long as the number of copies to be produced from each character is very large.

If that is not the case, and what we need is a few copies from many distinct characters, it is more economical to carve each individual type on a soft metal such as copper or even on wood, as was indeed done in China. Indeed, it may be fair to say that the crucial advantage of European over Chinese printing was not the fact that it used types which were movable, but that it used types which were reproducible in a standardized format. Type production was therefore far less costly in Europe.[31]

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[29] Van Zanden, "Explaining the global distribution", p. 333, gives an example of a movable type font in China where the average number of copies per character would have been 35. The example relates to a government project; an even smaller number of copies may be assumed for private firms. Contrast this with Europe, where the average number of copies per character would be around 1,000 for each font.

[30] Of course, the introduction of the printing press greatly reduced the cost of producing books in Europe as it marked the passage from handwritten manuscripts to printed books. The point I make is that Europeans would have experienced similar cost reductions with the Chinese method of producing copies, as long as the other elements of their printing technology had been in place. The online Appendix presents empirical support for this claim.

[31] The invention on the punch-matrix process has long been ascribed to Gutenberg, but this has been proved wrong by the work of Aguera y Arcas (2003). It is now accepted that the process was in place only by the 1470s, some 20 years after Gutenberg's invention of the printing press.

In addition to this, western alphabets also facilitated the process of text composition – when types are arranged into a form. In the West, copies of every existing character (in uppercase and lowercase) could be arranged within a middle-sized case with a few dozen compartments. Finding the next required character was easy. In contrast, finding a Chinese character among a collection of several thousand ones is a far more challenging task. The Chinese developed practical methods to navigate their collections of types, but a difference in the time required for text composition was inevitable.

In what follows I translate the above descriptions into precise statements about the cost functions for printing in China and Europe.

The total cost of any printing project may be divided into two broad categories. First, for every page of text there is the cost of producing woodblocks under block printing and composing the text under movable type. This cost is thus proportional to the number of distinct pages being printed. Second, there is the cost of producing copies out of each page. This corresponds to the cost of paper, ink and labour employed in printing; plus the cost of replacing types or woodblocks as these wear off with usage. This cost is proportional to the total number of printed pages, which equals the print run of the title times the number of distinct pages. To this, movable type printers should add a third item: the initial cost of producing a full set of types, which must be in place before the first page is composed.

Let us note as n the number of distinct pages to be produced and r the number of copies to be taken from each page - i.e. the print run. The total number of printed pages is therefore nr. The cost function for block printing would then be of the form:

$$C_b = \alpha_b nr + \beta_b n \qquad (1)$$

and that for movable type printing:

$$C_m = \alpha_m nr + \beta_m n + F \qquad (2)$$

with α_b and α_m being the cost per page of making copies out of existing woodblocks or forms, β_b the cost of creating a one-page woodblock, $\beta_m$the cost of composing one page of text, and F the cost of a full set of types.

As presented above, these cost functions correspond to the case where a single book title of n pages is to be printed r times. A simple change of variables allows us to use the same formulas for the case where J different titles are to be produced, each with its own number of pages n_i and its own print run r_i, where $i = 1 \ldots J$. In that case, the total cost using block printing technology would be $C_b = \alpha_b \sum_i n_i r_i + \beta_b \sum_i n_i$. Re-defining n as the total number of pages for all books ($n = \sum_i n_i$), leads to $C_b = \alpha_b \sum_i n_i r_i + \beta_b n$. This may be rewritten as $C_b = \alpha_b n \sum_i \frac{n_i}{n} r_i + \beta_b n$. Finally, re-defining r as the weighted average of print runs ($r = \sum_i \frac{n_i}{n} r_i$), leads to the exact same expression as in equation (1), with n and r interpreted as just described. The same applies to equation (2).

In order to assess which of these two costs functions will be selected by a profit-maximizing printing firm we need to move the analysis into quantitative territory, and give the different cost parameters a numerical estimate. I turn to this in the next section.

III

Using the historical literature, I estimate all cost parameters in local currency units for China and Europe (French values are used as representative of the European case). To avoid consistency problems between different sources all parameters for a given technology refer to the same source.

Cost parameters in local currency units are sufficient to analyze the choice of printing technology, as is done in section IV. In section V, however, I perform comparisons of printing costs between

China and Europe, which calls for costs to be transformed into a common metric. To achieve this, I normalize cost parameters using the daily wage of low-skill labour in each region. The normalized parameters are comparable under the assumption that low-skill labour was remunerated similarly in real terms in early modern Europe and China, an assumption which, with the exception of Europe's richest cities, is broadly correct.[32]

As the cost functions above require cost parameters on a per-page basis, it is important to consider whether a page of European text was the equivalent of a page of Chinese text – and what is meant by that. While two pages of text may be compared along physical dimensions such as height or width, it is arguably the amount of information they contain that is of relevance here. In other words, if we are interested in the cost of transmitting information via the printed word, the relevant unit of analysis ought to be the page *understood as a certain amount of information.* Was the information content of a page of European text similar to that of a page of Chinese text?

To address the question, we may begin by determining the typical number of words or characters that are found in a page of European or Chinese text. For early modern Chinese books the task is facilitated by the standard practice of placing characters along columns, each column having space for the same number of characters as the next one. A typical printed page would have space for ten columns, and each column would have space for around 20 characters - resulting in a total of 200 characters per page (actually somewhat less as not every available space was used). For European books the number of words per page would have been more variable, but 250 words per page is usually considered a good approximation in English publishing.[33] The question is then, are 200 Chinese characters and 250 English words equivalent in terms of information?

[32] Allen et al., "Wages, prices".
[33] Needless to say, modern technology has greatly expanded these numbers for both English and Chinese. 250 English words per page is roughly what you would get in a modern word processor using double-spaced text and a 12-point font, leaving some space on top and bottom.

The answer seems to depend on the kind of information we have in mind or, more specifically, on its origin. Take, for instance, the United Nations' Declaration of Human Rights – a text originally created in English for which an official Chinese translation is in place. There are 1,741 English words in the Declaration, while its Chinese translation requires 2,602 characters to convey the same message – a ratio of 1.49 Chinese characters per English word. Experimenting with other English texts using modern translation software suggests that values around 1.5 Chinese characters per English word are fairly typical.

Things look very different, however, when we perform the reverse operation, comparing a text originally created in Chinese and its English translation. As an example, consider the *Cai Gen Tan* – a Ming dynasty text of aphorisms translated into English in 1926 under the title "Musings of a Chinese Vegetarian". An online version of the Chinese text is 16,297 characters long, while its 1926 translation contains 23,288 English words – a ratio of 1.43 English words per Chinese character.[34]

From the above examples I deduce there is no simple equivalence ratio between the informational content of Chinese characters and English words – the answer depends on the text. Unsurprisingly, the Chinese writing system is capable of more precision when dealing with Chinese thoughts, and the opposite is true for thoughts of European origin. Given that a roughly similar ratio of 1.5 applies when translating text in both directions, an adequate compromise may be to consider a Chinese character and an English word as informationally equivalent. As the number of words and characters per page is also quite close, we may not be far from the truth by equating a page of European text to a page of Chinese text in terms of information. I will thus report cost parameters on a per-page basis for both regions, and explore the consequences of a different assumption later on.

[34] The actual ratio is closer to 1.5, as the 16,297 Chinese characters include punctuation signs, which are not counted in the English version. The reader should also keep in mind that the UN Declaration has been translated into Modern Chinese, while the *Cai Gen Tan* is written in Classical Chinese – some, but not all, of the difference would come from this fact. Again, I am indebted to Martin Heijdra for the example of the *Cai Gen Tan*.

My estimates of parameters $\alpha_b, \beta_b, \alpha_m, \beta_m$ and *F* for both China and Europe are summarized in table 1, while a detailed discussion of sources and calculations is provided in the online Appendix. For movable type in China I offer two sets of parameters: one using types made of wood and another one using types made of metal. European types were always made of metal, so the distinction is not relevant there.

[Table 1]

The cost advantage that Europeans enjoyed in movable type technology is in evidence on table 1 when we compare cost parameters normalized by wages. Setting up a printing enterprise using types made of metal would have been around 10 times more costly in China, even though the European firm is assumed to have far more equipment (see Appendix). The difference in the cost of text composition (β_m) is more modest but still sizeable, with the Chinese figure being two thirds larger than the European one. On the other hand, if we compare the cost of producing copies in China and Europe (α_b and α_m), we notice that Chinese block printing achieved a smaller cost per page than European movable type. To a large extent, this is due to the lower cost of paper in China. Chinese movable type had a higher cost of producing copies than Chinese block printing because of the cost of replacing types, which is proportional to the number of copies produced. As discussed in the Appendix, woodblocks would not need to be replaced for the typical print runs of early modern works.

The costs reported in table 2 do not include financing costs, which would be due if some of the expenditures were financed by credit. As interest rates were higher in China[35], this would increase Chinese costs with respect to European ones. While far from negligible, my view is that differences

[35] Van Zanden, *The Long Road*, p. 22-24.

in financing costs would be of second order when compared with the differences in cost parameters reported in table 1. As an example, assume that a Chinese entrepreneur finances the acquisition of metal types with a one year loan charging a 20% interest rate while his European counterpart does the same but pays an 8% interest rate. This would increase the ratio of Chinese to European costs from 10 times larger to 11 times larger.

With the parameter values of table 1 at hand, I proceed to analyze the choice of printing technology and its consequences in these two regions.

IV

Let us consider a printing entrepreneur wishing to produce one or more book titles for a total number of distinct pages equal to n and an average print run of r.

Using equations (1) and (2), it is easy to show that $C_m < C_b$ - and movable type will be the chosen technology - when the following condition is satisfied:

$$n > \frac{F}{(\beta_b - \beta_m) - (\alpha_m - \alpha_b)r} \equiv n^*(r) \qquad (3)$$

Equation (3) tells us that movable type will be preferred when the number of distinct pages to be printed is above a certain threshold - an intuitive result as the entrepreneur saves on each page of text that has to be composed instead of carved. The threshold beyond which movable type is employed is a function of r.

In this paper I will not model how printing entrepreneurs determine the optimal (that is, profit maximizing) combination of n and r to be produced. This is not required as we can observe from the historical literature the actual choices of n and r during the early modern period and use them in the analysis. My aim is to explain the choice of printing technology at the market equilibrium that

actually took place, not to derive the theoretically optimal market equilibrium. Furthermore, deriving the market equilibrium would require specifying the demand function for books in early modern Europe and China - a process open to large speculation.[36]

What, then, were typical early modern values for n and r? We shall think of these magnitudes as the output of a printing enterprise over a reasonable planning horizon, say a few years. Over the early modern period most printing enterprises were quite small: data reported by Jeremiah Dittmar suggests that, over the period 1450-1600, the average European firm produced 16.6 titles per decade.[37] If the average number of pages per title was somewhere around 200 this suggests an output of some 3,300 distinct pages per decade for the average firm. Reasonable values for n would then range from the high hundreds to the low thousands. I will assume a similar range for China.

As for print runs, we know that in most cases these would vary from as little as 500 to as much as 3,000 in Europe – with some exceptions outside this range.[38] Buringh and van Zanden assume an average print run of 1,000 for early modern Europe, explicitly stating this is rather conservative, while Febvre and Martin advance an average print run of between 1,000 and 1,500 for 16th century Europe.[39] The little we know about Chinese print runs suggests a similar range for most printing works – the exception being the printing of religious tracts for non-commercial purposes.

Turning back to expression (3), if we plot the $n^*(r)$ function on a bidimensional space with variable r on the horizontal axis, we will find it intercepts the vertical axis at $\frac{F}{(\beta_b-\beta_m)}$. If, in addition, $\alpha_m > \alpha_b$ (as is the case for China with the parameter values in table 1), the function $n^*(r)$ will be increasing in r and tend towards infinity as r approaches $(\beta_b - \beta_m)/(\alpha_m - \alpha_b)$.

[36] For instance, the earliest estimate of literacy in China corresponds to the 19th century (Rawsky, *Education*), and even for Europe we have only very rough estimates for a few countries during the early modern period (Allen, "Progress and poverty"). We are even more in the darkness with respect to the price and income elasticities of book demand, or the share of income dedicated to buy books.
[37] My own calculation, using data from Dittmar, "New media", p. 8.
[38] Dittmar, "New media", p. 45.
[39] Buringh and van Zanden, "Charting the Rise", p. 415; Febvre and Marting, *Coming of the Book*, p. 218.

Figure 1 displays the function $n^*(r)$ for the case of China, with parameter values for movable type corresponding to the case of wooden types as reported in table 1. The area above $n^*(r)$ corresponds to combinations of n and r which would be produced using movable type, while combinations falling below this function would be produced using block printing. As is readily apparent, most printing jobs would be performed using block printing technology - in particular any printing job with a number of pages and a print run in the high hundreds or the low thousands. As these were the typical ranges for commercial publishers, most of them would have employed block printing - in accordance with the historical record.

[Figure 1]

As reported in table 1, movable type in China saves on the cost of creating new pages of text but has a higher cost per printed page than block printing, and this is reflected in the region of figure 1 where movable type is preferred: works where the number of pages is large and the print run small. We should note, however, just how small the print run needs to be before movable type is preferred. It may not be too uncommon for a relatively large book producer to plan a set of books covering 6,000 pages of text, but figure 1 shows that such producer would still prefer to use block printing unless his average print run is below 160. Indeed, the print runs for which movable type becomes preferable are well below the lower-bound estimate for commercial producers, which we set at around 500. On the other hand, the type of printing projects for which we know movable type was actually employed in China do fit well the description of a large number of pages and a small print run. Government projects such as the *Gujin Tushu Jicheng* could reach page numbers in the hundreds of thousands, while their print run was quite small since the work was not for sale but for distribution in a few selected places. Similarly, family genealogies were printed in very small runs

since the only potential buyers were the members of the family in question. At the same time, no two family genealogies are alike, so printers had to produce different pages for each family, leading to a large value of n.

In fact, we can take the explanatory power of the model even further and give theoretical grounding to one additional historical fact briefly mentioned above: that commercial printers of family genealogies used types made of wood while the Chinese government sometimes commissioned metal types.

Figure 2 below plots two versions of function $n^*(r)$ for China. The first one, which simply reproduces the one displayed in figure 1, compares block printing with movable type using wood (notice the change of scale in the vertical axis). The second one compares block printing with movable type using metal. The area below both of these two curves corresponds to the combinations of n and r where block printing technology would be used. Combinations above only one of the two $n^*(r)$ functions would be produced using either wooden or metal types, according to which curve is below them. There are, however, certain combinations of n and r which lie above both $n^*(r)$ curves. In order to identify the version of movable type being used, we can compare the cost functions under each case. Using equation (2), it is straightforward to show that movable type using metal would be preferred to its wood-based version if the following condition is met:

$$n > \frac{1}{r}\frac{F_{met}-F_{wood}}{\alpha_{m,wood}-\alpha_{m,met}} \equiv \tilde{n}(r) \qquad (4)$$

where F_{met} and F_{wood} are the cost of a full set of types using metal or wood and $\alpha_{m,met}$ and $\alpha_{m,wood}$ are the cost of producing copies using metal or wood. The function $\tilde{n}(r)$ is plotted in figure 2 over its relevant range (when a movable type technology is chosen), and it completes the characterization of the choice of printing technology for all possible combinations of n and r. Wood-based movable type would be preferred in regions A and B, while the metal-based version becomes cost effective in regions C and D.

[Figure 2]

Figure 2 reveals that wood-based movable type is preferred to its metal-based counterpart when the number of pages is not too high: notice that $\tilde{n}(r)$ continually approaches the vertical axis as the print run tends towards zero. For instance, movable type using metal is never employed for a project of less than 15,000 pages, whereas wood-based movable type would be chosen for such a project if the print run is small enough. When the value of n is in the tens of thousands, however, metal movable type may well be chosen; and this becomes more or less a certainty if the number of pages reaches beyond a hundred thousand. Government-led printing projects such as Imperial Encyclopedias were pretty much the only type of printing endeavour running into such a number of pages - and the model correctly predicts they would employ metal types. Family genealogies, in contrast, were typically short titles and even a large number of them would not stretch beyond a few thousand pages. It is therefore not surprising they were produced using wooden types.

The final part of the analysis incorporates Europe. Figure 3 juxtaposes function $n^*(r)$ for the European case with the corresponding function for China as first displayed in figure 1. As α_m and α_b are estimated to be the same for Europe, the function $n^*(r)$ becomes a horizontal line crossing the n axis at the value $\frac{F}{(\beta_b - \beta_m)}$ which, for the European case, equals 1,117 pages. The implication is that any printing firm thinking of producing more than this number of pages over their planning horizon would chose movable type, irrespective of the print run - the print run being of no consequence as movable type in Europe results in no disadvantage on the production of copies. Given that 1,117

pages is well below the average decadal output of European printing firms, estimated above at around 3,300 pages, we would expect even small printing firms to chose movable type.[40]

[Figure 3]

In definitive, and despite its mathematical simplicity, the analytical method adopted here gives a surprisingly good account of why movable type was universally adopted in Europe, block printing was the preferred technology for most of Chinese printing, and even in which instances movable type, whether using wooden types or metal types, was to be preferred in China. The analysis is economical in its informational requirements, as the demand side of the market does not need to be specified. I conclude that, as anticipated by historians of Chinese printing with a more informal approach, a formal economic analysis of printing costs confirms that China's logographic writing system made the use of block printing technology preferable to that of movable type for all but some very specific printing projects. China was not deficient in technical knowledge in the area of printing and the production and consumption of books was ruled by market forces to a similar degree as in Europe. China was just unlucky to have a writing system that rendered movable type printing exceedingly costly.

The following section asks whether the handicap of a logographic writing system could also explain China's much more limited printing output.

[40] The condition of producing more than 1,117 distinct pages of text is actually too demanding, as this is the number of pages that would render profitable investing in an average-sized printing workshop. A firm producing less than this number of pages would still use movable type, but with a smaller workshop.

V

As books were the main carriers of knowledge in pre-industrial times, the figures on book titles presented previously suggest that a far larger number of ideas circulated among the European cultural area than among the Chinese one – at least 15 times more if we compare total title production. Could printing costs be, at least partially, responsible for this? Or were the Chinese putting fewer ideas in circulation because, for cultural and institutional reasons, they were simply creating less of them? If the first case, the difficulty of adapting China's logographic script to movable type printing could be perceived as a reason behind China's relative stagnation over the early modern period, and therefore a major explanatory factor behind the Great Divergence.

The possibility that I explore here is whether China's use of block printing technology resulted in higher costs, more expensive books, and, finally, fewer titles being demanded and sold on the market. A simple way to evaluate this hypothesis is by comparing the unit cost of producing books in early modern China and Europe. Did China's logographic writing system resulted in higher costs, and if so, by how much?[41]

Perhaps surprisingly, the answer is that China was very likely able to produce books at a lower cost than Europe. To understand why the use of block printing did not result in more expensive books, we simply need to consider the expressions for unit costs deriving from equations (1) and (2). For block printing technology this results in:

$$\frac{c_b}{r} = \alpha_b n + \frac{\beta_b n}{r} \qquad (5)$$

while for movable type we have:

[41] I note that it would be very difficult to answer this question by directly comparing quotations of book prices from the historical literature, as we would need to compare two books with the exact same characteristics (length, quality of the paper, number and quality of illustrations, quality of the binding, etc.). Book prices could vary widely, often by one or even two orders of magnitude, according to such characteristics. Instead, I compare here the cost of transmitting the same amount of information in printed form at the lowest possible cost.

$$\frac{C_m}{r} = \alpha_m n + \frac{\beta_m n + F}{r} \qquad (6)$$

In both cases, unit costs converge towards the cost of producing one copy of the book (or set of books) in question as the print run increases. This is important because, while the fixed cost elements of printing were several times cheaper in Europe thanks to the standardized production of types, the cost of producing copies was actually lower in China thanks to the cost of paper. European printing would then enjoy lower unit costs only if these fixed costs elements dominate – in other words, if the print run was small enough.

Figure 4 plots the unit cost of producing a set of books totalling 3,300 pages of text as a function of the print run. Europe is assumed to use movable type technology while China uses block printing, and unit costs are given in days of low-skill labour. The figure of 3,300 pages is chosen as the plausible output for an average printing firm over a 10-year horizon, but very similar results are obtained with outputs ranging from 1,000 to 10,000 pages.

[Figure 4]

Figure 4 reveals that having access to a cost effective movable type technology did not result in lower unit costs for European printing under typical early modern print runs. European unit costs could be lower, but only for print runs up to 400 copies. Beyond this figure fixed costs were sufficiently spread out for Chinese unit costs to become lower. With a print run of 1,000, unit costs were already 19% lower in China, and the difference reached 26% with a print run of 2,000. This is already quite close to the difference in the cost of producing copies, which was 33% lower for China. Printing projects with a larger number of distinct pages favour movable type, but not by much. Even with 10,000 pages European unit costs would be lower only for print runs up to 500.

The conclusions of the last paragraph do not change if we take into account financing costs. Assume, for instance, that Chinese firms need to finance the production of woodblocks with a one-year loan charging an interest rate of 20%, while European firms finance the acquisition of types and printing presses with a one-year loan charging an interest rate of 8%. Results are very similar with the difference that European unit costs would be lower up to a print run of 500, while Chinese unit costs would be 15% lower with a print run of 1,000 and 24% lower with a print run of 2,000. By the same token, reasonable changes in the cost parameters that reflect the uncertain nature of the estimation exercise would not change the overall picture. So far, then, there is no reason to believe the choice of printing technology can explain lower printing output via higher prices.

One change that would make a difference is the one relating to the information content of Chinese and European text. Let us load the dice in favour of Europe by assuming that European text packs more information – namely that you need an average of 1.5 Chinese characters to transmit the information content of one English word. A Chinese page of 200 characters would then be equivalent to 133 English words, which we may round to half a page of English text. Under this assumption the Chinese would need to print two pages of text to convey the same information as one European page.

This renders Chinese printing more costly, but even then the difference is far from sufficient to explain the observed gap in printing output. Under this assumption European unit costs are 33% below Chinese ones for a print run of 2,000, and the difference in the cost of producing copies is 25%. Assuming that lower unit costs translate into proportionally lower selling prices, we would expect European consumers to pay about 30% less for their books (which would contain half as many pages but the same amount of information). Present-day estimates of the price elasticity of book demand are consistently higher than 1 in absolute value, and in most cases lower than 2.[42] Taking the top of the interval, a price elasticity of 2 implies that a 30% decrease in price results in a

[42] See, for instance, Hjorth-Andersen, "Danish book market"; Prieto-Rodriguez et al., "Cultural goods"; Ringstad and Loyland, "Demand for books".

doubling of the number of books purchased ($e^{-2\log(0.7)} = 2.04$). Assuming that such an increase in demand is met entirely by putting more titles in the market (and not by extending the print run of existing titles), this would lead to a doubling in the number of titles available.

Thus, under these most favourable conditions, differences in the cost of production would be capable of explaining a ratio of 2 European titles for every Chinese one. As the actual difference in titles produced per capita is north of 24 European titles for every Chinese one, I conclude that most of this gap cannot be explained by cost differences, even under a set of assumptions that render European costs much lower.

There is, however, one change in the assumptions underlying the above exercise which, if accepted, would generate a difference in the number of titles produced of the magnitude observed in the historical record. This change does not relate to costs, which as we have seen have modest effects, but to print runs. Average print runs in Europe and China have been assumed equal in the preceding discussion, as we compared unit costs for a given print run. This implies that a similar price of books, leading to a similar number of books demanded, would be served by a similar number of book titles. If we were to assume that, because of some particularity of block printing technology, Chinese print runs were much larger, a similar demand for books would be served by a correspondingly smaller number of titles.

The reason for considering this possibility is the observation that Chinese woodblocks had the capacity of producing at least 15,000 copies before becoming unfit for printing (see Appendix). If the Chinese routinely produced print runs of this magnitude, they would require 10 to 20 times less titles per capita to satisfy a book demand of the same magnitude as in Europe.

While suggestive, I regard the idea of much larger print runs in China as highly implausible and that for several reasons.

First, there is no direct evidence for it. As already mentioned, the printing of some religious tracts may have reached print runs in the tens of thousands, but what we require here is an average print run across all titles of that magnitude. That seems highly unlikely and, had it been the case, we would expect to have a much larger number of extant copies per title for Chinese works as compared to European works. In reality, "Chinese scholars of the book are struck by the relatively larger number of extant copies of European books from the sixteenth and seventeenth centuries".[43]

Second, there was probably not enough demand to support such large print runs. On this point we should not be led astray by China's massive population: during the early modern period transport costs implied a large degree of market segmentation, so that books were produced to a large extent for the local market. If we take city population as a first approximation of market size, European and Chinese book markets would have been quite comparable in size. China's largest city was far larger than Europe's, but other Chinese cities were quite comparable to European ones in terms of total population.[44]

Third, while larger print runs decrease unit costs, the magnitude of the effect seems too small to convince consumers to sacrifice around 90% of book variety. Indeed, under block printing technology passing from a print run of 2,000 to a print run of 20,000 decreases unit costs by 14%. One would expect consumers to signal a willingness to pay 14% more in book prices in order to have access to the titles they really want. In a competitive market, producers would comply.

Finally, from the perspective of Chinese producers, there was probably not much competitive pressure to lower unit costs by expanding the print run. This deserves some elaboration as the absence of copyright protection meant that free entry characterized the market for books in both China and Europe. While that is true, the cost structure of block printing technology would have acted as a deterrent to having more than one firm supplying each title. Indeed, once a Chinese

[43] Chow, *Publishing, Culture, and Power*, p. 249.
[44] See the data on city population from Nunn and Qian, "The potato's contribution".

producer had invested in a set of woodblocks for a given title, it could produce new copies of it by incurring only the cost of paper, ink and labour for printing. New entrants could then be priced out by the incumbent as they had to invest in a new set of woodblocks. This still leaves a Chinese producer in competition with the producers of other book titles, all vying for the Chinese consumer's money. If different book titles were highly substitutable items, this would indeed lead to price competition and a rush towards larger print runs – but that is unlikely. A book on traditional medicine is a poor substitute for a novel, and even novels tend to be quite different from one another. Price competition would then be low, as consumers would not be diverted from their preferred title by a lower price, and producers would not feel compelled to expand their print runs.

To summarize, the analysis provided in this section does not support the idea that the different cost structures of printing in early modern China and Europe could be responsible for the difference in the number of titles produced. In my central estimate Chinese unit costs are actually lower than European ones at print runs of 1,000 copies or higher, which would have resulted in more titles being produced in China. Only a major revision of our cost estimates, for instance by assuming that a page of Chinese text contains half as much information as a page of European text, results in higher costs in China. Even then, the magnitude of the cost difference is far too small to account for more than a small share in the difference in number of titles produced.

In conclusion, additional characteristics of these two societies, including institutional and cultural factors, would need to come into the picture to account for the observed differences.

VI

Numerous scholars in history, economics and the social sciences have emphasized the importance of printing in the emergence of Europe as the leading producer of knowledge and ideas in the modern world, followed by its economic and political dominance. Less research effort has been directed towards the question of why printing did not have similar (and earlier) effects in China. A natural place to look for an answer is the complexity of China's logographic writing system, which makes printing by movable type particularly difficult.

After a careful analysis of printing costs and a set of simulations exercises, this paper contributes to our understanding of this issue by reaching two important conclusions. First, that China's writing system offers a compelling explanation for China's choices of printing technology: block printing for the vast majority of commercial works, movable type for a few works with a large number of pages and a small print run. Second, that despite this difference in the technology of printing, the cost of producing books in China was not very different from that of Europe - and therefore could not be responsible for much of the observed difference in printing output.

This second result may be restated as follows. Over the early modern period, differences in printing output were largely not determined by supply forces, in particular printing technology. Instead, it was probably differences in demand, themselves determined by factors such as literacy rates and reading habits, the emergence of institutions of higher education, the organization of the book market, and overall economic development, which would have played a major role. A similar opinion has been expressed by Jan Luiten van Zanden.[45]

Additional support for this thesis comes from observing that printing output within China and Europe could experience large changes over time without any intervening change in printing technology. Indeed, book production in Europe passed from 79 million books during the first half of the 16th century to 628 million books during the second half of the 18th century. This was almost certainly unrelated to printing technology since, as James Mosley explains, "Some slight

[45] Van Zanden, “Explaining”, p. 340.

qualifications aside, there was a long period from the 1480s until around 1800 when the technology of printing was very stable".[46] For China, both national and regional data show a 10-fold increase in book production between the first and second half of the Ming dynasty - under a largely unchanged technology of block printing.[47]

A similar lesson may be learned from the experience of the Ottoman Empire, where the use of movable type technology was banned until 1726.[48] Once this prohibition was lifted books were produced using movable type, as Arabic is written using an alphabetic script much like European languages. The number of titles produced, however, was very small. The removal of an institutional barrier could not take away the deeper problem of insufficient demand due to structural factors.

I conclude by advancing that the Chinese logographic writing system, while highly inadequate for movable type printing, should not have represented a major obstacle for China's development given the availability of block printing technology. This does not preclude the possible existence of other problems linked to the particularities of this writing system, but that is beyond the scope of the present paper. If China's lower printing output is to be explained by the demand side of the market, the current emphasis in culture, geography and institutions as explanatory avenues for the Great Divergence seems vindicated.

[46] Mosley, “technologies of printing”, p. 135. The figures for book production in Europe come from Buringh and van Zanden, “Charting the Rise”.
[47] Chia, “Mashaben”.
[48] Cosgel et al., “Political economy”; van Zanden, “Explaining”.

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Table 1
Costs of printing in China and Europe

Item	*Cost (in currency units)*	*Cost (in days of low-skill labour)*
Block Printing in China		
β_b (woodblocks)	0.062 tael per page	1.38 days per page
α_b (production of copies)	0.017 tael per 100 pages	0.38 day per 100 pages
Movable type in China (wood)		
F (full set of types)	138 taels per set	3,067 days per set
β_m (text composition)	0.025 tael per page	0.55 day per page
α_m (production of copies)	0.026 tael per 100 pages	0.58 day per 100 pages
Movable type in China (metal)		
F (full set of types)	500 taels per set	11,111 days per set
β_m (text composition)	0.025 tael per page	0.55 day per page
α_m (production of copies)	0.019 tael per 100 pages	0.42 day per 100 pages
Movable type in Europe		
F (cost of printing workshop)	351 livres per workshop	1,170 days per workshop
β_m (text composition)	2 sols per page	0.33 day per page
α_m (production of copies)	3.4 sols per 100 pages	0.57 day per 100 pages
Block Printing in Europe		
β_b (woodblocks)	8.3 sols per page	1.38 days per page
α_b (production of copies)	3.4 sols per 100 pages	0.57 day per 100 pages

Sources: see online Appendix.

Figure 1

Block printing vs. movable type in China

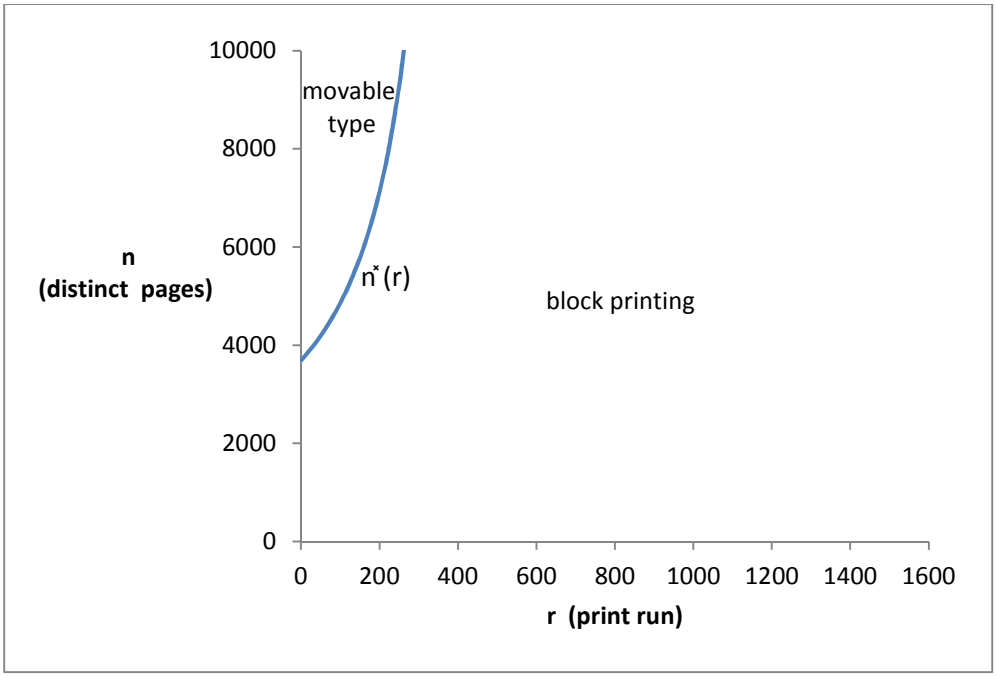


Figure 2

Movable type using wood and movable type using metal in China

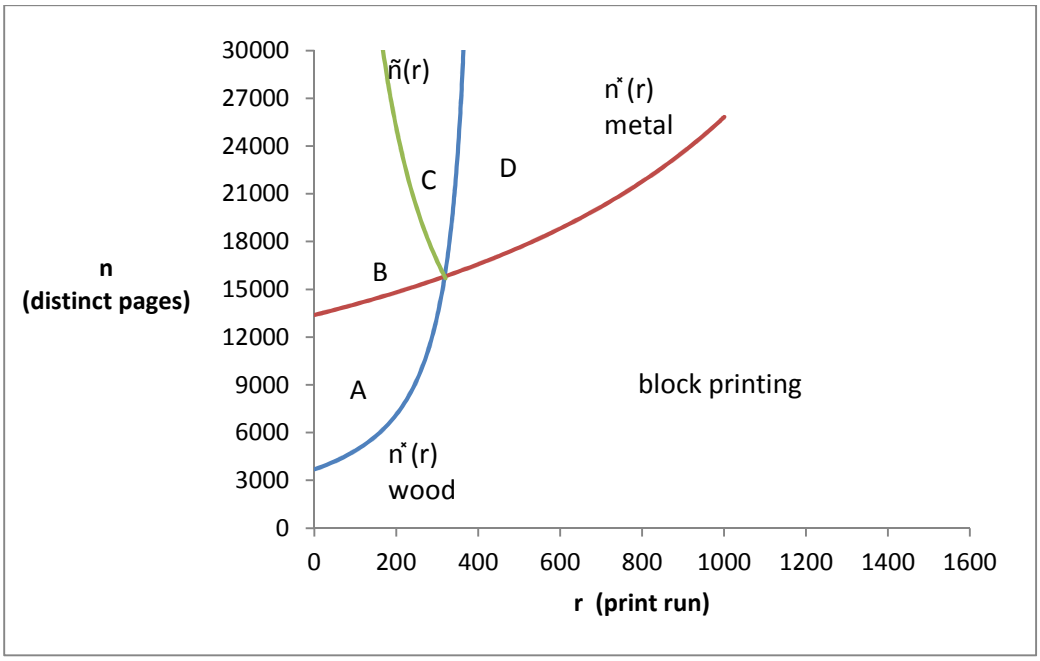


Figure 3
Block printing and movable type in Europe

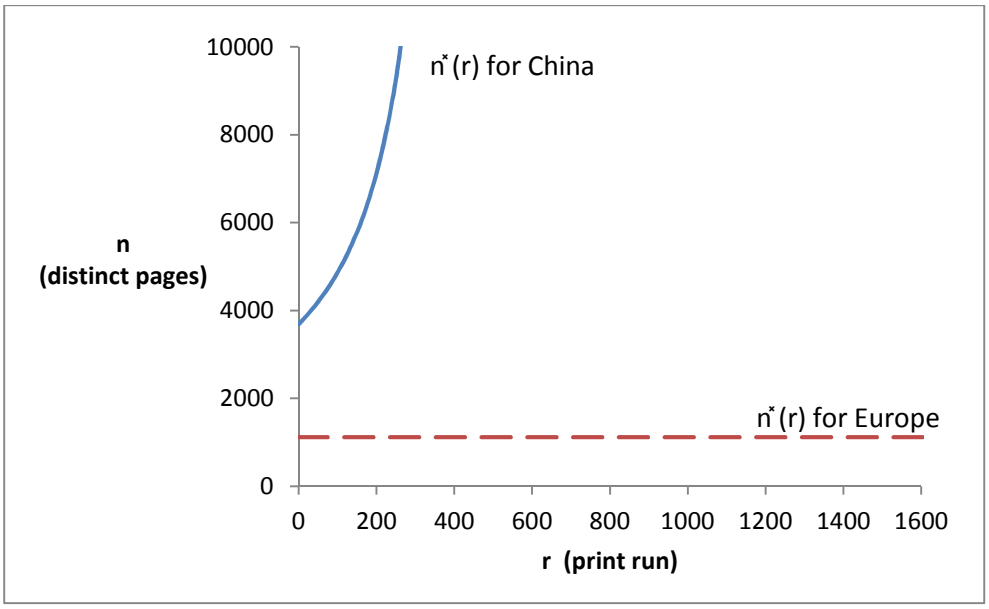
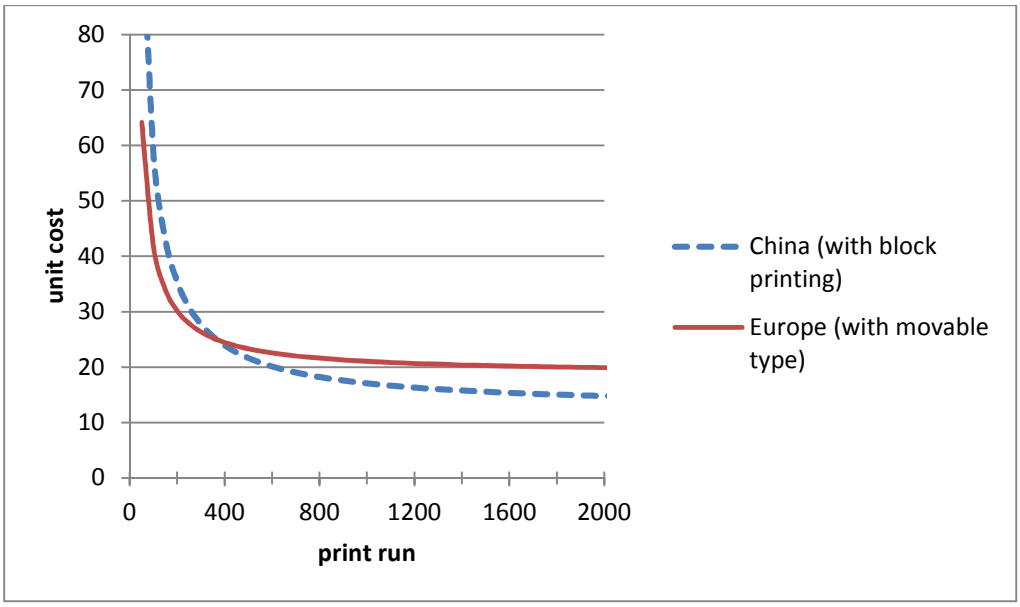


Figure 4
Comparing unit costs



Online Appendix for "The great divergence and the economics of printing", by Luis Angeles.

A. Estimating cost parameters for early modern China and Europe

i) Block printing in China

My source is the detailed analysis of Chinese printing in Kai-Wing Chow, which refers to the first half of the 17th century.[1] In block printing, the first element would be the cost of producing woodblocks. Chow (p. 37) estimates labour and materials for producing a standard woodblock side with two pages of text and 400 characters at between 0.10 and 0.15 tael. The cost per page is then between 0.05 and 0.075 tael, and I settle for a value of 0.062 tael per page in what follows.

Turning to the production of copies, Chow (p. 45) gives a detailed example in which the total cost of paper, ink and labour for printing and binding 560 copies of a 48-page document comes to 4.48 taels. This implies a cost of 0.008 tael per document, or about 0.017 tael per 100 pages printed. The paper employed in this case was bamboo paper, the most popular type of paper used in commercial printing in China and one of the least expensive ones. Since Chow (p. 29) also reports the cost of bamboo paper at 0.020 tael for 100 sheets (i.e. 200 pages), about 60% of the cost per printed page was due to the cost of paper – a figure quite in line with the European experience (see below).

In addition to the cost of paper, ink and labour, woodblocks would also need to be replaced due to wear and tear if a sufficiently large number of copies were produced. I am choosing not to include this cost in my calculations as the print runs of early modern works fall far below the estimated lifetime of woodblocks. Indeed, the literature suggests that the maximum number of copies that could be taken out of a woodblock lies anywhere between 15,000 and 40,000.[2] We have very scant evidence on print runs in early modern China, but the little we know suggests print runs in the high hundreds or the low thousands.[3] If print runs in early modern Europe are taken as a guide, no more than 3,000 copies would have been required for commercial publications.[4]

As discussed in the main text, cost parameters may be normalized by the daily wage of unskilled labour to allow for comparisons with Europe. Chow (p. 53) provides monthly wages for a number of occupations, and we may take the remuneration of a construction worker, at 0.99 tael per month, as

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[1] Chow, *Publishing, Culture, and Power.*

[2] Tsien (1985, p. 370) suggests a maximum of 25,000 copies out of a woodblock; McDermott (2006, p. 20-21) puts the figure at between 15,000 and 30,000, and possibly as much as 40,000; Drege (1994, p. 428) puts the highest number at 30,000.

[3] Drège, "L'impremerie", p. 427.

[4] Non-commercial publications such as religious tracts could be printed in higher numbers as the objective was precisely the widest possible distribution - not the production of profit. As discussed by McDermott, *A Social History*, p. 24, Christian missionaries considering different printing methods for the diffusion of the Bible in 19th century China did not opt for xylography precisely because their intended print run was well above 40,000. My analysis does not apply to such a case which, needless to say, is very different from the vast majority of book titles, which were printed for profit.

representative of low-skill labour. As monthly wages were between 20 and 25 times the daily wage[5], this results in a low-skill wage of between 0.04 and 0.05 tael per day for 17th century China. I will use a figure of 0.045 tael, almost identical to Allen et al.'s estimate of the average daily wage for 18th century China (0.044 tael).[6]

ii) Movable type in China

My source in this case is Martin Heijdra, who reports printing costs for two cases of movable type usage in 18th century China.[7] First, the production of a "Confucian Library" for the Hall of Military Eminence in Beijing (*Wuying dian*) - a government project using types made of wood. Second, the already mentioned *Gujin Tushu Jicheng*, also a government project but this time using types made of metal. As I will compare the cost of movable type during the 18th century to that of block printing during the 17th century, I am in fact favouring the choice of movable type in China as technical innovations may have lowered the cost of this technology in the century or so between the two estimates.

Government projects entailed the production of a huge number of types, about 250,000 in the case of the *Wuying dian*, as several different pages would have been printed in parallel. My objective here is to evaluate the cost of implementing movable type for a small commercial producer, for whom a far smaller set of types would have been sufficient. A printer of family genealogies offers a good example of such a small producer, and a set of just 20,000 types would have been enough for his printing activity using only one font.

Heijdra reports that wooden types for the *Wuying dian* were priced at 0.0069 tael per character - giving us a cost of 138 taels for a 20,000 set. For metal types, Heijdra reports a cost of 0.0250 tael per character, which results in a cost of 500 taels for a full set of types

The cost of paper, ink and labour for printing would have been the same as for block printing since the process was similar once the text was composed. I will thus use the estimate of 0.017 tael per 100 pages printed derived above. To this, however, we need to add the cost of replacing types, as these would wear out continuously during the printing process.

Based on the literature, a reasonable estimate for the number of impressions that could be taken out of a woodblock would be about 20,000 (see above). This gives an order of magnitude for the duration of wooden types as the material is the same, although types would have a shorter lifespan since they go through the process of text composition. Here I set their expected lifetime at 15,000 impressions, three quarters that of a woodblock. Unlike woodblocks, however, types are reused in

[5] See data from van Dyke, "The Canton trade".
[6] Allen et al., "Wages, prices".
[7] Heijdra "Technology, Culture and Economics".

different pages. Since each type corresponds to one character, a set of 20,000 types would need complete replacing after producing 300 million printed characters (under the assumption that all characters are used with equal frequency). With 200 characters per page this corresponds to 1.5 million printed pages. Thus, a set of 20,000 types would need to be replaced every 1.5 million pages, a rate of one type every 75 pages. With a price of 0.0069 tael per wooden type, printing cost would need to be augmented by 0.009 tael per 100 pages, taking the cost of producing copies with wooden types to 0.026 tael per 100 pages .[8]

It is more difficult to judge on the expected lifespan of metal types but, based on Heijdra, one could expect at least 10 times the number of impressions as for wooden type. This would result in an average replacement rate of one metal type every 750 pages which, with a cost of 0.0250 tael per type, leads to a cost of type replacement of 0.003 tael per 100 pages. The cost of producing copies with metal type would then amount to 0.019 tael per 100 pages.

The last element for assessing movable type technology is the cost of text composition. Unfortunately I do not have a direct quotation in nominal terms but at least two sources allow us to estimate its magnitude in relation to the production of woodblocks. The first one is Heijdra, who estimates the cost of composing a page of text in Chinese at almost exactly 50% the cost of producing that same page on a woodblock. The second one is McDermott, where the same comparison leads to a figure of 31%.[9] I will use an intermediate value of 40% in my calculations, which corresponds to a cost of 0.025 tael per composed page. I note that these figures do not imply that composing a page of text took between one third and one half the time of carving that same page, as the wages for compositors would have been much higher than the wages for carvers.

iii) Movable type (and block printing) in Europe

My source is the seminal work of Febvre and Martin, which details printing costs for early modern France.[10] One aspect that needs discussing is the fact that my estimates for movable type printing in China correspond to a very small printing enterprise - operating with a single font of 20,000 types. Most European printing firms were larger than this: they would have several letter fonts available, quite possibly more than one printing press (a piece of equipment never introduced in China) and, for the relatively large firms, punches and matrices to produce types (small firms would buy the types from larger firms). In theory, a small printing shop could be set up for as little as 50 livres, as the cost of one set of types ranges between 20 and 30 livres and a printing press would sell for between 23 and 30 (p. 110-111). While this constitutes a plausible lower bound, I will focus on larger estimates which better represent the average European printing firm. Febvre and Martin give

[8] I note that 1.5 million printed pages is not an implausibly high output over a planning horizon of a few years. It corresponds to the printing of 7 or 8 titles of 200 pages each with a print run of 1,000.
[9] McDermott, *A Social History*, p. 40-41.
[10] Febvre and Martin, *Coming of the Book*.

inventory values for three different printing firms in early modern France. I will use their middle example, which corresponds approximately to an average workshop, and comes at a value of 351 livres. Dittmar corroborates this value by giving an interval of between 250 and 600 livres for the cost of setting up a printing enterprise in early 16th century Europe.[11]

Turning to text composition, Febvre and Martin report that compositors in 16th century France were paid 12 sols per day by royal decree and completed between one and three forms per day (p. 131-132). We may assume that the rate of 3 forms per day corresponds to the folio format, where 2 pages of text are composed on each form, to be printed on one side of a sheet of paper.[12] As this format corresponds well to the Chinese one, I'll base my calculations on it. A European compositor would then prepare 6 pages per day, for a cost of text composition of 2 sols per page.[13]

The main element in the cost of producing copies was paper, and this would be the one area where we would expect Europeans to be at a disadvantage. Paper was more expensive in Europe since it was produced from rags, textile waste and cordage, which were in relative short supply as opposed to the abundance of bamboo and other plant material in China. Chow (p. 29) clearly states that paper was more expensive in Europe, and discusses how 16th century Dutch workers would have to sacrifice between 6 and 8 days of wages to buy a ream of paper (500 sheets, or 1,000 folio pages) - while the corresponding figure for China would be less than 3 days of labour. I have verified this claim using quinquennial data on paper prices from Jan Luiten van Zanden[14] and on wages for journeymen from de Vries and van der Woude[15], both for the Netherlands. Over the period 1550-1700 the ratio of these two measures fluctuates rather closely around an average of 6 days of labour for one ream of paper – which is the figure I use in what follows. Febvre and Martin report a wage for low-skill labour of 6 sols per day (p. 132), resulting in a price of 36 sols for one ream of paper.

This higher cost of European paper was to a large extent compensated by a more intensive usage. Indeed, Chinese paper was typically printed on only one side[16], while European paper was invariably printed on both sides. Thus, 36 sols would buy enough paper for printing 2,000 pages of text, as each sheet was printed with two pages recto and verso. In definitive, the cost of paper would amount to 1.8 sols per 100 pages.

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[11] Dittmar, “Information Technology”, p. 1155.

[12] The other European formats were the quarto and the octavo with, respectively, four and eight pages of text per form.

[13] We may verify this estimate by assuming a 10-hour workday, so that 6 pages per day imply a rate of one page every 100 minutes. If the average number of words per page is 250, this requires composing two and a half words per minute, not unreasonable for a well-trained compositor.

[14] Dataset "The prices of the most important consumer goods, and indices of wages and the cost of living in the western part of the Netherlands, 1450-1800". Available online at http://www.iisg.nl/hpw/brenv.php#biblio .

[15] De Vries and van der Woude, *Modern Economy*.

[16] McDermott, A Social History, p. 19. Arguably Chinese bamboo paper was too thin to permit impression on both sides.

To the cost of paper we need to add other costs of producing copies which, for the European case, include ink, labour for printing and binding, and the replacement of types. Paper was about half of total printing costs in early modern Europe[17], a ratio which would include among the total the cost of text composition but not the initial outlay in establishing a printing firm. Assume that the figure of 50% refers to a printing project of average size; say a 200-page text with a print run of 1,000. In that case the cost of text composition would amount to 400 sols and the cost of paper to 3,600 sols. Other printing costs would then equal 3,200 sols, or 1.6 sols per 100 pages. This takes the total cost of producing copies, including paper, ink, labour, and replacement of types, to 3.4 sols per 100 pages.

I finalize with an assessment of the likely cost of block printing in Europe. To the best of my knowledge, no direct estimates exist for the simple reason that this technology was hardly ever used in Europe: movable type replaced it shortly after its introduction. As the production of woodblocks would not have differed much between China and Europe, a reasonable approximation may be obtained by assuming that the cost of producing them, when expressed in terms of the daily wage, would have been the same as in China. As the Chinese cost of 0.062 tael per page corresponds to 1.38 times the daily wage, a reasonable estimate for Europe would be 8.3 sols per woodblock page. The cost of producing copies out of these woodblocks may be taken from the cost of producing copies using movable type in Europe, or 3.4 sols per 100 pages. This figure includes the cost of replacing types, which would not be present for block printing. Unlike the Chinese case, however, the cost of type replacement would have been extremely small in Europe. Assuming a cost of 30 livres for a set of 20,000 types results in 0.03 sol per type. With the same durability as metal types in China, this comes to a cost of 0.004 sol per 100 pages – quite insignificant next to an overall cost of 3.4 sols per 100 pages.

As for the Chinese case, all European costs may be normalized using the wage rate for low-skill labour which, as already mentioned, equalled 6 sols per day.

B. How important was the European printing press?

The cost estimates calculated above include any savings enjoyed by Europeans from the use of the printing press for the production of copies – instead of the manual method employed by the Chinese. I mention in the main text that the European printing press was probably of far less relevance than the standardization of type production in terms of cost reductions. Here I substantiate this claim.

According to Febvre and Martin (p. 132), a printing press, operated by two pressmen, would produce about 3,000 impressions per day. Quite surprisingly, this is not more than Matteo Ricci's estimate of

[17] Dondi, "The European Printing Revolution", p. 87; Febvre and Martin, *Coming of the Book*, p.113.

the number of copies that could be taken using the Chinese method – which he sets at 1,500 per person per day.[18] If we accept this figure, there would be no difference in the labour cost of producing copies between the two methods – something that I regard as unlikely since Europeans would have had no incentives to buy printing presses in the first place.

Instead, let us accept a lower estimate from Joseph McDermott, who reports that two men could produce about 2,000 impressions a day with the Chinese method.[19] If that is the case, using the Chinese manual method instead of a printing press would increase the labour cost of producing copies by 50% – how significant is that? As 3,000 impressions imply 6,000 pages of text in the folio format, the cost per printed page would be 1/3000 the daily wage of a pressman. This equals 0.2 sol per 100 pages if pressmen were paid 6 sols per day, and twice as much if they were paid as much as compositors. An increase of 50% in this cost would then equal between 0.1 and 0.2 sol per 100 pages, or between 3 and 6% the total cost of producing copies in Europe. As we see, the printing press may well have increased labour productivity substantially, but the labour cost of producing copies was a relatively small part of overall printing costs.

To put the above figure in perspective, consider the implications of the punch-matrix process on the cost of replacing types. Using metal types, the Chinese would have spent 0.003 tael per 100 pages in type replacement (see above), or 15% of the daily wage of low-skill labour. If we translate this in a European context, it would correspond to 0.9 sol per 100 pages. This cost would be almost entirely eliminated with the punch-matrix process. Once the savings on the initial outlay for a printing firm are added to this, the cost reductions from the punch-matrix process are about an order of magnitude larger than those from the printing press.

Note, however, that the savings made via the printing press were certainly large enough to make its acquisition a sound business. If 3,000 impressions could be taken at a cost of two days wages, instead of three days wages with the Chinese method, having a printing press would save one day of wages per day of operation. If a printing press sold for 30 livres, such savings would pay for it after a mere 50 to 100 days of usage.

Finally, if the acquisition of a printing press was such a sound business, why were they never adopted in China? Albeit the answer to this question is not essential for the main arguments of the paper, we may speculate that a higher cost of capital goods and a more restricted access to lines of credit are the likely causes.

[18] Chow, *Publishing, Culture, and Power*, p. 70.
[19] McDermott, *A Social History*, p. 23.

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