Ideas, Technology, and Economic Change: The Impact of the Printing Press

Jeremiah Dittmar*

April 10, 2009

DRAFT – COMMENTS WELCOME

Abstract

The movable type printing press was the signal innovation in early modern information technology, but economists have found no evidence of its impact in measures of aggregate productivity or income per person. A conventional explanation is that the printing press transformed a very small text and information processing sector which was marked by modest price elasticities. However, that argument makes no attempt to gauge the positive externalities associated with the diffusion of printing. This paper examines these externalities by exploiting city-level data on the establishment of printing presses in 15th century Europe. It analyses two principal questions: Was the new information technology associated with city growth? If so, how large was the association? I use propensity scoring methods to estimate the probability of technology adoption and the association between the adoption of the printing press and city growth. Between 1500 and 1600, cities where printing presses were established in the late 1400s grew at least 60 percent faster than similar cities which were not early adopters. Between 1500 and 1800, print cities grew 25 percent faster. I show that cities that adopted printing had no such advantage prior to adoption and that the association between adoption and subsequent growth was not due to printers anticipating future city growth or choosing auspicious locations. These findings are supported by analysis using OLS, difference-in-difference, and synthetic matching techniques. They address lacunae in the existing scholarship and speak to contemporary questions concerning ideas, growth, and the economic impact of information technology. Historical evidence confirms that the printing press was associated with localized spillovers in human capital accumulation and technological change.

*Contact: UC Berkeley, Department of Economics, Evans Hall #3880, Berkeley, CA 94720. Email: jdittmar@econ.berkeley.edu. Web: http://jedittmar.googlepages.com. This research is supported by a National Science Foundation Graduate Research Fellowship. I thank Barry Eichengreen, Chad Jones, Christina Romer, Brad DeLong, Peggy Anderson, and Suresh Naidu for discussions. The errors are mine.

1 Introduction

The movable type printing press was the signal innovation in early modern information technology. The first printing press was established in Mainz, Germany between 1448 and 1450. Over the next fifty years the techology diffused across Europe. Between 1450 and 1500, the price of books fell by 65 percent, transforming the ways ideas were disseminated and the conditions of intellectual work. Historians suggest the printing press was one of the most revolutionary inventions in human history.[1] Yet economists have found no evidence of the technology's impact in measures of aggregate productivity or per capita income – much as, until the mid-1990s, economists found no evidence of productivity gains associated with computer-based information technologies. A conventional economic explanation is that the economic effects of the printing press were limited: whatever the advances, they occurred in a very small sector marked by modest price elasticities.[2] However, that argument makes no attempt to gauge the positive externalities associated with the diffusion of printing. It leaves us to wonder whether the transformation in the ways ideas were disseminated and human capital was accumulated, and the associated development of business practices and a bourgeois public sphere, may have shaped the development of cities where printing technology was adopted early. This paper examines these spillovers by exploiting new, city-level data on the adoption of the movable type printing press in 15th century Europe. It uses city-level data to examine two principal questions: Was the new printing technology associated with city growth? And, if so, how large was the association?

To explore these questions, this paper compares cities where printers established presses to similar cities where they did not. The goal is to examine the key geographic, institutional, and demographic factors influencing whether or not a press was established in a given city by 1500. I use this analysis to estimate the conditional probability that a printing press would locate in a given city and then – controlling for this likelihood – to estimate the impact of the printing press on city growth using propensity scoring methods. I find that, between 1500 and 1600, cities that adopted the press in the late 1400s grew at least 60 percent faster than otherwise *similar* cities that did not; between 1500 and 1800 early adopters enjoyed a 25 percent growth advantage. Prior to adopting the press, cities that adopted the technology enjoyed no such growth advantage. Moreover, the association between technology adoption and subsequent growth is not due to printers correctly anticipating future city growth or

[1]See for instance Roberts (1996), Rice (1994), Braudel (1979c), and Gilmore (1952). On prices see van Zanden (2004).

[2]Clark (2001) argues that printing had a minimal macroeconomic impact for these reasons. Mokyr (2005a, 2005b) argues that it took centuries for the effects to fully emerge.

simply choosing auspicious locations. In general, entrepreneurial printers located in cities that were large, important, and housed universities and other public institutions – cities that had previously grown quickly. These cities typically grew slowly after 1500. This suggests that the correlation between growth and the printing press may reflect the positive spillovers elided in conventional economic treatments of the printing press.

Table 1 summarizes the key findings in this paper. It shows that cities that were early adopters of the movable type printing press grew significantly faster than similar cities that were not early adopters only after they adopted the technology in the late 1400s. Between 1500 and 1600, early adopters grew at least an additional 0.18 log points, when average growth across all cities was 0.27 log points. Between 1500 and 1700, early adopters grew an added 0.2 log points, when average city growth was again 0.27 log points. Prior to 1500, cities that adopted the movable type printing press in the later 1400s grew no faster than those that did not. It is also notable that while OLS estimates suggest that printing cities had an increasing and highly significant growth advantage through 1800, the estimates based on propensity scoring techniques suggest a more modest, stable growth advantage that was, by 1800, only borderline significant at conventional confidence levels. The pattern of growth over these longer periods reflects the significant demographic losses experienced by German printing cities over the 30 Years War (1618-1648).

Table 1: The Printing Press and Log City Growth

	Adopting Cities			
Period	Mean Years with Press	Growth Advantage OLS Estimate	Growth Advantage Propensity Score	Mean Growth for All Cities
(1)	(2)	(3)	(4)	(5)
1400 to 1500	24	0.05	0.00	0.18
		(0.08)	(0.08)	(0.53)
1500 to 1600	100	0.18 **	0.33 **	0.27
		(0.06)	(0.10)	(0.53)
1500 to 1700	200	0.24 **	0.20	0.27
		(0.09)	(0.14)	(0.78)
1500 to 1800	300	0.31 **	0.23 *	0.63
		(0.10)	(0.14)	(0.91)

Note: The propensity score estimates of print cities' growth advantage are calculated controlling for the probability of technology adoption. For details of the OLS and propensity score calculation see section 5. For estimates standard errors (in parentheses) are heteroskedasticity robust and significance at the 90 and 95 percent confidence levels is denoted "*" and "**", respectively. The data are described in section 4.

The historical evidence indicates that the printing press was associated with positive, localized economic spillovers in the accumulation of human capital, technological change broadly defined, and the emergence of urbane, commercial cultures. These spillovers were localized by the high transport costs associated with print media.

These findings bear on important questions concerning the diffusion of technology and ideas, growth, and economic geography. They qualify influential arguments concerning the role of Atlantic trading cities as key drivers of institutional change and economic development in pre-industrial Europe. They add a new dimension to arguments stressing the role of European cities as sites where information was exchanged, new ideas were produced, and the business practices and social groups that drove the rise of European capitalism developed.

2 Literature

Macroeconomic research emphasizes the central role ideas play in technological change and economic growth (for instance, Jones [2001a] and Jones [2004]). Moreover, a strand in the economics literature has framed technological change as a process in which existing ideas are combined in novel ways, to create new ideas. Mokyr (1995: 9) observes that, "successful invention feeds upon the exchange of ideas across different fields, a sort of technological recombination," and Weitzman (1998) formalizes just such a theory of "recombinant growth." This work suggests that major changes in the conditions of intellectual work – or in the the ways ideas can be compared, transmitted, exchanged, and combined – may have far reaching consequences.

In large-scale surveys, social historians have hailed the movable type printing press as an innovation with a revolutionary social impact. Braudel (1979c: 435) frames movable type printing as one of the three great technological revolutions marking the period running from 1400 to 1800 (the other two being advances in artillery and navigation). Gilmore (1952: 186) states that, "The invention and development of printing with movable types brought about the most radical transformation in the conditions of intellectual life in the history of western civilization." Roberts (1996: 220) argues that, "The outcome was a new diffusion of knowledge and ideas dwarfing in scale anything which had occurred since the invention of writing itself...That the innovation of scholars and scientists and the facts on which they were based could be diffused more easily than ever before was of outstanding importance."

Historians specializing in the study of the diffusion of printing present more mixed views. Eisenstein (1979: 33, 72-75) argues that the advent of movable type printing inaugurated "a new cultural era," diffusing ideas, bringing scattered ideas into contact, and opening new possibilities for "combinatory intellectual activity." However, Eistenstein emphasizes that the new technology wrought its changes very gradually. Febvre and Martin (1958) similarly argue that the effects of movable type printing emerged over the very long run. Febvre and Martin (1958: 420) stress the role of print media in the rise of humanism, the development of scientific thought, and the intellectual opening associated with the reformation. However, they observe that, "by popularising long-held beliefs, buttressing old prejudices and seductive errors, it seems to have contributed to the social inertia opposing many new ideas" and contend that, "On the whole it could not be said to have hastened the acceptance of new ideas."[3]

For their part, leading economic arguments concerning Europe's transition to "modern," capitalist economic growth devote relatively little attention to information technology *per se*. The literature on "unified growth" models describes how technological and demographic change may lead to the emergence of an industrial revolution and "modern" economic growth when the returns to human capital are increasing (e.g Lucas [1997], Goodfriend and McDermott [1995], Galor and Weil [2000], and Jones [2001b]). This literature emphasizes population growth as the factor driving the innovations of the industrial revolution.[4] However, Mokyr (2002: 29) suggests that, "the true key to the timing of the Industrial Revolution has to be sought in the scientific revolution of the seventeenth century and the Enlightenment movement of the eighteenth century." Historical studies suggest that the printing press facilitated these intellectual developments, the process of sharing and recombining ideas that economists have tied to technological progress, and the development of economic activities in which literacy, numeracy, and other intellectual skills were valuable. Indeed, there is an argument to be made that – via its pervasive and fundamental impact on a wide range of economic activities – printing technology may qualify as a general purpose technology.[5]

Among economic historians, there is some difference of opinion about the extent to which the movable type printing press was a revolutionary innovation. Stressing the technical aspects of the innovation, Mokyr (1990: 12) suggests that, "Some inventions, such as the printing press...contradict the gradualist model of technological

[3]All translations from foreign language sources are mine.

[4]In Goodfriend and McDermott (1995) the transition from a pre-industrial to an industrial era occurs as population growth drives the expansion of a market sector: eventually a sufficiently large population and increasing returns in the modern sector lead people to begin investing in learning, precipitating an industrial revolution. In Galor and Weil (2000), population growth is the underlying cause of the technological changes that drive the economy away from a Malthusian regime. In Jones (2001b) population growth raises the rate at which new ideas are discovered, driving an acceleration in growth rates and precipitating an industrial revolution.

[5]Lipsey et al. (1998) suggest, in passing, that printing was a general purpose technology.

progress." Jones (1981: 60-62) describes the invention of movable type printing as a "quantum jump," arguing that "the printing press began to push down the price of information" and that "western progress owed much to the superior means of storing and disseminating information." Mokyr (2005a: 1120-1122) observes that innovation depends crucially on the cost of accessing existing knowledge, and that the printing press, "clearly was one of the most significant access-cost-reducing inventions of the historical past." Recent work by Baten and van Zanden (2008) is consistent with this argument. Baten and van Zanden examine Allen's (2003) simulated model of historic economic growth and find a significant association between simulated national-level wages and empirical differences in aggregate book production.[6] However, Clark (2001: 53) finds that, following the introduction of Gutenberg's print technology in the mid-1400s, there is no evidence of increases in the growth rates of aggregate productivity or output per person. Mokyr (2005a: 1118, 2005b: 299) similarly argues that the aggregate effects were small and that two centuries passed before the printing press "lived up to its full potential."

The fact that the book and manuscript sector was tiny may lead us to expect that innovations in printing would have had negligible effects on overall economic productivity and measures of well-being. But as Clark (2001: 56) observes, the perspective of aggregate productivity may not provide a complete picture of an economy's technological dynamism:

> Suppose that prior to the Industrial Revolution innovations were occurring randomly across various sectors of the economy – innovations such as guns, spectacles, books, clocks, painting, new building techniques, improvements in shipping and navigation – but that just by chance all these innovations occurred in areas of small expenditure and/or low price elasticities of demand. Then the technological dynamism of the economy would not show up in terms of output per capita or in measured productivity.

This argument about the impact of printing – whatever the advances, they occured in a small sector with modest price elasticities – recalls Fogel's argument for why railroads could not have accounted for large economic changes in the post-Bellum USA. But just as one would not want to neglect the institutional and organizational spillovers associated with the railroads, so one would want to see whether the externalities associated with the diffusion of print technologies might be estimated.

Printing was an urban technology. This paper documents that there were important, localized spillovers to the technology at the city level (see sections 3 and 5

[6] The simulation in Allen (2003) treats the country-specific wage as an endogenous variable in a simple, five equation model of European development.

below).

Economists working on a range of questions emphasize the importance of cities. Lucas (1988: 38) observes that the spillovers associated with human capital accumulation and economic growth are what secure "the central role of cities in economic life." Contemporary work on urban economics indicates that cities are associated with increased sharing of information, superior matching between workers and employers (and between buyers and sellers in general), and significant technological spillovers.[7] Historically, European cities played a central role in the emergence of modern, idea-based capitalist economic growth. Bairoch (1988: 499) characterizes the city as the "agent of civilization," and calls our attention to the fact that urban life opened the way for "social contacts fostering the circulation of information" and favoring innovation. Postan (1975: 239) schematically described the cities of pre-modern Europe as "non-feudal islands in a feudal sea," and Braudel (1979a: 586) has argued that, "Capitalism and towns were the same things in the West."[8] Historians and economists have observed that city sizes were historically important indicators of economic prosperity; that broad-based city growth was associated with macroeconomic growth; and that cities produced the economic ideas and social groups that transformed the European economy.[9]

3 The Mechanism

This section describes how the adoption of printing technology impacted city growth in early modern Europe. The key point is that cities that adopted print media benefitted from positive, localized spillovers in human capital accumulation and technological change broadly defined. These spillovers contributed to city growth by exerting an upward pressure on the returns to labor, making cities culturally dynamic, and thus attracting migrants. They were localized by high transport costs historically associated with inter-city trade.

City growth typically reflects how attractive cities are as places to live and as labor markets (Glaeser et al. 1995). Historically, migration drove city growth. Migration was central because urban death rates exceeded urban birth rates, and cities drew migrants to the extent that they offered relatively high wages and attractive cultural

[7]See Duranton and Puga (2004) for a review of the micro evidence and theories.

[8]Historical research has qualified these generalizations but confirms the importance of cities. See Dittmar (2008) for further discussion.

[9]See, for example, Acemoglu et al. (2005), DeLong and Shleifer (1993), Bairoch (1988), Braudel (1979a, 1979c), and Hilton (1978).

and economic opportunities.[10] Moreover, in the pre-industrial era, commerce was in general a much more important source of urban wealth and income than exportable industrial production.[11] As a result, city growth was typically contingent on commercial success.[12]

Print media played a key role in the acquisition and development of skills that were valuable to merchants and businessmen. Print media contributed to the spread of literacy, the accumulation of human capital, and technological change. More broadly, print media fostered the emergence of dispositions, competencies, and aptitudes (a "habitus") reflective of and suited to life in a commercial environment.[13]

For merchants engaged in large scale and long-distance trade, numeracy and the ability to keep sophisticated accounts were associated with high returns. Following the invention of movable type printing, European presses produced a stream of commercial arithmetics. The commercial arithmetics of the European renaissance were the first printed mathematics textbooks and were designed for students studying maths in preparation for careers in business.[14] They transmitted commercial know-how and quantitative skills by working students through problem situations concerned with determining payments for goods, currency exchanges, calculating interest, and the determination of profit shares in business partnerships.[15] The first known printed mathematics text is the *Treviso Arithmetic* (1478). It begins:

> I have often been asked by certain youths...who look forward to mercantile pursuits, to put into writing the fundamental principles of arithmetic...Here beginneth a Practica, very helpful to all who have to do with that commercial art... (Reproduced in Swetz [1987: 40])

[10]On migration and the demography of pre-industrial cities see Woods (2003b), de Vries (1984), Bairoch (1988), Braudel (1979a), Feher (2001), and McIntosh (2001).

[11]See *inter alia* Nicholas (1994: 7) and Braudel (1972: 319)*.

[12]Political capitals were exceptions to this rule. See Dittmar (2008) for discussion.

[13]Historians have emphasized the role of print media in the reformation and the role of religious sentiment in creating a demand for printed texts (e.g. Gilmont [1998], Edwards [1995], Eisenstein [1979], and Hay [1962]). I stress here the effects of print media on the development of economically useful skills and knowledge and – more broadly – schemes of perception, thought, and action acquired in and reflective of a commercial environment.

[14]They were employed in urban schools and by private teachers that specialized in teaching commercial arithmetic. The schools and instructors taught mathematics to adolescents who planned to enter commercial careers, and operated parallel to universities, which typically did not provide business-oriented preparation. The Italian system of *scula d'abbaco* was the model. In Italy a teacher was known as a *maestri d'abbaco*, in France as a *maistre d'algorisme*, in German cities as a *rechenmeister*. See Docampo (2006), Speisser (2003), Swetz (1987), and Goldthwaite (1972).

[15]For example, a typical problem in Johannes Widman's *Arithmetic* (1489) opens: "A man goes to a money-changer in Vienna with 30 pennies in Nuremberg currency..." The *Treviso Arithmetic* (1478) poses questions such as: "Three merchants have invested their money in a partnership....Piero put in 122 ducats, Polo 200 ducats, and Zuanne 142 ducats. At the end of a certain period they found that they had gained 563 ducats. How much falls to each man so that no one shall be cheated." Quoted in Nicholas (1994: 177).

Gaspar Nicolas, author of the first Portuguese arithmetic (1519), opens his volume in a similar fashion:

> I am printing this arithmetic because it is a thing so necessary in Portugal for transactions with the merchants of India, Persia, Ethiopia, and other places." (Quoted in Swetz [1987: 25])

The first German and Catalan arithmetics were printed in 1482. The first French and Spanish arithmetics were printed in 1512. The first English commercial arithmetic was printed in 1537. Hundreds of commercial arithmetics were printed 1480-1550.[16]

Print media was also associated with the diffusion of cutting-edge business practice. In 1494, Venetian printers published Luca Pacioli's *Summa de arithmetica, geometria, proportioni et proportionalita*. The *Summa* was the leading comprehensive mathematics textbook of its day and is notable for containing the first published description of double-entry book-keeping. Social scientists have stressed the importance of double-entry book-keeping as a technological innovation since the early 20th century, when Werner Sombart and Max Weber argued that it played a key role in the emergence of rational, optimizing business practice.[17] More generally, merchants' handbooks often combined instruction in accounting and commercial arithmetic with non-quantitative guidance on business practice. For instance, Catalan printers published the *Llibre que esplica lo que ha de ser un bon mercader* (1490) and English printers produced John Browne's *Marchant's Avizo* (1589), which provided guidance on business practice and cross-cultural communication for merchants engaged in international trade and ran into several editions. Other handbooks contained tables designed to simplify the calculation of interest on loans.

The role of print media in the diffusion of industrial innovations may have been more limited.[18] However, by the 16th century, technical books such as Brunschwygk's *Liber de Arte Distillandi* (1500), Biringuccio's *Pirotechnia* (1540) which described reverberatory furnaces employed in glass industries, Digges's *Panometria* (1571), and Zimmermann's *Probierbuch* (1573) appeared in all the major European languages, and significantly influenced workshop practices.

[16]See Docampo (2006) and van Egmond (1980).

[17]The idea pre-dates Sombart and Weber. In *Wilhelm Meister's Apprenticeship* (1795, Bk. I, Ch. X), Goethe ironizes, "What advantages does he derive from the system of book-keeping by double entry! It is among the finest inventions of the human mind..."

[18]Cipolla (1972) observes that Zonca's *Nuovo Teatro di Machine et Edificii* (1607) provided a detailed description of silk throwing machines that were only brought to England 100 years later – after several years of active industrial espionage. Cipolla observes that historically the diffusion of technology was dependent on the movement of skilled workers themselves. This observation is consistent with the emphasis this paper places on localized spillovers from print media and the pattern of technology diffusion described below.

More broadly, print media was associated with the development of new, bourgeois competences, preferences, and ways of thinking.[19] The urban middle classes were the principle purchasers of books. Between 1450 and 1500, printing technologies spread to meet a specific demand:

> demand for books among the merchants, substantial artisans, lawyers, goverment officials, doctors, and teachers who lived and worked in towns...men who needed to read, write, and calculate in order to manage their businesses and conduct civic affairs, who were being educated in increasing numbers in town and guild schools, and who in the fifteenth century were swelling the arts faculties of the universities. (Rice 1994: 6)

A culture developed in which schooling in languages was part of a progression in which pupils went from "arts to marts". For the first time, some cities began to run schools for children who were not going to learn Latin – using printed grammar school texts. In the 15th century, it became expected that the children of the upper bourgeoisie would attend school.[20] Bolgar (1962: 428) observes that, "Some measure of elementary education was sought after by all who wished to raise themselves a little in the world." This sort of mobility – one contingent on education and literacy – was the mobility of city dwellers. Moreover, as Eisenstein (1979: 250-151) observes, the printer's workshop brought scholars, merchants, craftsmen, and mechanics together for the first time in a commercial environment. It produced not just books, but the printer-scholar, "a 'new man'...adept in handling machines and marketing products even while editing texts, founding learned societies, promoting artists and authors, [and] advancing new forms of data collection." Broadly, the new technology was associated with an emerging culture of information exchange and the development of an urban, bourgeois public sphere.[21]

However, high transport costs limited the circulation of print media and imparted a localized bias to the spillovers from print technologies. While widely traded, print media was famously heavy, sensitive to damp, and as a result costly to transport.[22] For instance, Febvre and Martin (1958: 169) observe that joint contracts between printers in Lyons and Poitiers from the late 1500s indicate that the allowance for transport costs associated with a journey of approximately 360 kilometers raised the

[19] Mokyr (2005a) defines competence as extending beyond the ability to read, interpret, and execute the instructions of a technique to include supplemental tacit knowledge. Nicholas (1994: 187) notes that print media was "the important avenue by which 'civility' reached the citizen." Eisenstein (1979: 44) observes that printing introduced a "new element to urban culture."

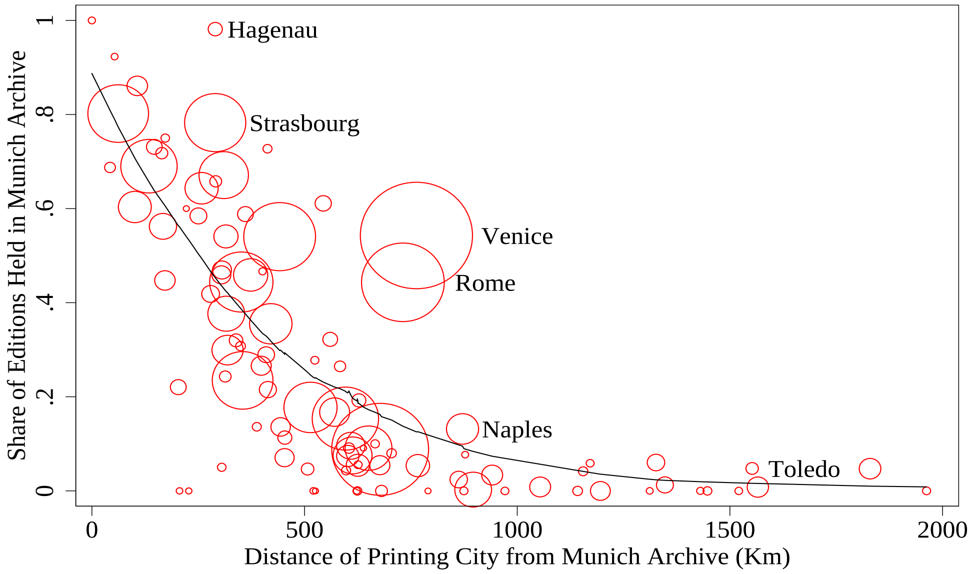
[20] See Nicholas (1994) and Bolgar (1962).

[21] See Zaret (1992, 2000), Long (1991), Smith (1984), Hay (1962), and Laqueur (1976).

[22] See Barbier (2006) and Febvre and Martin (1958).

sale price of transported books by 20 percent. Archival holdings provide additional evidence of the limits on the trade in print media. The Bayerische Staatsbibliothek (Bavarian State Library, in Munich) houses the world's largest and most comprehensive collection of books printed 1450-1500.[23] Figure 1 examines the Bayerische Staatsbibliothek holdings. It shows that the proportion of the editions produced in a given city and held in the Bavarian archives declines sharply in the distance between the printing city and the archive. Consistent with this evidence, historians observe

Figure 1: Evidence of Limits on Book Trade
Archive Holdings & Distance from Point of Production



Note: This figure presents data for the 100 printing cities with the highest output of *incunabula* editions 1450-1500. For each city it shows what share of its editions are held in the Bayerische Staatsbibliothek in Munich and how far the city is from Munich. The markers are scaled to reflect the magnitude of each city's book production. Fitted values estimated with locally weighted regression. The data are described below.

that transport costs in early modern Europe were sufficiently high that print media often spread through reprinting rather than inter-city trade.[24]

[23]The Bayerische Staatsbibliothek holds historical collections acquired by Duke Albrecht V. In 1558, Albrecht acquired the private library of Johann Albrecht Widmannstetter. In 1571, Albrecht also purchased the private library of the international banker Johann Jakob Fugger. Additional acquisitions were made as German monasteries were dissolved in the 1802-1803 period. As discussed below, books from this infant industry era are called *incunabula*.

[24]Edwards (1994: 8) observes: "If, for example, there was an interest in Strasbourg for a work first published in Wittenberg, it was more common for a printer in Strasbourg to reprint the work than it was for the printer in Wittenberg to ship a large number of copies [500 kilometers] to Strasbourg."

4 Data

This paper exploits data on the diffusion and output of printing presses over the technology's infant industry period. Between 1450 and 1500, entrepreneurs established printing presses across Europe and the price of books fell by at least 65 percent. Between 1500 and 1800, printing technology was largely unchanged and the declines in the price of books were relatively modest. Historical research emphasizes that the period 1450-1500 was the critical "first infancy" of printing. Books produced over this period are referred to as *incunabula*, from the Latin for cradle or infancy.[25]

Data on the production of *incunabula* editions provide valuable but imperfect measures of production: pamphlets, booklets, and other ephemera constituted a large, unmeasured share of output. The production of booklets and ephemera was less concentrated than the production of expensive books and the inter-city trade in these forms of print media was relatively limited.[26] Because booklets and other ephemera played an important role in the development of literacy and print culture, this paper emphasizes the establishment of printing presses.

I construct data on the location and output of printing presses over the infant industry period from three principal sources.[27] I match the printing press locations to data on historic cities defined and described below.

- The first source is the *Incunabula Short Title Catalogue* (ISTC 1998) maintained by the British Library. The ISTC (1998) is an international database that "records nearly every [incunabulum] printed from movable type before 1501." The ISTC (1998) records 27,873 printed books. Each record includes the title, publication date, and location of publication. A limited number of records are without information on publication date or the precise location of the printing press. The ISTC catalogues 15th century editions printed in 196 historic cities.[28]

- The second source of data is Febvre and Martin's (1958) *L'Apparition du Livre*. Febvre and Martin document 181 historic cities that adopted the printing press

[25]Barbier (2006), Glomski (2001), Clair (1976), and Febvre and Martin (1958) discuss the infant industry period. Füssel (2005), Raven (1992) and Febvre and Martin (1958) discuss the absence of significant technical change 1500-1800. For book prices see van Zanden (2004). The *OED* defines *incunabula* as: "(1) The earliest stages or first traces in the development of anything. (2) Books produced in the infancy of the art of printing; specifically those printed before 1500."

[26]See Edwards (1994: 8), Eistenstein (1979: 59), Febvre and Martin (1958), and Barbier (2006).

[27]In addition to the three principal sources, *Meyers Konversations-Lexikon* (1885) and Cipolla (1982) provide data on the location and timing of adoption for relatively small subsets of cities.

[28]Of the 27,873 records, 1,352 are either undated or are associated with dates outside 1450-1500 and 738 do not give a precise city location, indicating only a regional location or possible city locations. Of the 2,204 historic cities identified by Bairoch et al. (1988), 196 appear in the ISTC (1998) as early adopters of the new technology.

between 1450 and 1500.

- The third source of data is Clair's (1976) *A History of European Printing*, which provides data on the establishment of printing presses in continental Europe between 1450 and 1500. Clair documents 188 historic cities that adopted the press over the infant industry period.

The data on the locations and populations of Europe's historic cities are from Bairoch et al. (1988). Their approach is to identify the set of cities that ever reached 5,000 inhabitants between 1000 and 1800, and then to search for population data for these cities in all periods. The data are intended to record (in thousands) the populations of urban agglomerations, not simply populations within administratively defined boundaries.[29] These data – henceforth the "Bairoch data" – are recorded every 100 years up to 1700, and then every 50 years to 1850. This data set contains a total of 2,204 historic European cities.[30]

In total, the historical sources identify 205 unique cities that adopted the printing press between 1450 and 1500.[31] Table 2 summarizes the data on printing presses and cities. It bears noting here that ISTC (1998), Clair (1976), and Febvre and Martin (1958) identify printing presses at some locations that do not appear in the Bairoch city data. These were overwhelmingly printing presses in more or less isolated religious establishments.[32] Other "missing" print centers were close to cities that did have presses and may represent a sort of duplication. Westminster with its proximity to the city of London is a case in point. In keeping with the economic understanding

[29]Bairoch et al. (1988: 289) make a special effort to include, "the 'fauborgs', the 'suburbs', 'communes', 'hamlets', 'quarters', etc. that are directly adjacent" to historic city centers. Bairoch et al. draw data from urban censuses, tax records, archaelogical work, as well as other primary and secondary sources. Prior to publication the data was reviewed by 6 research institutes and 31 regional specialists in urban history.

[30]I exclude Malta and a small number of cities formerly in Soviet central Asia. The Bairoch data accord closely with the leading independent source for city population data, the database in de Vries (1984). These data are examined in greater detail in Dittmar (2008).

[31]This figure comprises the 196 cities on which we have records of printed editions from ISTC (1998). It also includes four cities identified by Febvre and Martin, four cities identified by Clair, and one city identified by both Clair and Febvre and Martin.

[32]In total there are 40 such locations. Of the 14 missing centers in Italy, 6 were located at towns that were seats of Catholic dioceses. Subiaco is a representive example of a "missing" print center. Conrad Sweynheim and Arnold Pannartz established a printing press by the hillside monastery of St. Scholastica at Subiaco, Italy in the 1460s. Known for its sacred grotto, Subiaco was not a historical city and does not appear in the Bairoch data. Like Gutenberg himself, Sweynheim and Pannartz left Mainz in mid-1460s, following the city's sack by Archbishop Adolf II, the imprisonment and exile of opponents, and the revocation of the city's privileges. They came to Subiaco at the invitation of Cardinal Torquemada and by 1472 had moved on to establish a press in Rome. Other examples of non-urban religious sites that received the press are found in England (St. Albans, near London), Sweden (the monastery of Vadstena), France (the archbishopric of Embrun, the epispocal see at Moûtiers, and the monastery and bishopric of Tréguier), Germany (the monastery at Schussenried), and Spain (the diocesian seat of Coria).

Table 2: The Diffusion of the Printing Press 1450-1500

20th Century Polity	Cities Adopting Printing Press	Total Number of Historic Cities	Share Adopting
(1)	(2)	(3)	(4)
Austria	1	17	6%
Belgium	9	72	13%
Czechoslovakia	5	36	14%
Denmark	2	10	20%
England	3	165	2%
France	39	341	11%
Germany	40	245	16%
Hungary	1	47	2%
Italy	56	406	14%
Netherlands	11	60	18%
Poland	3	55	5%
Portugal	6	53	11%
Spain	24	265	9%
Sweden	1	20	5%
Switzerland	4	19	21%
Total	205	1,811	11%

Note: See text for sources.

of urban agglomeration, and the construction of the Bairoch data, this paper treats production of print media at Westminster as London output.

The econometric work below also exploits a new database on the historical characteristics of European cities, including data recording: which cities were located on navigable rivers, ports, and the sites of Roman settlement; which were political or religious centers; and measures of economic institutions. These and all other data are described as introduced and in the appendix.

5 Empirics

5.1 Overview

Per capita income data is not available at the city level, and the existing data on urban wages is confined to a small number of cities.[33] However, the consensus in the literature on urbanization in Europe is that population size was an indicator of the overall vitality and well-being of cities in early modern Europe.[34] Moreover, city

[33]For instance, Allen (2007) has compiled data on real wages in 20 cities.
[34]Acemoglu et al. (2005), Bairoch (1988), and de Vries (1984).

growth may reflect technological progress.[35] For these reasons, this paper focuses on the relationship between the adoption of print technologies and city growth. Because data on the number of presses in operation are only available for a few cities, and because the available measures of output are very coarse, I focus on adoption. However, I exploit data on the number of editions printed in a given location as an index of total production.

The starting point for teasing out the impact of print technologies is a comparison of average outcomes for adopters and non-adopters. However, the cities adopting printing were unusual. They were large, concentrated in particular regions, and often housed institutions of higher learning. With this in mind, the next step in the analysis is to adjust for differences in exogenous characteristics that may be associated with post-1500 city growth. After analysing the diffusion process, this paper exploits several approaches to do this. First, it estimates the probability that each city will adopt, conditional on its exogenous characteristics. Accounting for this conditional probability, I use propensity scoring approach to estimate the average treatment effect of technology adoption on city growth. I also present estimates based on difference-in-differences, first-differences, and synthetic control group techniques.

5.2 Comparison of Average Outcomes

This section first compares the population growth of cities that were early adopters of print technology to the growth of cities that were not. It then presents regression estimates showing that there was a very large, statistically significant association between the establishment of printing presses and subsequent city growth. Sections 5.3 and 5.4 explore the diffusion process and selection effects in greater detail.

Table 3 compares, by country, the growth 1500-1600 for cities that were early adopters to the growth of cities that were not. It includes all cities for which population data is available. It shows that, on average, cities that adopted the press in the late 1400s grew 20 percentage points more and over 4 times faster than non-printing cities 1500-1600. However, the cities that adopted were unusually large. For the countries in Table 3, 26 percent of cities with population data adopted, but adopting cities account for 54 percent of total urban population in 1500. However, the Netherlands stand out as an economy in which printing press cities grew relatively slowly 1500-1600. Table 4 shows that the print cities' growth advantage declined to a more modest 7 percentage points 1500-1800, implying print cities grew 1/5 faster over the

[35] See Glaeser et al. (1995) for modern economies. In a Malthusian economic regime, or one with Lewis-style unlimited supplies of surplus labor in agriculture, technological change in the urban sector will also show up in city growth.

Table 3: Print Technology and City Growth 1500-1600

20th Century Polity	Press Adopted: No. of Cities	Press Adopted: Urban Pop. 1500	Press Adopted: Weighted Average Growth	Press Not Adopted: No. of Cities	Press Not Adopted: Urban Pop. 1500	Press Not Adopted: Weighted Average Growth	Print City Growth Advantage
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Austria	1	20	0.92	7	43	-0.03	0.95
Belgium	8	202	-0.08	15	136	-0.27	0.19
Czechoslovakia	2	85	0.23	6	25	0.25	-0.02
Denmark	1	10	1.39	1	3	0.51	0.88
England	2	55	1.16	38	166	0.21	0.95
France	21	662	0.20	28	347	0.04	0.16
Germany	27	360	0.16	53	318	0.12	0.04
Italy	34	1,119	0.26	62	442	0.24	0.02
Netherlands	9	104	0.34	17	119	0.53	-0.19
Poland	3	77	0.60	14	96	0.08	0.52
Portugal	4	87	0.56	3	19	0.04	0.52
Spain	19	359	0.37	55	554	-0.15	0.51
Sweden	1	7	0.25	17	27	0.06	0.20
Switzerland	3	27	0.25	3	8	0.00	0.25
Totals	135	3,174	0.27	319	2,303	0.07	0.20

Note: The print growth advantage (column 8) is calculated the difference between average growth for adopting and non-adopting cities (column 4 - column 7).

three centuries following the diffusion of the press. It also shows that in Germany – where printing originated – print cities grew relatively slowly over long periods.[36]

For Germany this slow growth was associated with military conflict in which many large, previously flourishing cities were depopulated. In Germany, print cities grew quickly through 1600, and then experienced slow growth in the 17th century. From 1618, Germany suffered through the Thirty Years War; and, as Heilleiner (1967: 40 and 43) observes, "The demographic catastrophe which befell the German people in the decades after 1618 had no parallel in other countries." In the Netherlands, the relatively poor growth record of print cities over the period to 1800 is entirely accounted for by slow growth before 1700. The Netherlands were the site of military conflict through much of the 16th century and from 1621, following the expiration of the Twelve Years Truce.[37] However, "exogenous" factors are not the whole story: in Holland printers set up presses in the commercial cities of the Hanseatic league (De-

[36]The slow growth of formerly Czechoslovak print cities is entirely accounted for by Prague's demographic collapse, which was associated with the re-imposition of serfdom and the city's fall from being a political capital.

[37]Leiden was notable as the city in which the Elsevier publishing house was based. In 1572, Leiden was besieged by Spanish (Catholic) forces and lost 1/3 of its population.

Table 4: Print Technology and City Growth 1500-1800

20th Century Polity	Press Adopted: No. of Cities	Press Adopted: Urban Pop. 1500	Press Adopted: Weighted Average Growth	Press Not Adopted: No. of Cities	Press Not Adopted: Urban Pop. 1500	Press Not Adopted: Weighted Average Growth	Print City Growth Advantage
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Austria	1	20	2.51	7	43	0.09	2.42
Belgium	8	202	0.32	25	174	0.05	0.27
Czechoslovakia	4	109	-0.05	7	29	0.87	-0.92
Denmark	1	10	2.31	1	3	-0.41	2.72
England	3	60	2.48	52	213	1.19	1.29
France	26	700	0.44	48	440	0.44	-0.01
Germany	30	374	0.26	79	387	0.44	-0.18
Hungary	1	12	0.73	4	29	1.15	-0.41
Italy	34	1,119	0.38	67	463	0.37	0.01
Netherlands	11	118	0.32	22	142	0.72	-0.40
Poland	3	77	0.39	15	100	-0.02	0.41
Portugal	4	87	1.05	21	114	0.26	0.79
Spain	19	359	0.30	56	556	-0.07	0.37
Sweden	1	7	2.38	17	27	0.67	1.72
Switzerland	3	27	0.60	8	26	0.51	0.09
Totals	149	3,281	0.43	429	2,746	0.36	0.07

Note: The print growth advantage (column 8) is calculated the difference between average growth for adopting and non-adopting cities (column 4 - column 7).

venter, Zwolle, and Nijmegen) that had previously been fast growers but experienced slow growth after 1500.

As post-Reformation conflicts, the wars in Germany and the Netherlands owed something to printing. Historians observe that the intellectual ferment and spread of the Reformation was closely linked to the innovations in printing.[38] The wars in Germany and the Netherlands were, along important dimensions, religious struggles. So we cannot reject out of hand the possibility that the printing press – by helping open an era of religious strife – may have had deleterious economic effects. Any such negative effects would tend mute the positive effects of technological adoption. They would also raise the possibility that the technology had heterogeneous effects across economies. I return to this question below.

Table 5 presents regression estimates. These estimates show that cities that adopted the printing press in the late 1400s grew no faster than other cities 1400-1500,

[38]Martin Luther was Europe's first best-selling author. In the 1520s, 20 percent of pamphlets printed in Germany were Luther's work. See Scott (2004), Gilmont (1998), and Edwards (1995).

but enjoyed very large and significant growth advantages after 1500. The estimates

Table 5: Regression Analysis of Print Media and City Growth
Dependent Variable is Log City Growth

Independent Variable	Pre-Adoption 1400-1500	Post-Adoption 1500-1600	Post-Adoption 1500-1700	Post-Adoption 1500-1800
(1)	(2)	(3)	(4)	(5)
Print Adoption	0.04	0.18 **	0.24 **	0.28 **
	(0.08)	(0.06)	(0.08)	(0.09)
Editions Per Capita	0.04	0.03	0.03	0.05
	(0.04)	(0.02)	(0.03)	(0.03)
University	-0.03	0.01	0.17 *	0.15
	(0.10)	(0.07)	(0.09)	(0.10)
Catholic Site	-0.38 **	0.29 **	0.09	0.14
	(0.19)	(0.14)	(0.20)	(0.18)
Roman Site	0.09	-0.03	0.10	0.06
	(0.06)	(0.05)	(0.07)	(0.07)
Capital	0.33 **	1.03 **	1.54 **	2.11 **
	(0.12)	(0.16)	(0.22)	(0.26)
Exec Constraint Index	-0.47 **	0.27 **	-0.29 *	-0.46 **
	(0.06)	(0.13)	(0.16)	(0.11)
Freedom Index	-0.28 *	0.32 **	0.17	0.05
	(0.14)	(0.16)	(0.18)	(0.13)
Port	0.14	0.42 **	1.19 **	1.22 **
	(0.16)	(0.13)	(0.22)	(0.22)
Navigable River	0.15 **	0.18 **	0.24 **	0.40 **
	(0.08)	(0.06)	(0.09)	(0.09)
Population	-0.22 **	-0.31 **	-0.43 **	-0.64 **
	(0.04)	(0.04)	(0.05)	(0.05)
Country FE	Yes	Yes	Yes	Yes
Observations	291	495	515	622
R Square	0.33	0.31	0.32	0.44

Note: Editions per capita measured as editions published 1450-1500 per 100 inhabitants in 1500. City growth 1400-1500 is taken as a placebo (in each of these samples the average date of adoption was 1476). The Appendix presents similar results estimated over a balanced panel of cities and excluding the cities of Eastern Europe. Heterskedasticity-robust standard errors in parentheses. Significance at the 90 and 95 percent confidence indicated "*" and "**", respectively.

control for the geographic, institutional, and cultural growth factors identified in the economic history, urban economics, and economic geography literatures as determining urban growth: population size, the presence of religious, political, and educational institutions; the nature of economic institutions securing protection against expropriation; and advantages associated with locations at ports, navigable rivers, and sites where Roman settlements were established (see Hohenberg and Lees [1985], DeLong and Sheifer [1992], Acemoglu et al. [2005], and Dittmar [2008]). They show that the adoption of the printing press was strongly associated with subsequent city growth, but not with growth before its invention. On average European cities grew by 0.27 log points 1500-1600. Table 4 shows print cities growing an additional 0.18 log points over this period (i.e. 67 percent faster). The estimates also show that, controlling for adoption, high levels of print output in the late 15th century were associated with relatively fast growth between 1600 and 1800. Appendix B presents similar results estimated over a balanced panel and excluding the cities of Eastern Europe that were exposed to the institutions of the Second Serfdom post-1500. These findings support the conclusion that print technologies mattered for city growth within Western Europe.[39]

5.3 Technology Adoption

Because the printing press was not randomly assigned to cities, an examination of its impact must account for the diffusion process and the factors associated with the establishment of printing presses. This section describes the process through which the technology was brought to and adopted by the cities of Europe.

The movable type printing press was developed in Mainz, Germany around 1450.[40] In subsequent decades entrepreneurial printers spread the technology across Europe:

> For a long time the printer's trade...was almost exclusively German. The master printers in the first workshops were either apprentices of Gutenberg and Schoeffer or workmen who had learned from these apprentices...The enterprise and spirit of adventure of this small group of men was astonishing. They were willing to leave their master's shop and travel across Europe. (Febvre and Martin 1958: 257)

Over the period 1450-1500, the barriers to entry were financial and technical – not regulatory. The production of movable type required specialized skills and knowledge of metallurgy. The cost of a complete set of equipment was equivalent to the wages a craftsman would earn over a period of 4 to 10 years.[41] However, printing with movable type was a sufficiently radical break from past practice that it fell outside

[39] On the impact of the "second serfdom" see Dittmar (2008).

[40] Before he moved to Mainz, Gutenberg was developing the technology in Strasbourg. There were also concurrent attempts along similar lines in Avignon and Haarlem. But the break-through was in Mainz, and the technology diffused from there. See Barbier (2006), Glomski (2001), and Clair (1976).

[41] Gilmont (1998: 18) states that a press cost 20 to 40 *livres tournois* in the mid-16th century, but that purchasing a font cost between 250 and 600 *livres*. Febvre and Martin (1958: 110-115) report data from a 1520 bequest consistenting of three presses, two molds and dies, and 8 worn fonts – valued at 351 *livres*. They also report a bequest of the materials of a top-of-the-line establishment

existing guild regulations. Füssel (2005: 59) observes that over the infant industry period the business was, "free to develop without regulation by governments, princely houses or the Church, nor is there any evidence that any restrictions were imposed by guilds." Barbier (2006) and Nicholas (1994) confirm that printing fell outside the set of regulated trades and that entry was free and unregulated.[42]

In the decades after Gutenberg's innovation, worker-enterpreneurs installed printing presses throughout Europe. Ulrich Hahn established the first press in Rome in 1467. Heinrich Botel and Georg von Holz established a press in Barcelona in 1473. Hans Wurster and Heinrich Turner established presses in Modena (1475) and Toulouse (1476), respectively. Hans Pegnitzer and Meinard Ungat established a press in Granada (1496), just four years after the last of the Nasrid monarchs (Muhammad XII) surrendered to Ferdinand and Isabel. Map 1 shows the pattern of diffusion.

The technology diffused through a search process. The process was shaped by demand-side fundamentals, as entrepreneurs looked for locations that could sustain a printing press, but had an important random component. Febvre and Martin (1958: 257, 265) observe that, "What they all sought was a financial backer to provide capital so they could establish themselves permanently," and a town with, "a stable and sufficiently extensive clientele." Cities with universities, or with sovereign political and legal institutions, typically provided stable markets. However, historians observe that the entrepreneurs' information was incomplete and that random and accidental factors shaped the process through which they settled on locations. Clair (1976: 23) observes that a notable fraction of the early printers became "nomads, trusting to luck to find a backer who would enable them to settle and establish themselves." Febvre and Martin (1958: 261) observe that the interest of particular capitalists, patrons, and religious institutions had in making texts available was the "first factor" in the diffusion process, suggesting idiosyncratic factors mattered.[43] Gilmont (1992: 349) observes that the diffusion process was "anarchic" and that a set of early print centers were able to "maintain an eminent position in subsequent centuries." Gilmont (1998: 12) further argues that early diffusion was, "guided more by chance than

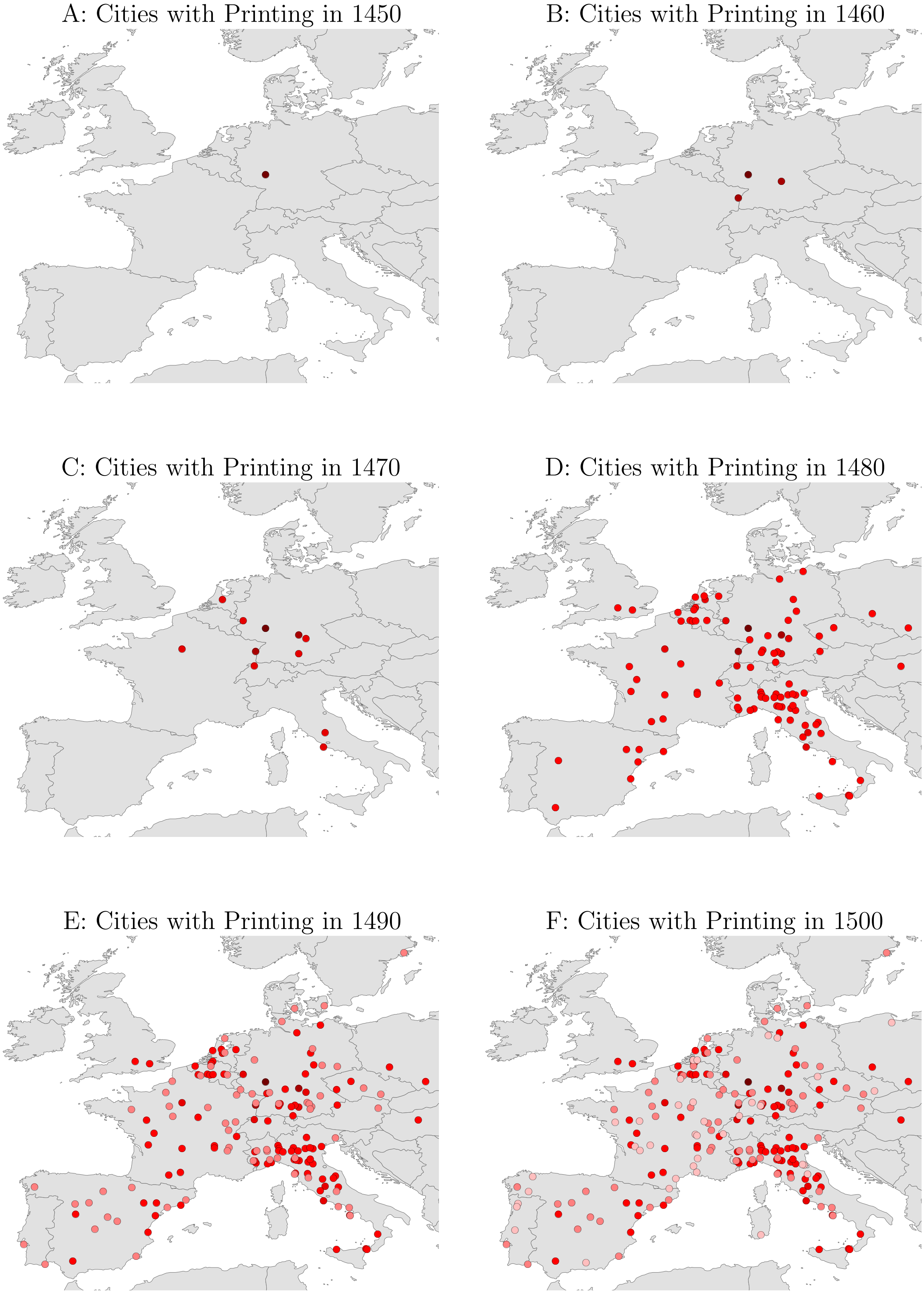
---

including 5 presses and 10 good fonts and valued at over 700 *livres*. A *livre* was worth 18.7 grams of silver between 1500 and 1550 (see Allen and Unger [2007]). Data in Allen (2007) shows that the average nominal wage earned by a Parisian craftsman over this period was 4.4 grams of silver per day (across 18 European cities it was 4.7 grams). Assume, conservatively, that craftsmen worked 275 days a year once Sundays, Saints' Days, and other holidays are accounted for. Then, assuming equipment costs between 250 and 600 *livres*, the capital needed to purchase the equipment and materials required to establish a press was equivalent to the wages the average Parisian craftsman would earn over a period of between 4 and 10 years.

[42] Barbier (2006: 173): "les métiers nouveaux liés à l'imprimerie ne s'insèrent pas dans le cadre des anciennes corporations...dans les faits la liberté rest tout à fait réele et les voies d'ascension ouvertes." Nicolas (1994: 125): "Trades that became large after the list of officially approved guilds was drawn up often escaped guild regulation...Printing is the most obvious example."

[43] Examples include printers invited to Rome, Chartres, Erfurt, and Florence.

Map 1: The Diffusion of the Movable Type Printing Press

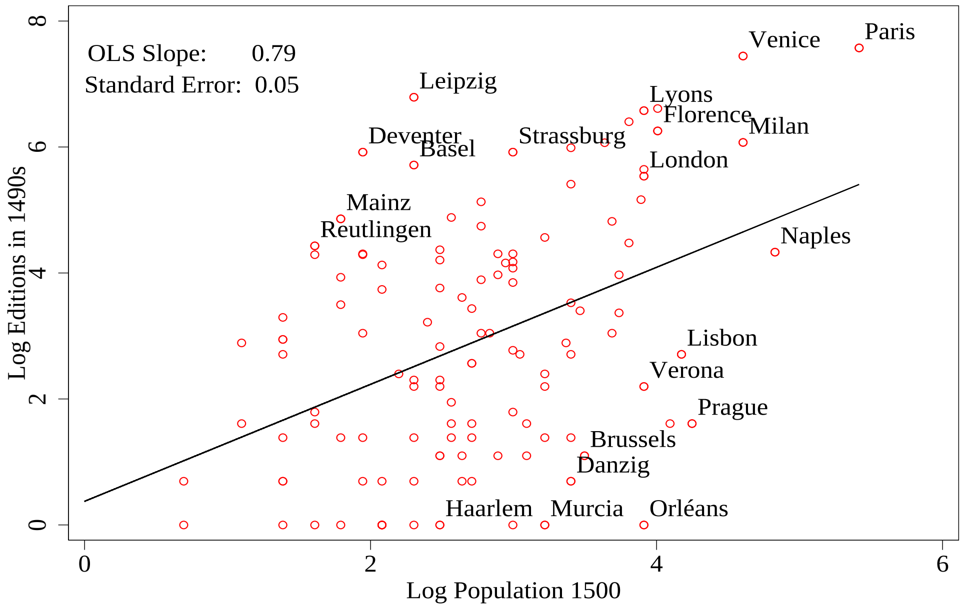


Note: This figure documents the diffusion of the movable type printing press from Mainz, Germany. In total, 204 cities adopted the technology over the infant industry period. Approximately, 1 in 10 European cities were early adopters.

by any assessment of profitable centers" in which to establish presses. Similarly, and in keeping with the the evidence in Map 1, Barbier (2006) observes that cities relatively close to Mainz were more likely to receive the technology other things equal. Consistent with a "noisy" search process, 40 of Europe's 100 largest cities did not have printing presses in 1500.

Among cities with printing presses, larger cities tended to produce more print media, but there was no significant correlation between per capita output and city size.[44] Figure 1 plots the number of editions printed in the 1490s against city population in 1500. It shows that print media production was relatively low in several very large cities and very high in a number of smaller German cities.

Figure 2: Print Media Output and City Population Circa 1500



Note: Output is the number of *incunabula* editions recorded in ISTC (1998).

5.4 Propensity Score Analysis

This section employs a propensity scoring approach developed in the program evaluation literature to examine the factors associated with adoption and the association between print technology and city growth.[45] The propensity score is an index of the likelihood of adoption. In this context, it sheds light on potential endogeneity

[44]The correlation coefficient is 0.1 and is insignificant.

[45]See Imbens and Wooldridge (2008), Imbens (2004), and Wooldridge (2002) for reviews.

problems in ways OLS methods cannot. Specifically, I find that while adoption of the printing press was associated with high growth, the likelihood of adoption was negatively associated with future growth. This analysis suggests that entrepreneurs established printing presses at cities that had previously experienced relatively high growth, but that they did not accurately forecast future growth.

Let us denote the logarithm of gross city population growth over some period after 1500 by Y_i. Let us denote the binary adoption (or "treatment") variable by T_i:

$$T_i = \begin{cases} 1 & \text{if} \quad \text{city adopted printing press by 1500} \\ 0 & \text{if} \quad \text{city did not adopt printing press by 1500} \end{cases}$$

A vector X_i captures each city's pre-treatment population growth and other pre-treatment characteristics (e.g. the presence of a university, important religious site, or political capital; country indicators; location on a navigable river, port, or Roman site; and institutional variables). For every city i, we observe (T_i, Y_i, X_i). We posit:

$$Y_i \equiv Y_i(T_i) = (1 - T_i)Y_i(0) + (T_i)Y_i(1)$$

In a clean experiment, the average treatement effect (ATE) of technology adoption is:

$$ATE = \mathbb{E}_i \left[Y_i(1) - Y_i(0) \right].$$

But historical data are marked by an unobserved counterfactual. For any city we observe $Y_i(0)$ or $Y_i(1)$, not both. Hence to estimate the ATE we need to construct a comparison of outcomes across similar treated and control observations – a comparison of cities that saw the establishment of presses to similar cities that did not.

The propensity score is the probability of technological adoption, conditional on city characteristics:

$$P(X_i) = \Pr(T_i = 1 | X = X_i) = \mathbb{E}\left[T_i | X = X_i \right]$$

By accounting for this conditional probability, we can control for selection into technology adoption and examine the extent to which cities with printing presses grew faster (or slower) than otherwise similar cities that did not adopt the new information technology.

I estimate propensity scores using a logit model in which the binary variable capturing whether or not print technology was adopted by 1500 is a function of: city size, the Polity-IV index of national-level constraints on the executive in 1400 and 1500, an extended version of DeLong and Shleifer's (1993) indicator for whether the prevailing regime was "Prince" or "Free", the presence of a university, and country fixed effects. I also include variables capturing whether a city was on a port or navigable river or the site of Roman settlement and whether the city was historically the location of a university or important religious site.[46] It is reasonable to inquire whether the establishment of printing presses in neighboring cities impacted adoption decisions elsewhere.[47] However, I find no evidence of such effects once one controls for country fixed-effects and distance from Mainz and do not report these specifications.[48]

Table 6 presents parameter estimates from an OLS and logit regressions examining the factors associated with the adoption of print technology. It shows that adoption was significantly associated with city size, the presence of a university, and – even controlling for cities' country location – with distance from Mainz, Germany. The results also suggest that access to waterborne transport was not a significant determinant of adoption. City size in 1400 and city size in 1500 are included as regressors to capture the association between pre-treatment growth rates and adoption. The identifying assumption is that – although adoption occurred in the late the 15th century – the adoption decision did not impact city size in 1500. The country fixed effects begin to capture and control for the regional aspect of diffusion, but should not be taken to suggest that national economies and were anything more than incipient. The baseline specification examines cities with observed population in 1400 and 1500. The alternative specification examines all cities population observed in 1500. As shown below, the estimated association between printing and growth is very large and significant across either sample. However, with a larger number of observations, estimates using the alternative sample have lower standard errors.[49] Of more concern is omitted variable bias, an issue to which I return below.

I use the parameter estimates from Table 6 to compute propensity scores.[50] Figure 3 plots the densities of propensity scores for adopting and non-adopting cities. It shows that the propensity scores of cities that adopted the printing press in the late 1400s are typically high and that most non-adopting cities had low estimated

[46]The results I report below are not contingent on the inclusion of the extended DeLong-Shleifer freedom index either qualitatively or in terms of rough magnitude. Including an indicator for political capitals does not substantively change the OLS results. Because all capitals adopted printing presses, these observations are dropped from logit specfications.

[47]Barbier (2006: 170) suggests Parisian and Lyonnais presses "imposed themselves" on the Spanish market.

[48]I examined the effect of neighbors' adoption within various distances and using distance and distance squared as weights.

[49]The increase in sample size 1400-1500 is overwhelmingly due to new observations on the populations of Western cities. Of the "new" cities first observed in 1500, 52 are Spanish, 25 Portuguese, 48 Italian, 15 Dutch, 65 German, 32 French, 34 English, and 15 Belgian.

[50]A flexible logit specification in which adoption is a function of each of the variables in Table 5, their squares, and interactions yields very similar propensity scores and does not substanticely change the conclusions one draws about the association between print technology and city growth.

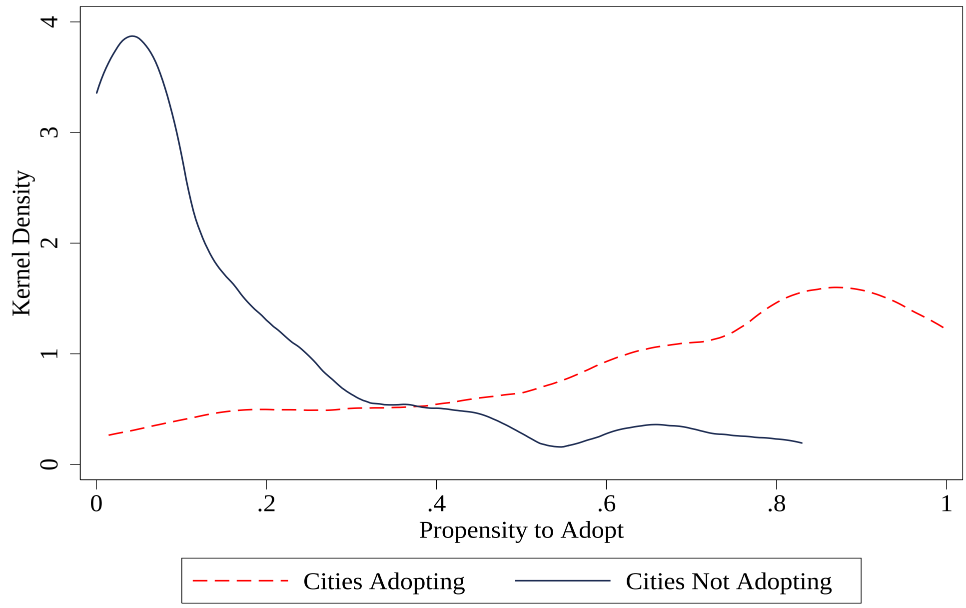
Table 6: Regression Analysis of the Adoption of the Print Press

Independent Variable	Baseline Logit	Baseline OLS	Alternate Logit	Alternate OLS
(1)	(4)	(5)	(2)	(3)
City Population 1500	0.60	0.07	1.37 **	0.16 **
	(0.42)	(0.05)	(0.18)	(0.02)
City Population 1400	1.14 **	0.13 **		
	(0.41)	(0.05)		
Distance Mainz	-0.25 **	-0.03 **	-0.20 **	-0.02 **
	(0.11)	(0.01)	(0.08)	(0.01)
University	2.61 **	0.33 **	2.28 **	0.40 **
	(0.73)	(0.07)	(0.46)	(0.05)
Roman Site	0.58	0.09 *	0.70 **	0.11 **
	(0.43)	(0.05)	(0.30)	(0.04)
Catholic Site	0.12	0.01	0.74	0.09
	(0.98)	(0.11)	(0.67)	(0.08)
Exec Constraint 1500	2.78	0.33 **	-0.26	0.18 *
	(1.74)	(0.15)	(1.71)	(0.09)
Exec Constraint 1400	0.94	0.16	2.25 **	0.14 **
	(1.25)	(0.15)	(0.95)	(0.06)
Freedom 1500	-3.74 **	-0.86 **	-2.84	-0.55 **
	(1.84)	(0.37)	(2.30)	(0.20)
Freedom 1400	0.85	0.13	0.21	0.07
	(1.41)	(0.13)	(0.83)	(0.08)
Navigable River	0.52	0.07	0.38	0.06
	(0.49)	(0.06)	(0.36)	(0.05)
Port	-0.78	-0.07	-0.42	-0.04
	(0.54)	(0.06)	(0.40)	(0.04)
Country FE	Yes	Yes	Yes	Yes
Observations	291	291	631	631
F Statistic		10.64		16.81
LR Chi Square	175.15		257.15	
R Square	0.47	0.47	0.37	0.37

Note: "Exec Constraint" is the value of the Polity-IV index of constraints on arbitrary executive authority. "Freedom" is the DeLong-Shleifer coding of political institutions. All variables described in text and/or Appendix. Heterskedasticity-robust standard errors in parentheses. Significance at the 90 and 95 percent confidence indicated "*" and "**", respectively.

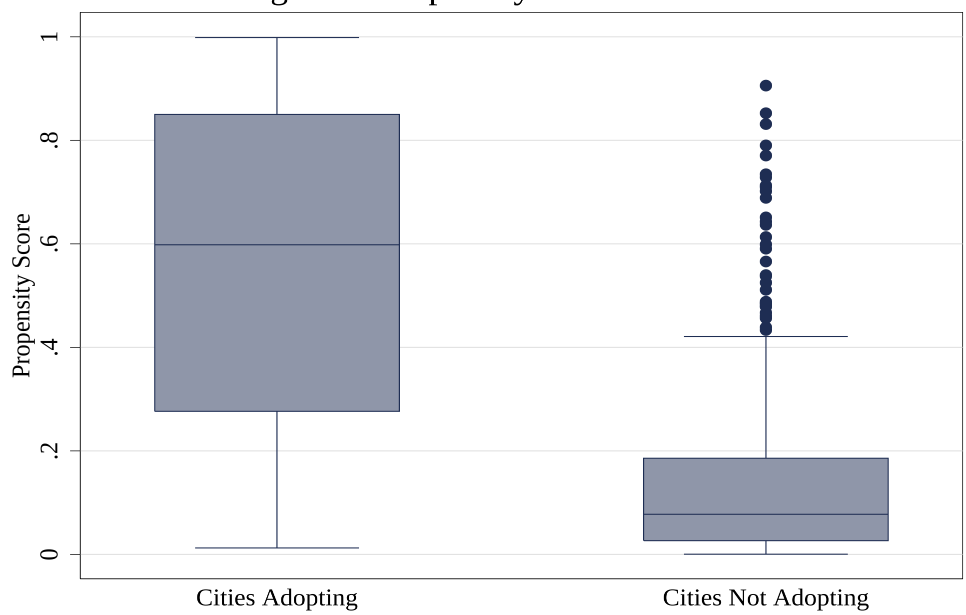
propensity scores. Figure 4 presents a box-plots of the distribution of the propensity score estimates for cities under the the baseline sample. The "dots" in Figure 4 are substantial cities that did not adopt printing by 1500. They show that a considerable number of cities are in the thin upper tail of the propensity score distribution for non-adopting cities. Non-adopting cities with estimated propensity scores over 0.5 include: Bordeaux, Reims, Braunschweig, Groningen, Lille, Maastricht, Cordoba, Arezzo, Aachen, Dublin, Tournai, Bourges, Montpellier, and Aix-en-Provence.

Figure 3: Propensity Score Densities



Note: This figure shows that distribution of propensity scores in the baseline sample. For the densities of the alternate sample propensity scores see the Appendix.

Figure 4: Propensity Score Distribution



Note: The boxes describe the 25th-75th percentile range. The line dividing the box marks the median estimate. The "whiskers" describe the upper and lower adjacent values. Dots designate individual observations.

Non-adopting cities with estimated propensity scores $\hat{P} \in (0.4, 0.5)$ include Bremen, Marseilles, Malaga, Beauvais, Dortmund, Rimini, Dordecht, Poznań, Salerno, Goslar, Mechelen, and Arras. Although they subsequently did, neither Amsterdam nor Berlin nor Madrid adopted the press in the 1400s.[51] More obviously, there is also meaningful overlap in the distributions for adopting and non-adopting cities propensity scores for $\hat{P}(X_i) \in (0.20, 0.4)$. This overlap provides purchase for econometric identification.[52]

The estimated propensity scores can be used to examine possible endogenity (selection) effects in technology adoption. An endogeneity problem would arise if (i) adoption is associated with above par growth in future years, and (ii) adoption is associated with the accurate expectation of above par growth – or, more broadly, with factors that augured well for city growth. If this were the case, the association between adoption and subsequent growth need not reflect the impact of the technology. However, analysis using the propensity score shows that there was a *negative* association between the propensity to adopt and future growth. This fact indicates that adoption was not driven by correct expectations about future city growth: between 1450 and 1500 entrepreneurs established presses in the sorts of cities that ended up growing relatively *slowly*. This is explained by the fact that (i) printing technology was by-and-large adopted in cities that were already relatively large, and (ii) large cities grew relatively slowly 1500-1600 (and to some extent 1700-1750). In contemporary economies, random or size-independent growth is the norm. However, as shown in Dittmar (2008) city growth in pre- and early modern Europe was non-random: big cities confronted difficulties feeding themselves and typically grew relatively slowly.

Regression analysis of early technology adoption confirms that there was both a positive printing press effect and a negative association between the likelihood of adoption and future growth. In general, we expect an outcome Y_i to be some function of the treatment T_i and the propensity score $\hat{P}_i = \hat{P}(X_i)$ measuring the probability that a given observation receives treatment. Following an approach developed in the program evaluation literature, the estimated propensity score can be employed as a control function and we can estimate the ATE in a model:

$$Y_i = \alpha_0 + \alpha_1 \hat{P}i + \alpha_2 T_i + \epsilon_i \tag{1}$$

[51] This evidence contradicts Eisenstein's (1979: 440) claim that by 1500 there were printers' workshops in "every important municipal center."

[52] Because it is natural to be broadly concerned about propensity scores $\hat{P}(X_i)$ close to 0 or 1, Imbens and Wooldridge (2008: 42) propose a rule of thumb for trimming the data in order to improve overlap in covariate distributions. They suggest that researchers examine first the complete data and then observations propensity scores $\hat{P}(X_i) \in \mathbb{A} = [0.1, 0.9]$. The estimates of the "print effect" one estimates with trimmed data are very close to those reported below for the complete data. Although, of course, the treatment effect over the set $\mathbb{A}$ is not identical to the ATE.

Here the treatment effect is captured in α_2, the coefficient on technology adoption. The estimate of α_2 is consistent assuming (i) $\mathbb{E}[Y(1) - Y(0)|X_i]$ is uncorrelated with $\text{Var}(T|X_i)$ and (ii) unconfoundedness (sometimes called "selection on observables").[53] Because $\text{Var}(T|X_i)$ is a nonmonotonic quadratic in $P(X_i)$ and $\mathbb{E}[Y(1) - Y(0)|X_i]$ will likely be linear in several elements of X_i, zero correlation may hold approximately.[54]

Table 7 reports results estimating the model in equation (1) over several different periods. Panel A shows the baseline results associated with propensity scores esti-

Table 7: The Printing Press and City Growth – Propensity Score Analysis

Variable	Pre-Adoption City Growth 1400-1500	Post-Adoption City Growth 1500-1600	City Growth 1500-1700	City Growth 1500-1800
(1)	(2)	(3)	(4)	(5)
Panel A: Baseline Propensity Score				
Propensity to Adopt	-0.17	-0.43 **	-0.44 **	-0.68 **
	(0.12)	(0.13)	(0.18)	(0.20)
Adopt Printing by 1500	0.00	0.33 **	0.20	0.23 *
	(0.08)	(0.10)	(0.14)	(0.14)
Observations	291	258	260	291
Panel B: Alternate Propensity Score				
Propensity to Adopt	0.30 **	-0.49 **	-0.59 **	-0.96 **
	(0.13)	(0.09)	(0.15)	(0.16)
Adopt Printing by 1500	-0.23 **	0.20 **	0.20 *	0.21 *
	(0.08)	(0.06)	(0.10)	(0.10)
Observations	291	495	515	622
Panel C: Baseline Propensity Score Non-German Cities				
Propensity to Adopt	-0.19	-0.46 **	-0.50 **	-0.73 **
	(0.14)	(0.15)	(0.20)	(0.22)
Adopt Printing by 1500	0.03	0.37 **	0.32 **	0.33 **
	(0.10)	(0.12)	(0.16)	(0.16)
Observations	243	215	223	243

Note: This table reports estimates from regressions of the form: $Y_i = \alpha_0 + \alpha_1 P_i + \alpha_2 T_i + \epsilon_i$, where Y_i is city i's log population growth, T_i is an indicator capturing whether city i adopted the printing press by 1500, and P_i is the estimated propensity score. Significance at 90 and 95 percent confidence denoted "*" and "**", respectively.

mated over the small sample of cities on which population data for 1400 and 1500 is available. Three points are notable. First, the estimates show printing cities had no growth advantage prior to adoption. Second, the estimate of their growth advantage in the century after adoption is highly significant and very large: print cities grew an

[53]Formally, the unconfoundedness assumption is that $\mathbb{E}[Y(j)|T, X] = \mathbb{E}[Y(j)|X]$, for $j \in 0, 1$.
[54]See Wooldridge (2002: 617-618) for discussion.

extra 0.33 log points (39 percentage points). For comparison, mean city growth for all cities was 0.27 log points (31 percentage points) both 1500-1600 and 1500-1700.[55] Third, the estimated print growth advantage 1500-1800 is a more modest 0.23 log points and is only boderline significant while the print growth advantage 1500-1700 is not significant at conventional confidence levels.[56] As discussed above, these results may reflect the massive demographic losses German print cities experienced during the 30 years war (1618-1648).[57]

Panel B shows results associated with the alternative propensity score estimated for all cities with population data for 1500. The key differences are two-fold. First, these estimates show that the association between the likelihood of adoption and city growth (parameter $\hat{\alpha}_1$) is positive and statistically significant prior to and over the immediate adoption period (1400-1500). Second, the estimates suggest that technology adoption was associated with with an increase in growth of 0.2 log points (23 percentage points) 1500-1600, a figure that is still very large but substantially smaller than the baseline estimate of 0.33.

Panel C shows the results using the baseline sample but excluding German cities. Outside Germany, cities that adopted the press in the late 1400s had no growth advatage 1400-1500 but a consistent, significant advantage of over 0.3 log points after 1500. Essentially, these estimates control for the slow growth German print cities experienced during the 1600s. However, historical research suggests that print media played a key role in precipitating the conflict that wracked Germany 1618-1648.

In situations where there is reason to suspect selection into treatment, and where we are willing to add the assumption that the expectation of the outcome is linear in the propensity score, we can further control for these effects by introducing a term that captures the association between the outcome and the interaction between treatment and the propensity score[58]:

$$Y_i = \alpha_0 + \alpha_1 \hat{P}_i + \alpha_2 T_i + \alpha_3 \left[T_i \cdot (\hat{P}_i - \mu_{\hat{P}}) \right] + \epsilon_i \tag{2}$$

Estimates of equation (2) show no evidence of selection into treatment. Table 8 Panel A shows these estimates for the alternative propensity score. Panel B shows the estimates are robust to trimming the data to exclude observations with propensity

[55] See Table 1 above for mean growth rates of all cities.

[56] All standard errors adjusted via delta method to reflect presence of endogenous regressors.

[57] As noted above, the negative association between the probability of adoption and future growth reflects the fact that big cities were likely to adopt and to grow slowly. If one introduces city size as an additional regressor, the estimated impact of printing is unchanged while the negative associated between probability of adoption and subsequent growth vanishes.

[58] Formally, the interaction term is the interaction between treatment and the deviation from the de-meaned propensity score. The linearity assumption is $\mathbb{E}[Y(j)|\hat{P}]$ is linear in $\hat{P}$.

scores close to 0 or 1 (Panel B restricts to observations with $\hat{P} \in [0.1, 0.9]$).

Table 8: Testing for Selection in Adoption
Dependent Variable is Log City Growth 1500-1600

Constant	Propensity	Print	Interaction
(1)	(2)	(3)	(4)
Panel A: Complete Data			
0.29 **	-0.48 **	0.32 **	0.07
(0.06)	(0.19)	(0.10)	(0.26)
Panel B: Trimmed Data			
0.16	-0.20	0.37 **	-0.12
(0.10)	(0.25)	(0.11)	(0.39)

Note: Parameter estimates for equation (2). There are 258 and 142 observations (cities) in the complete data and the trimmed data, respectively. Heteroskedasticity-robust standard errors in parentheses. Under the null of selection, we expect the "Interaction" coefficient to be positive and significant.

Taken together, these results suggest that cities that adopted the printing press in the late 1400s grew at least 60 percent faster than those that did not 1500-1600. These estimates may even be conservative. As noted above, as printing spread after 1500 cities that were not early adopters subsequently did adopt the technology, and this would likely mute the advantage conferred by early adoption. And, whether or not the printing press was adopted, books circulated widely, bringing knowledge and information spillovers from larger cities to towns and – Bairoch (1988: 191) suggests – even the country.

5.5 Difference-in-Differences and First-Differences

This section shows that difference-in-differences and first-differences estimates of the effect of adopting printing support the OLS and propensity score estimates. Using either difference-in-differences or first-differences, we find that the early adoption of printing technology was associated with a growth advantage of 0.17 log points 1500-1600. Mean city growth was 0.27 log points 1500-1600, implying that cities that adopted the technology in the late 1400s grew 60 percent faster than similar cities over this period.

Difference-in-difference estimators account for the effects of unobserved confounding variables provided the latter are constant over time. The difference-in-difference estimator can be estimated:

$$Y_{it} = \alpha_0 + \alpha_1 T_i + \alpha_2 \mathit{YEAR1500}_t + \alpha_3 (T_i \cdot \mathit{YEAR1500}_t) + \beta' X_{it} + \epsilon_{it} \tag{3}$$

As before, Y_{it} is log growth and T_i is an indicator capturing whether a city adopted printing technology in the late 1400s ("treated" observations). The variable $\mathit{YEAR1500}_t$ is an indicator for the post-treatment period.[59] X_{it} is a vector of additional city characteristics. The parameter of interest is α_3, which captures the average treatment effect of adopting print technology in the late 1400s.

Table 9 presents results from difference-in-difference regressions estimated over data for 1400-1600 (i.e. examining growth 1400-1500 and 1500-1600). It shows that across specifications we estimates the average treatment effect to be $\hat{\alpha}_3 \approx 0.17$. Model 1 is the basic difference-in-differences model. Here $\hat{\alpha}_3 = 0.17$ and is significant at the 95 percent confidence level. Model 2 controls for city size and suggests a slightly lower estimate. Model 3 controls for a rich set of covariates associated with city growth.[60] Adding the complete set of controls, we find a highly significant estimate of $\hat{\alpha}_3 = 0.18$. Given the fact that printing presses established near universities, it is noteworthy that there is no association between the presence of a university and city growth.[61] Model 4 drops the time invariant regressors but adds city fixed effects. Under this specification, $\hat{\alpha}_3 = 0.17$ and the parameter on the indicator for simply being a printing city is now *negative* and highly significant. This is consistent with the findings in Table 6, Panel B and suggests that print cities were growing relatively slowly before adoption.

We obtain similar estimates of the impact of technology adoption if we exploit the panel structure of the data and estimate an unobserved (fixed) effects model in a first-differenced equation. In this case, one examines the association between changes in growth rates and changes in a variable capturing the presence of a printing press at the start of each period. Formally, $\Delta Y_i \equiv Y_{i1500} - Y_{i1400}$, and T_i is equivalent to the change in an indicator capturing the presence of a printing press at time t ($T_i \equiv \Delta PRINT_i \equiv PRINT_{i1500} - PRINT_{i1400}$). The estimating equation is:

$$\Delta Y_i = \beta_0 + \beta_1 T_i + \nu_i \tag{4}$$

[59] $\mathit{YEAR1500}_t = 1$ if $t = 1500$. As discussed above, the average city adopted the printing press in 1476. To the extent printing cities benefitted from technology adoption immediately (i.e. 1476-1500), the difference-in-difference estimates presented here will be conservative.

[60] Adding controls to the difference in difference model can typically remove bias and/or yield more precise parameter estimates. See Wooldridge (2004).

[61] Additional results (not shown here) indicate that there is also no association between city growth and university-print interactions.

Table 9: Analysis of City Growth 1400-1600
Difference-in-Differences Estimates of Log City Growth

Variable	Model 1	Model 2	Model 3	Model 4
(1)	(2)	(3)	(4)	(5)
Constant	0.18 **	0.52 **	1.16 **	0.54 **
	(0.07)	(0.10)	(0.05)	(0.05)
Year1500	0.02	0.05	0.00	0.02
	(0.07)	(0.07)	(0.07)	(0.10)
Print	-0.07	0.16 **	0.13 **	-0.40 **
	(0.06)	(0.06)	(0.04)	(0.04)
Print x Year1500	0.17 **	0.15 **	0.18 **	0.17 **
	(0.06)	(0.05)	(0.05)	(0.08)
Log Size		-0.20 **	-0.28 **	
		(0.04)	(0.04)	
University			-0.06	
			(0.07)	
Catholic Site			-0.01	
			(0.06)	
Roman Site			0.09 **	
			(0.04)	
Med Port			0.35 **	
			(0.11)	
Atlantic Port			0.52 **	
			(0.09)	
River			0.14 **	
			(0.05)	
Capital			0.62 **	
			(0.13)	
Freedom Index			0.03	
			(0.12)	
Country FE			Yes	Yes
City FE				Yes
Observations	516	516	516	516
F Statistic	3.10 **	8.33 **	--	--

Note: Regression estimated for 258 cities on which populations are observed 1400, 1500, and 1600. Heteroskedasticity-robust standard errors clustered at country level. Significance at 90 and 95 percent confidence denoted "*" and "**", respectively.

Estimating (4) over the balanced panel of 258 cities, one obtains $\hat{\beta}_1 = 0.17$ with heteroskedasticity-robust standard error of 0.1 and associated t-statistic of 1.75.

5.6 Synthetic Control Group Methods

The intuition behind synthetic control methods is that a combination of control units often provides a better comparison for a unit exposed to a treatment than any single control unit.[62] A synthetic control group is a weighted average of available control units. Synthetic control group methods generalize the difference-in-differences model. They allow for unobserved confounding variables, but restrict the effects of these factors to be constant over time. The synthetic control estimates the treatment effect as the difference between a treated outcome and a synthetic control outcome:

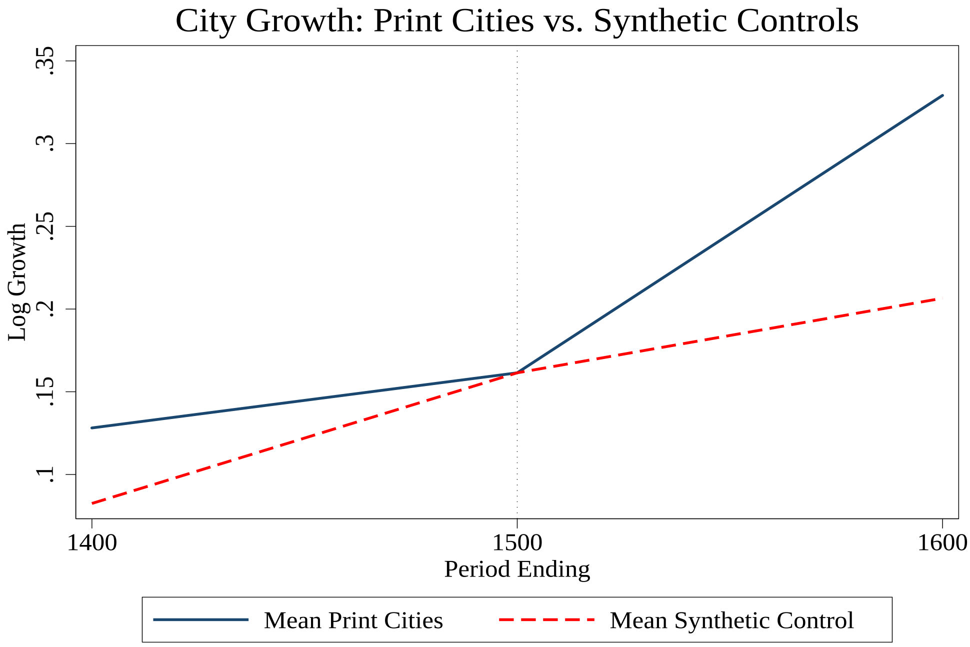
$$\hat{\alpha}_{\text{sc}} = Y_{1t} - \sum_{k=2}^{K+1} \omega_k^* Y_{kt} \tag{5}$$

Here Y_{1t} is the outcome for a treated unit at time t and there are potential control units with outcomes Y_{kt} indexed with $k = 1, \ldots, K$. The weights ω_k^* are computed to minimize the distance between pre-intervention outcomes and other predictors of post-interventions outcomes for the treated observation and the control group.[63] This can be implemented to minimizing the distance between city growth 1400-1500 and the distance between other key city characteristics: city growth 1300-1400, the presence of a university, and location on a port or navigable river or site of a Roman settlement.

Figure 5 summarizes the results of synthetic control group methods to analyse the relative growth performance of cities that adopted the printing press. It examines the divergence between city growth for the set of printing cities and similar non-printing cities. The average growth divergence between print cities and synthetic controls was small for the period 1300-1400: print cities had a growth advantage of approximately 4 percentage points. By construction, the difference between the growth of printing cities and the synthetic controls is negligible 1400-1500. Following the introduction of the printing press, on average print cities grew 12 percentage points faster than their synthetic controls 1500-1600.

[62] See Abadie et al. (2007), Hainmueller (2008), and Imbens and Wooldridge (2008).

[63] Let X_1 be a $m \times 1$ vector of pre-treatment characteristics for a printing city and X_0 a $m \times n$ matrix of pre-intervention characteristics for the cities that did not adopt the printing press 1450-1500. The vector of weights W^* is chosen to minimize a 'distance' $||X_1 - X_0W|| = \sqrt{(X_1 - X_0W)'V(X_1 - X_0W)}$, subject to the weights being non-negative and summing to 1 and with V a $k \times k$, positive semidefinite and symmetric matrix. Here V is chosen to minimize the difference in city growth prior to the advent of the movable type printing press. Synthetic control groups are constructed using the algorithm in Hainmueller (2008).



Note: This figure compares mean growth of adopting cities to mean growth of their respective synthetic control groups. The figure summarizes growth in the balanced panel of cities with population data observed 1300-1600 (i.e. growth for the period ending 1400 is growth 1300-1400). This panel contains 83 cities that adopted printing in the late 1400s and 119 cities that did not.

5.7 Spillovers

The estimates presented in Table 7 (above) are consistent estimates of treatment effects under the assumption that technology adoption only impacted own-city growth. They are thus based on the assumption of what the program evaluation literature calls "stable unit treatment values." This section examines this assumption and whether adoption had positive or negative spillovers between cities. It presents regression analysis that shows no evidence of cross-city spillovers.

Because propensity score analysis has been developed in contexts with stable treatment units, there is not a well-developed literature on spillovers (see Wooldridge and Imbens [2008] for discussion).[64] However, it is reasonable to imagine that a city's growth could be a function of that city's propensity score and adoption decision and the propensity scores and adoption decisions of its neighbors.

This section exploits data on cities' geographic location (latitude and longitude) to test whether technology adoption in neighboring cities has an impact on city growth.

[64] A few studies have addressed related questions in the context of experiments with crop treatments in neighboring fields.

In particular, this section considers a regression model in which population growth for city i is a function of technology adoption and propensity scores both in city i and in other, neighboring cities:

$$Y_i = \alpha_0 + \alpha_1 P_i + \alpha_2 T_i + \alpha_3 P_i^* + \alpha_4 T_i^* + e_i \tag{6}$$

Here P_i and T_i are city i's propensity score and binary treatment. The variables P_i^* and T_i^* capture the propensity scores and the technology adoption decisions in neighboring cities and are constructed as distance-weighted sums:

$$P_i^* = \sum_{j \neq i} \frac{P_j}{d_{ij}} \qquad \text{and} \qquad T_i^* = \sum_{j \neq i} \frac{T_j}{d_{ij}}$$

As before, P_j and T_j are city j's propensity score and technology adoption decision, respectively. d_{ij} is the distance between city i and city j. Distance is calculated using latitude and longitude as "great circle" distance.[65]

Table 10 presents the estimates of equation (6) alongside the earlier estimates which do not control for the characteristics and adoption decisions of neighboring cities. It shows that introducing controls for the propensity scores and adoption decisions of neighboring cities generates no change in the estimated association between print technology and city growth. Interestingly, under the alternate propensity score model this is because the advantages of having neighbors with the printing press are essentially cancelled out the disadvantages of having neighbors with the characteristics associated with technology adoption.

6 Conclusion

Economists have found no evidence that the printing press was associated with increases in productivity at the macroeconomic level. Some have concluded that the economic impact of the printing press was limited. This paper exploits city level data on the diffusion and adoption of the printing press to examine the technology's impact from a new perspective. The estimates presented here show that cities that adopted the printing press in the late 1400s enjoyed no growth advantages prior to adoption, but grew at least 20 percentage points – and as much as 35 percentage

[65]Ideally, we would have a measure of distance that reflected travel times and costs and/or trade flows. Data on inter-city trade and on travel times is exceedingly limited. On the latter see Braudel (1966) and de Vries (1984), which suggests a rough and ad hoc set of adjustments that can be applied to great circle distances to better reflect the ease of traveling to cities on navigable waterways. Using de Vries' suggested adjustment factors yields results similar to those estimated here on the basis of great circle distances. Non-linear weights yield similar results.

Table 10: Testing for Cross-City Spillovers to Technology Adoption
Dependent Variable is Log City Growth 1500-1600

	Baseline Propensity Score			Alternate Propensity Score		
Variable	Model 1	Model 2	Model 3	Model 1	Model 2	Model 3
(1)	(2)	(2)	(3)	(4)	(5)	(6)
Print	0.20 **	0.20 **	0.21 **	0.33 **	0.33 **	0.33 **
	(0.07)	(0.06)	(0.06)	(0.10)	(0.10)	(0.10)
Propensity	-0.49 **	-0.50 **	-0.50 **	-0.43 **	-0.47 **	-0.49 **
	(0.11)	(0.10)	(0.10)	(0.13)	(0.14)	(0.14)
Print Neighbors		0.05	-0.15		0.18	0.85 **
		(0.16)	(0.37)		(0.25)	(0.43)
Propensity Neighbors			0.29			-1.12 *
			(0.50)			(0.58)
Observations	495	495	495	258	258	258
F Statistic	10.62	9.18	7.00	6.71	4.59	3.94

Note: "Print Neighbors" represents the distance-weighted sum of an indicator capturing other-cities' adoption decision: $T_i^* = \sum_{j \neq i} T_j/d_{ij}$. Similarly, "Propensity Neighbors" represents the distance-weighted sum of other cities' propensity scores: $P_i^* = \sum_{j \neq i} P_j/d_{ij}$. Distances d_{ij} are great circle distances.

points – more than similar cities that did not over the period 1500-1600. Between 1500 and 1600, mean city growth was 32 percentage points. Thus cities that adopted printing in the late 1400s grew at least 60 percent faster than similar cities that were not early adopters 1500-1600. Cities that were early adopters of the printing press had limited if any additional growth advantages after 1600. However, the evidence suggests that early adopters maintained the growth advantage established 1500-1600 over the longer periods running 1500-1700 and even 1500-1800.

Between 1500 and 1800, European cities were seedbeds of the ideas, activities, and social groups that launched modern, capitalist economic growth. The findings in this paper suggest that movable type print technologies had very substantial effects in European economic history through their impact on cities.

A Appendix: Data

City populations are from Bairoch et al. (1988) and de Vries (1984). City locations are from Bairoch et al. (1988), cross-checked using http://www.batchgeocode.com/. Data on printing from *Meyers Konversations-Lexikon* (1885), Febvre and Martin (1958), Clair (1976), Cipolla (1982), and ISTC (1998). Data for the Bayerische Staatsbibliothek on-line at: http://mdzx.bib-bvb.de/bsbink/treff2feld.html.

Data on the historical location of universities are from Darby (1970), Jedin (1970), and Bideleux and Jeffries (2007). Data on the historical location of religious institutions are from Magosci (1993) and Jedin (1970). Data on Roman settlements are from Stillwell et al. (1976).

Data on the historical location of ports are from Acemoglu et al. (2005), supplemented by data in Magosci (1993) and Stillwell et al. (1976), and the sources cited in Dittmar (2008). The data in this paper supplements Acemoglu et al. (2005) by coding for cities that were historically ports on the Baltic. These cities include: St. Petersburg, Gdańsk, Kaliningrad, Szczezin, Rostock, and Lübeck. In addition, the coding in this paper accounts for Mediterranean and Black Sea ports omitted in Acemoglu et al. (2005): Gaeta, Fano, Kerch, Korinthos, Pozzuoli, and Trapani.

Data on the location of navigable rivers are drawn from Magosci (1993), Pounds (1979, 1990), Livet (2003), Cook and Stevenson (1978), Graham (1979), Stillwell et al. (1976), and de Vries and van der Woude (1997). The coding captures the principal historically navigable waterways, and does not class as "navigable" waterways that required substantial improvements (dredging, re-channeling, etc.) and became navigable only over the early modern era.

The historical coding of the Polity-IV index of constraints on arbitrary executive authority is from Acemoglu et al. (2002, 2005). DeLong and Shleifer (1993) class regional institutions as either promoting relatively unrestrained and autocratic rule ("prince") or as securing relative freedom ("free"). I extend this coding to Poland and Ottoman Europe, neither of which meet the criteria for classification as "free" between 1300 and 1850 (this was confirmed by DeLong).

B Appendix: Robustness

Section 5.2 (above) presents OLS regression estimates examining the association between the adoption of print technology and city growth. In each period, those estimates relied on the complete set of available city-level observations. Table B shows that analysis of a balanced panel of cities on which we observe population data in all relevant periods yields very similar results.

Table B: Regression Analysis of Print Media and City Growth
Dependent Variable is Log City Growth

	Pre-Adoption	Post-Adoption		
Independent Variable	1400-1500	1500-1600	1500-1700	1500-1800
(1)	(2)	(3)	(4)	(5)
Print Adoption	0.09	0.30 **	0.22 *	0.28 **
	(0.09)	(0.10)	(0.13)	(0.14)
Editions Per Capita	0.07 *	0.00	0.02	0.04
	(0.04)	(0.03)	(0.05)	(0.05)
University	(0.02)	0.04	0.20 *	0.17
	(0.11)	(0.09)	(0.12)	(0.14)
Catholic Site	(0.40) **	0.33	0.05	0.25
	(0.19)	(0.21)	(0.26)	(0.25)
Roman Site	0.12	0.03	0.10	0.08
	(0.07)	(0.07)	(0.09)	(0.09)
Capital	0.26 **	1.07 **	1.54 **	2.01 **
	(0.13)	(0.26)	(0.31)	(0.40)
Exec. Constraint	(0.49) **	0.08	(0.19)	(0.34) **
	(0.06)	(0.14)	(0.13)	(0.15)
Freedom Index	(0.32) **	(0.01)	0.26	0.17
	(0.14)	(0.17)	(0.20)	(0.21)
Port	0.23	0.42 **	0.92 **	1.06 **
	(0.17)	(0.19)	(0.25)	(0.30)
Navigable River	0.17 **	0.12	0.16	0.25 **
	(0.08)	(0.08)	(0.11)	(0.12)
Population	(0.22) **	(0.31) **	(0.40) **	(0.60) **
	(0.05)	(0.05)	(0.07)	(0.08)
Country FE	Yes	Yes	Yes	Yes
Observations	237	237	237	237
R Square	0.35	0.38	0.40	0.50

Note: Editions per capita measured as editions published 1450-1500 per 100 inhabitants in 1500. City growth 1400-1500 is taken as a placebo (in each of these samples the average date of adoption was 1476). Heterskedasticity-robust standard errors in parentheses. Significance at the 90 and 95 percent confidence indicated "*" and "**", respectively.

This section will be completed (with exercises with trimmed data, synthetic controls, inverse weighted propensity scores, etc.)

References

[1] Abadie, A. et al. (2001), "Implementing Matching Estimators for Average Treatment Effects in Stata," *The Stata Journal*, Vol. 1, No. 1, pp. 1-18.

[2] Abadie, A. et al. (2007), "Synthetic Control Methods for Comparative Case Studies," Harvard University working paper.

[3] Acemoglu et al. (2005), "The Rise of Europe," *American Economic Review*, Vol. 95, No. 3, June.

[4] Allen, R. (2007), *Wages, Prices & Living Standards: The World-Historical Perspective*,
http://www.economics.ox.ac.uk/Members/robert.allen/WagesPrices.htm.

[5] Allen, R. and R. Unger (2007), *Allen-Unger Database: European Commodity Prices 1260-1914*. On-line:
http://www2.history.ubc.ca/unger/htm_files/new_grain.htm.

[6] Bairoch, P. (1988), *Cities and Economic Development*, Chicago; University of Chicago.

[7] Bairoch, P. et al. (1988), *La Population Des Villes Européenes*, Geneva; Librarie Droz.

[8] Barbier, F. (2006), *L'Europe De Gutenberg: Le Livre et L'Invention de la Modernité Occidentale*, Paris; Belin.

[9] Baten, J. and J. van Luiten (2008), "Book production and the onset of modern economic growth," *Journal of Economic Growth*, No. 13, pp. 217-235.

[10] Bolgar, R. (1962), "Education and Learning," in R. Wernham, ed., *The New Cambridge Modern History, Vol III: the Counter-Reformation and the Price Revoltion 1559-1610*, Cambridge; Cambridge University.

[11] Braudel, F. (1966), *La Méditerranée et le Monde Méditerranéen À L'Époque De Phillippe II*, Vol. I, Paris; Armand Colin.

[12] Braudel, F. (1979), *Civilisation, Économie et Capitalisme*, Vol. I, Paris; Armand Colin.

[13] Cipolla, C. (1972) "The Diffusion of Innovation in Early Modern Europe," *Comparative Studies in Society and History*, Vol 14, pp. 46-52.

[14] Cipolla, C. (1982), *Before the Industrial Revolution: European Society and Economy 1000-1700*, 2nd Edition, London; Methuen.

[15] Clair, C. (1976), *A History of European Printing*, London; Academic.

[16] Clark, G. (2001), "The Secret History of the Industrial Revolution," Mimeo, UC Davis.

[17] Darby, H. ed. (1970), *The New Cambridge Modern History*, Vol. XIV, Cambridge; Cambridge University Press.

[18] DeLong, J. and A. Shleifer (1993), "Princes and Merchants: City Growth Before the Industrial Revolution," *Journal of Law and Economics*, Vol. 36, October, pp. 671-702.

[19] Dittmar, J. (2008), "Cities, Institutions, and Growth: The Emergence of Zipf's Law," http://jedittmar.googlepages.com/home.

[20] Docampo, J. (2006), "Reading Luca Pacioli's *Summa* in Catalonia," *Historia Mathematic*, No. 33, pp. 43-62.

[21] Duranton, G. and D. Puga (2004), Micro-Foundations of Urban Agglomeration Economies, in J. V. Henderson and J-F. Thisse, eds., *Handbook of Urban and Regional Economics*, Vol. 4, Amsterdam; North-Holland.

[22] Edwards, M. (1995), *Printing, propaganda, and Martin Luther*, Berkeley; University of California.

[23] Egmond, W. van (1980), *Practical Mathematics in the Italian Renaissance: A Catalog of Italian Abbacus Manuscripts and Printed Books to 1600*, Florence; Instituto e Museu di Storia della Scienza Firenze.

[24] Eisenstein, E. (1979), *The Printing Press as an Agent of Change: Communications and Cultural Transformations in Early-Modern Europe*, Cambridge; Cambridge University Press.

[25] Febvre, L. and H-J Martin (1958), *L'Apparition du Livre*, Paris; Éditions Albin Michel.

[26] Füssel, S. (2005), *Gutenberg and the Impact of Printing*, Aldershot; Ashgate.

[27] Galor, O. and D. Weil (2000), "Population, Technology, and Growth: From Malthusian Stagnation to the Demographic Transition and Beyond," *American Economic Review*, Vol. 90, No. 4, November.

[28] Gilmont, J-F (1992), “Les Centres de la Production Imprimée,” in S. Cavaciocchi ed., *Produzione e Commercio della Cart e del Libro, Secc. XIII-XVII*, Firenze; Le Monnier.

[29] Gilmont, J-F (1998), “Printing at the dawn of the sixteenth century” in J-F Gilmont ed., *The Reformation and the Book*, Aldershot; Ashgate.

[30] Glaeser, E. et al. (1995), “Growth in a Cross-Section of Cities,” *Journal of Monetary Economics*, Vol. 36, pp. 117-143.

[31] Glomski, J. (2001), “*Incunabula Typographiae*: Seventeenth Century Views on Early Printing,” *The Library Transactions of the Bibliographical Society*, Vol. VII, No. 2, pp. 336-348.

[32] Goldthwaite, R. (1972), “Schools and Teachers of Commercial Arithmetic in Renaissance Florence,” *Journal of European Economic History*, Vol. 1, pp. 418-433.

[33] Goodfriend, M. and J. McDermott (1995), “Early Development,” *American Economic Review*, Vol. 85, No. 1, March, pp. 116-133.

[34] Hainmueller, J. (2008), “Synthetic Matching for Causal Effers: A Multivariate Reweighting Method to Produce Balanced Samples in Observational Studies,” Harvard University working paper.

[35] Hay, D. (1962), “Literature: the Printed Book,” in G. Elton, ed., *The New Cambridge Modern History, Vol. II: The Reformation 1520-1559*, Cambridge; Cambridge University.

[36] Helpman, E. (1998), “Introduction,” in E. Helpman ed., *General Purpose Technologies and Economic Growth*, Cambridge; MIT.

[37] Hilton, R. ed. (1978), *Transition from Feudalism to Capitalism*, London; Verso.

[38] Imbens, G. (2004), “Nonparametric Estimation of Average Treatment Effects Under Exogeneity,” *The Review of Economics and Statistics*, February, 86 (1), pp. 4-29.

[39] Imbens, G. and J. Wooldridge (2008), “Recent Developments in the Econometrics of Program Evaluation,” Harvard University working paper.

[40] ISTC (1998), *Incunabula Short Title Catalogue*, London; British Library.

[41] Jedin, H. et al. (1970), *Atlas Zur Kirchen-Geschichte*, Freiburg; Herder.

[42] Jones, C. (2001a), "Population and Ideas: A Theory of Endogenous Growth," Mimeo, UC Berkeley.

[43] Jones, C. (2001b), "Was an Industrial Revolution Inevitable? Economic Growth over the Very Long Run," *Advances in Macroeonomics*, Vol.1, No. 2.

[44] Jones, C. (2004), "Growth and Ideas," Mimeo, UC Berkeley.

[45] Jones, E. (1981), *The European Miracle: Environments, economics, and geopolitics in the history of Europe and Asia*, Cambridge; Cambridge University Press.

[46] Laqueuer, T. (1976), "The Cultural Origins of Popular Literacy in England 1500-1850," *Oxford Review of Education*, Vol. 2, No. 3, pp. 255-275.

[47] Lipsey, R. et al. (1998), "What is to be explained?" in E. Helpman ed., *General Purpose Technologies and Economic Growth*, Cambridge; MIT.

[48] Long, P. (1991), "The Openness of Knowledge: An Ideal and Its Context in 16th-Century Writings on Mining and Metallurgy," *Technology and Culture*, Vol. 32, No. 2, Part 1, April, pp. 318-355.

[49] Lucas, R. (1988), "On the Mechanics of Economic Development," in *Lectures on Economic Growth*, Delhi; Oxford University Press, 2002.

[50] Lucas, R. (1997), "The Industrial Revolution: Past and Future," in *Lectures on Economic Growth*, Delhi; Oxford University Press, 2002.

[51] *Meyers Konversations-Lexikon* (1885), entry on "Buchdruckerkunst."

[52] Mokyr, J. (2005a), "Long-Term Economic Growth and the History of Technology," in P. Aghion et al. eds., *The Handbook of Economic Growth*, ; Elsevier.

[53] Mokyr, J. (2005b), "The Intellectual Origins of Modern Economic Growth," *Journal of Economic History*, Vol. 65, No. 2, pp. 285-351.

[54] Mokyr, J. (2002), *The Gifts of Athena: Historical Origins of the Knowledge Economy*, Princeton; Princeton University Press.

[55] Mokyr, J. (1995), "Urbanization, Technological Progress, and Economic History," in H. Giersch ed. *Urban Agglomeration and Economic Growth*, Berlin; Springer.

[56] Mokyr, J. (1990), *Lever of Riches: Technological Creativity and Economic Progress*, Oxford; Oxford University Press.

[57] Rice, E. (1994), *The Foundations of Early Modern Europe*, New York; Norton.

[58] Smith, W. (1984), "The Function of Commercial Centers in the Modernization of European Capitalism: Amsterdam as an Information Exchange in the Seventeenth Century," *The Journal of Economic History*, Vol. 44, No. 4, December, pp. 985-1005.

[59] Speisser, M. (2003), "Les manuels darithmtique pour les marchands dans la France du XVe siècle," *Bulletin de lAPMEP*, No. 444, pp. 32-50.

[60] Stillwell, R. et al. (1976), *Princeton Encyclopedia of Classical Sites*, Princeton; Princeton University.

[61] Swetz, F. (1987), *Capitalism and Arithmetic: The New Math of the 15th Century*, La Salle, IL; Open Court.

[62] de Vries, J. (1984), *European Urbanization 1500-1800*, Cambridge; Harvard University Press.

[63] Weitzman, M. (1998), "Recombinant Growth," *Quarterly Journal of Economics*, Vol. 113, No. 2, pp. 331-360.

[64] Woods, R. (2003), "Rural-Urban Mortality Differentials: An Unresolved Debate," *Population and Development Review*, Vol. 29, No. 1, pp. 29-46.

[65] Wooldridge, J. (2002), *Econometric Analysis of Cross Section and Panel Data*, Cambridge; MIT.

[66] van Zanden, J. (2004), "Common workmen, philosophers and the birth of the European knowledge economy," Paper for GEHN

[67] Zaret, D. (1992), "Religion, Science, and Printing in the Public Spheres in Seventeenth-Century England," in C. Calhoun ed., *Habermas and the Public Sphere*, Cambridge; MIT University Press.

[68] Zaret, D. (2000), *Origins of Democratic Culture: Printing, Petitions, and the Public Sphere in Early-modern England*, Princeton; Princeton University Press.