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

Jeremiah Dittmar*

March 13, 2009

DRAFT: VERY PRELIMINARY – 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, this 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 15th century grew 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 the social and economic impact of information technology.

*Contact: UC Berkeley, Department of Economics, Evans Hall #3880, Berkeley, CA 94720. Email: `jdittmar@econ.berkeley.edu`. I thank Barry Eichengreen, Chad Jones, Christina Romer, Brad DeLong, and Peggy Anderson 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, this 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 15th century grew 60 percent faster than otherwise *similar* cities that did not, and that between 1500 and 1800 they enjoyed a 25 percent growth advantage. I find that prior to adopting the press, cities that adopted the technology enjoyed no such growth advantage. I argue that the association between technology adoption and subsequent growth is not due to printers correctly anticipating future

[1] As discussed below, Roberts (1996), Rice (1994), Braudel (1979c), and Gilmore (1952) provide representative arguments.

[2] Clark (2001) argues that printing had a limited economic impact for these reasons. For a perspective consistent with the findings in this paper and data on prices see van Zanden (2004).

city growth or simply choosing auspicious locations. In general, entrepreneurial printers located in cities that were large, important, and housed universities and other public institutions. However, these cities typically grew slowly after 1500, suggesting 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 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 0.19 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.

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	-0.22 **	0.18
		(0.08)	(0.08)	(0.53)
1500 to 1600	100	0.18 **	0.20 **	0.27
		(0.06)	(0.06)	(0.53)
1500 to 1700	200	0.24 **	0.19 *	0.27
		(0.09)	(0.11)	(0.78)
1500 to 1800	300	0.31 **	0.19 *	0.63
		(0.10)	(0.11)	(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 4. Mean growth across all cities is calculated using city population data from Bairoch et al. (1988). Standard errors in parentheses. For estimates standard errors are heteroskedasticity robust and significance at the 90 and 95 percent confidence levels is denoted "*" and "**", respectively. The data are described in section 3.

These findings bear on important questions concerning the diffusion of technology, growth, and economic geography. The finding that the adoption of the printing press was strongly associated with subsequent city growth intersects with recent research on the role externalities and intellectual innovation play in economic growth. It qualifies influential arguments concerning the role of Atlantic trading cities as key drivers of institutional change and economic development in pre-industrial Europe. It adds precision to arguments stressing the role of European cities as sites where information was exchanged, new ideas were produced, and the social groups that drove pro-growth institutional changes and 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 far-reaching, revolutionary social impact. Fernand 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." Rhodes and Sawday (2000: 1) contend that, "The defining moment of the European Renaissance is neither the fall of Constantinople in 1453, nor the discovery of the Americas in 1492. Rather, it was the 'Gutenberg Revolution' of the mid-15th century which marked the emergence of modernity in the Christian West."

Historians specializing in the study of the diffusion of printing present more mixed views. Elizabeth Eisenstein (1979: 33) argues that the advent of movable type printing inaugurated "a new cultural era in the history of Western Man," but emphasizes that the new technology wrought its changes very gradually. Febvre and Martin (1958) similarly argue that the effects of movable type printing worked themselves out 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 in 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."[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 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 tends to emphasize 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 progress."[6] 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." Recent work by Baten and van Zanden (2008) is

[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]See Helpman (1998) and Lipsey et al. (1998), which suggests that printing was a general purpose technology.

[6]Mokyr (2002) has also emphasized the epistemological foundations of technical change, but does not dwell on the ways print technology may have laid the groundwork for subsequent *macro*inventions by opening new possibilities for the dissemination of ideas.

consistent with this argument. Baten and van Zanden examine Allen's (2003) calibrated model of historic economic growth and find a significant association between calibrated national-level wages and empirical differences in aggregate book production.[7] However, Gregory 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.

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.

The fact that printing was an urban technology suggests that the action may have been at the city level. Printing presses were established in cities and the urban middle classes were the principle purchasers of books. Wealthy collectors of books resisted the new proto-mass production. Between 1450 and 1500, printing technologies spread rapidly to meet a specific demand:

> the unsatisfied 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

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

fifteenth century were swelling the arts faculties of the universities. (Rice 1994: 6)

Initially, a very large share of printing output was religious, and historians have emphasized the role of print media in the reformation – and the role of religious sentiment in creating a demand for printed texts and an interest in literacy.[8] I return to this question below, but will stress here the role of printing in the development of practical knowledge useful in production and commerce.

Print media facilitated the transmission of ideas and lowered the cost of investments in human capital. Following the invention of movable type printing, European presses produced a stream of publications addressing worldy concerns. In the 15th century, general works on mathematics such as Luca Pacioli's *Summa* discussed accounting. In the 16th century, technical books such as Biringuccio's *Pirotechnia* (1540), Digges's *Panometria* (1571), Zimmermann's *Probierbuch* (1573) appeared in all the major European languages, and significantly influenced workshop practices. Moreover, commercial activities and account keeping increasingly demanded basic literacy and arithmetic. Alongside religious tracts, printers produced John Browne's *Marchant's Avizo* (1589), which provided "not only a formulary, but extensive notes on business practice," and ran into several editions. 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.[9] 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. Broadly, the new technology was associated with urban life, an emerging culture of information exchange, and the development of an urban, bourgeois public sphere.[10] Print media was widely traded, but was famously heavy, sensitive to dampness, and expensive to transport. Transport costs limited the diffusion of print media and imparted a localized bias to the spillovers from print technologies.[11]

Economists working on a range of questions emphasize the economic role 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

[8]Hay (1962), Edwards (1995), Gilmont (1998), Rice (1994), Eisenstein (1979).

[9]This paragraph draws on Bolgar (1962), p. 428.

[10]Historically education was not simply an investment in human capital. It provided capabilities that allowed individuals to engage in a range of political, religious, economic, and cultural activities. See Zaret (1992, 2000), Long (1991), Smith (1984), Hay (1962), and Laqueur (1976).

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

increased sharing of information, superior matching between workers and employers (and between buyers and sellers in general), and significant technological spillovers.[12] 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."[13] Moreover, 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.[14]

The work of social historians suggests that the spread of printing both reflected and advanced the dynamism of Europe's urban centers, and that there may have been substantial externalities to the adoption of the new technology. This paper uses city-level data on the diffusion of the printing press to explore this possibility, and attempts to quantify the technology's impact.

3 Data

This paper exploits data on the diffusion and production 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.[15]

I construct data on the location (and output) of printing presses over the infant industry period from three principal sources.[16] I match these printing press locations to data on historical cities described below.

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

[13] Historical research has qualified these generalizations but confirms the importance of cities. See Merrington (1975) and Dittmar (2008) for further discussion.

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

[15] Glomski (2001), Clair (1976), Barbier (2006), and Febvre and Martin (1958) discuss the infant industry period. For discussion of book prices, see van Zanden (2004).

[16] 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.

- 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 item 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 cities.[17]

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

The data on the locations and historical populations of European city populations are from Bairoch et al. (1988).[18] 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.[19] 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 European cities.[20]

In total, the historical sources identify 205 unique cities that adopted the printing press between 1450 and 1500.[21] 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

[17] 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 historical cities identified by Bairoch et al. (1988), 196 appear in the ISTC (1998) as early adopters of the new technology.

[18] 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.

[19] 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.

[20] 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).

[21] This figure comprises the 197 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.

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: Data on the adoption of the printing press from *Meyers Konversations Lexicon* (1885), Febvre and Martin (1958), Clair (1976), ISTC (1998). Data on historic cities from Bairoch et al. (1988).

Bairoch city data. These were overwhelmingly printing presses in more or less isolated religious establishments.[22] 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 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

[22]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).

described as introduced and in the appendix.

4 Empirics

4.1 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.[23] 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.[24] Moreover, to the extent that pre-industrial Europe was in a Malthusian economic regime, population growth may indicate technological progress.[25] 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. This paper exploits several approaches to do this. The empirical section estimates the probability that each city will adopt, conditional on its exogenous characteristics. Accounting for this conditional probability, propensity scoring approach to estimate the average treatment effect of technology adoption on city growth. I also present estimates based on difference-in-difference and synthetic control group techniques.

4.2 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 results showing that there was a very large, statistically significant association be-

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

tween the establishment of printing presses and subsequent city growth. Sections 4.3 and 4.4 explore the diffusion process and selection effects in greater detail.

Table 3 compares, by country, the growth of cities that were early adopters to the growth of cities that were not. It includes all countries with at least five cities that adopted the new technology and all cities for which population data is available. Panel A shows that, on average, cities that adopted the press in the late 1400s grew

Table 3: Print Technology and City Growth

Panel A: City Growth Between 1500 and 1600

	Press Adopted			Press Not Adopted			
20th Century Polity	No. of Cities	Urban Pop. 1500	Weighted Average Growth	No. of Cities	Urban Pop. 1500	Weighted Average Growth	Print City Growth Advantage
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Belgium	8	202	-0.08	25	174	-0.27	0.19
France	26	700	0.20	48	440	0.04	0.16
Germany	30	374	0.16	83	400	0.12	0.04
Italy	34	1,119	0.26	67	463	0.24	0.02
Netherlands	11	118	0.34	22	142	0.53	-0.19
Portugal	5	90	0.56	22	118	0.04	0.52
Spain	19	359	0.37	57	561	-0.15	0.51
Totals	133	2,962	0.23	324	2,298	0.05	0.18

Panel B: City Growth Between 1500 and 1800

	Press Adopted			Press Not Adopted			
20th Century Polity	No. of Cities	Urban Pop. 1500	Weighted Average Growth	No. of Cities	Urban Pop. 1500	Weighted Average Growth	Print City Growth Advantage
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Belgium	8	202	0.32	25	174	0.05	0.27
France	26	700	0.44	48	440	0.44	-0.01
Germany	30	374	0.26	83	400	0.44	-0.18
Italy	34	1,119	0.38	67	463	0.37	0.01
Netherlands	11	118	0.32	22	142	0.72	-0.40
Portugal	5	90	1.05	22	118	0.26	0.79
Spain	19	359	0.30	57	561	-0.07	0.37
Totals	133	2,962	0.38	324	2,298	0.28	0.10

Note: This table presents data for all economies with 5 print cities and all cities for which population data is available in the relevant periods. The print growth advantage (column 8) is calculated the difference between average growth for adopting and non-adopting cities (column 4 - column 7). See Appendix for complete set of countries.

18 percentage points more and over 4 times faster than non-printing cities 1500-1600. If we were to consider all countries – not just those with 5 print cities – the growth

advantage would rise (see Appendix B). Panel B shows that this advantage declined to a still sizable 10 percentage points 1500-1800, implying print cities grew 1/3 faster over the three centuries following the diffusion of the press. However, the cities that adopted were unusually large. For the countries in Table 3, 29 percent of cities with population data adopted, but adopting cities account for 56 percent of total urban population in 1500. Moreover, Germany – where printing originated – and the Netherlands stand out as economies in which printing press cities grew relatively slowly over long periods.

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. However, it is unclear whether military shocks can explain the differential growth pattern in the Netherlands.

It is notable that these wars were post-Reformation conflicts and owed something to printing. Historians observe that the intellectual ferment and spread of the Reformation was closely linked to the innovations in printing.[26] 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 4 presents regression estimates that examine the association between the diffusion of print media and city urban growth more closely. The estimates control for the geographic, institutional, and cultural growth factors identified in the economic history, urban economics, and economic geography literatures as contributing to urban growth (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

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

Table 4: Regression Analysis of Print Media and City Growth
Dependent Variable is Log City Growth

Independent Variable	Pre-Adoption 1400-1500	Post-Adoption 1500-1600	1500-1700	1500-1800
(1)	(2)	(3)	(4)	(5)
Print Adoption	0.05	0.18 **	0.24 **	0.31 **
	(0.08)	(0.06)	(0.09)	(0.10)
Editions Per Capita	0.04	0.03	0.06 **	0.06 **
	(0.04)	(0.02)	(0.03)	(0.03)
University	(0.02)	0.01	0.13	0.15
	(0.10)	(0.07)	(0.09)	(0.10)
Catholic Site	(0.35) *	0.29 **	0.11	0.15
	(0.19)	(0.14)	(0.20)	(0.19)
Roman Site	0.08	(0.02)	0.06	0.01
	(0.06)	(0.05)	(0.07)	(0.08)
Capital	0.34 **	1.03 **	1.59 **	2.10 **
	(0.13)	(0.16)	(0.20)	(0.26)
Exec Constraint Index	(0.47) **	0.02	0.10 **	0.25 **
	(0.06)	(0.03)	(0.05)	(0.04)
Freedom Index	(0.28) **	0.08	(0.16)	(0.07)
	(0.14)	(0.15)	(0.20)	(0.37)
Port	0.12	0.42 **	1.13 **	1.29 **
	(0.16)	(0.13)	(0.22)	(0.26)
Navigable River	0.16 **	0.18 **	0.26 **	0.35 **
	(0.08)	(0.06)	(0.09)	(0.10)
Population	(0.22) **	(0.31) **	(0.46) **	(0.67) **
	(0.04)	(0.04)	(0.05)	(0.06)
Country FE	Yes	Yes	Yes	Yes
Observations	291	495	441	440
R Square	0.32	0.31	0.38	0.46

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.

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.[27]

[27] Excluding cities of Eastern Europe that were exposed to the institutions of the Second Serfdom post-1500 does not materially change the results. On these institutions see Dittmar (2008).

4.3 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.[28] 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)

The very first workers were sworn to secrecy and left the Rhine basin with trade secrets and specialized skills. However, over the period 1450-1500, the barriers to entry were principally financial and technical. The production of movable type required specialized skills and knowledge of metallurgy. As a result, the cost of a complete font was equivalent to the wages a craftsman would earn over a period of 4 to 10 years.[29] Significantly, the printing press was a sufficiently radical break from past practice that occupations related to printing fell outside existing guild regulations.[30] Furthermore, there is no evidence that guild restrictions limited the diffusion of the technology.[31]

---

[28]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).

[29]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. Data collected by Allen and Unger (2007) indicates that a *livre* was worth about 18.7 grams of silver between 1500 and 1550. Data in Allen (2007) suggests 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, depending on whether one takes Gilmont's lower or higher cost estimates, 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.

[30]Barbier (2006: 173) notes: "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."

[31]See Barbier (2006). It is also notable that the technology diffused more rapidly in regions with relatively developed guild structures. For important recent discussions of guilds and technological change see Epstein (1998, 2008) and Prak et al. (2006).

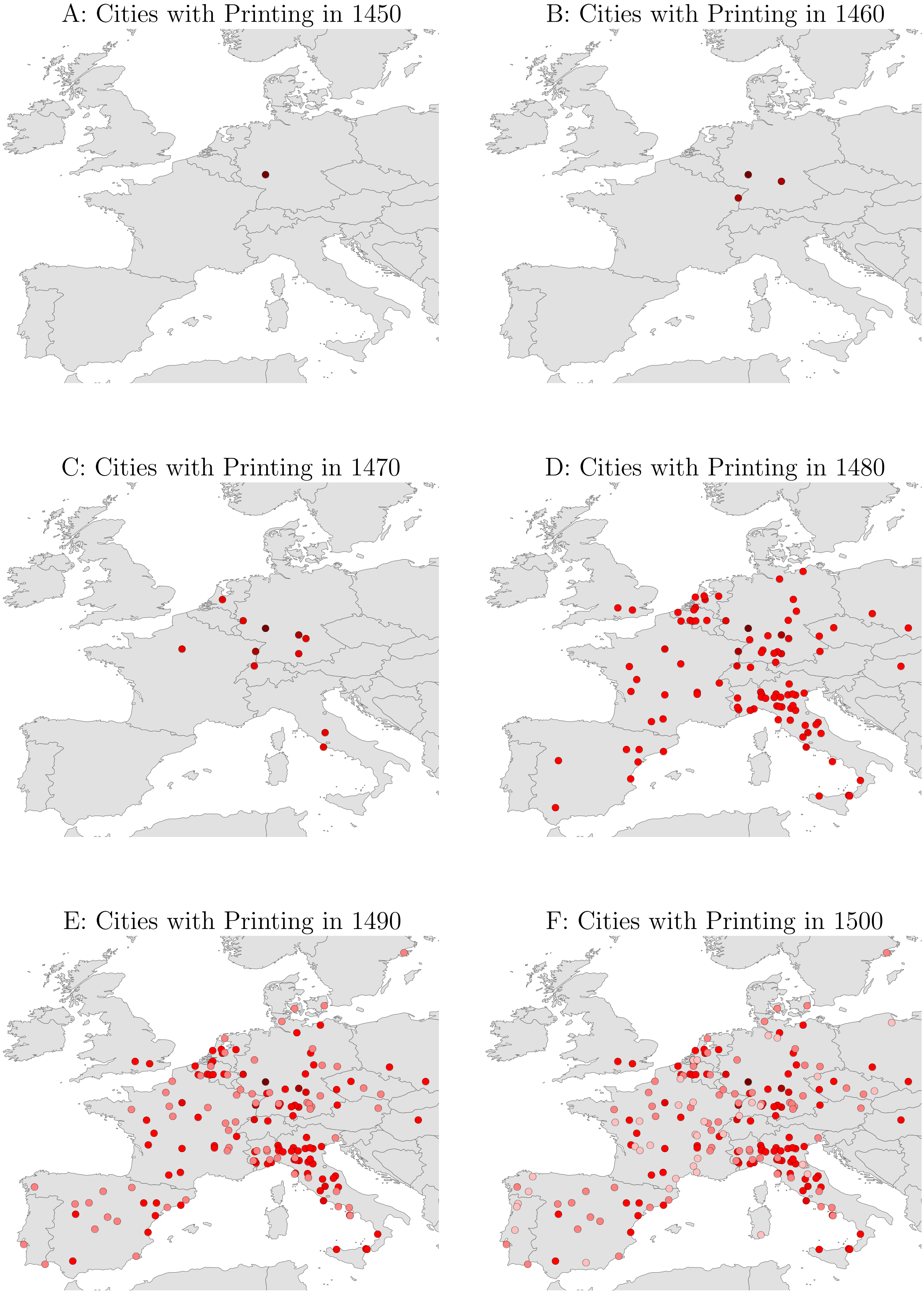
In the decades after Gutenberg's innovation, worker-enterpreneurs installed printing presses throughout Europe. Ulrich Hahn established the first press in Rome in 1467. Heinrich Botel and Georg von Holz established a press in Barcelona in 1473. Hans Wurster and Heinrich Turner established presses in 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: *171*) observe that the idiosyncratic interest of particular capitalists, patrons, and institutions had in making texts available was a "prime factor" in the diffusion process.[32] 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 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.[33] 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.

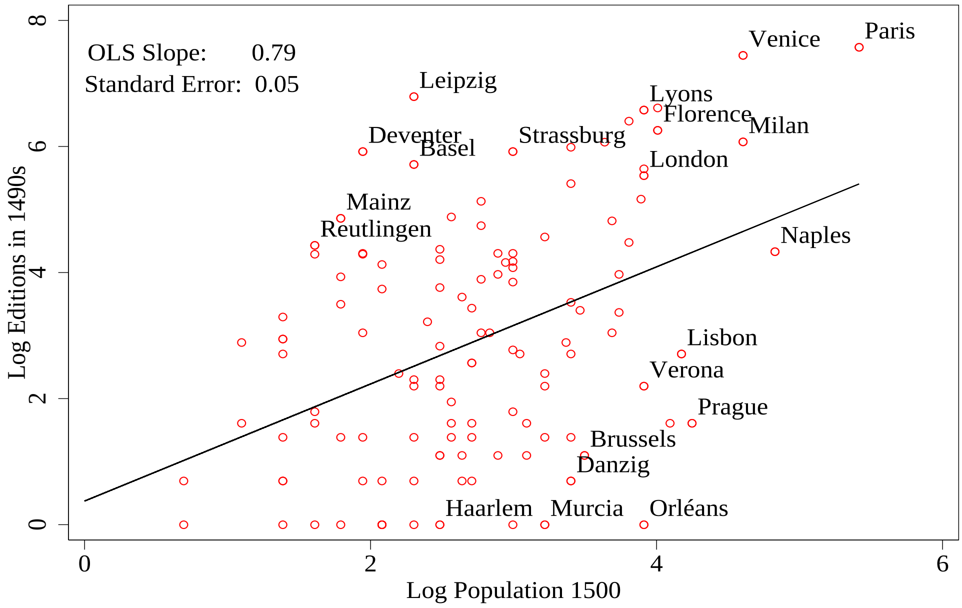
[32] Examples include printers invited to Rome, Chartres, Erfurt, and Florence.
[33] The correlation coefficient is 0.1 and is insignificant.

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.

Figure 1: Print Media Output and City Population Circa 1500



4.4 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.[34] The propensity score is an index of the likelihood of adoption. In this context, it sheds light on potential endogeneity 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

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

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 the 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"[35], the presence of a university, and country fixed effects. I also include variables capturing whether a city was on a port or river or the site of Roman settlements and whether the city was historically the location of a university or important religious site.[36]

Table 5 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

[35]The results I report below are not contingent on the inclusion of this variable either qualitatively or in terms of rough magnitude.

[36]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.

Table 5: Regression Analysis of the Adoption of the Print Press

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

Note: Distance from Mainz, Germany is a continuous variable in scaled in hundreds of miles. "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.

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.

To compute propensity scores I employ a flexible logit specification in which adoption is a function of each of the variables in Table 5, their squares, and interactions. However, this specification does not drive the results: stripped-down models without the interactions and squares and without institutional variables lead to similar conclusions. Of more concern is omitted variable bias, an issue to which I return below. These regressions are estimated without employing population in 1400 as a regressor (the large, "baseline" sample of 631 cities) and including population in 1400 as a regressor (the small, "alternative" sample of 291 cities).[37] The regressions have a pseudo R-squared of 0.37 and 0.46 respectively.

Figure 2 presents a box-plots of the distribution of the propensity score estimates for cities under the the baseline sample. It compares cities that adopted the printing press and cities that did not – showing both the complete data and the data trimmed to remove outliers. Figure 2 reveals there are sharp differences in city characteristics across the two groups. However, there is meaningful overlap in the distributions: a number of cities that had very high propensity scores were not early adopters and there is substantial overlap for propensity scores $\hat{P}(X_i) \in (0.20, 0.4)$. This overlap provides purchase for econometric identification. 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 $\hat{P}(X_i) \in \mathbb{A} = [0.1, 0.9]$.[38]

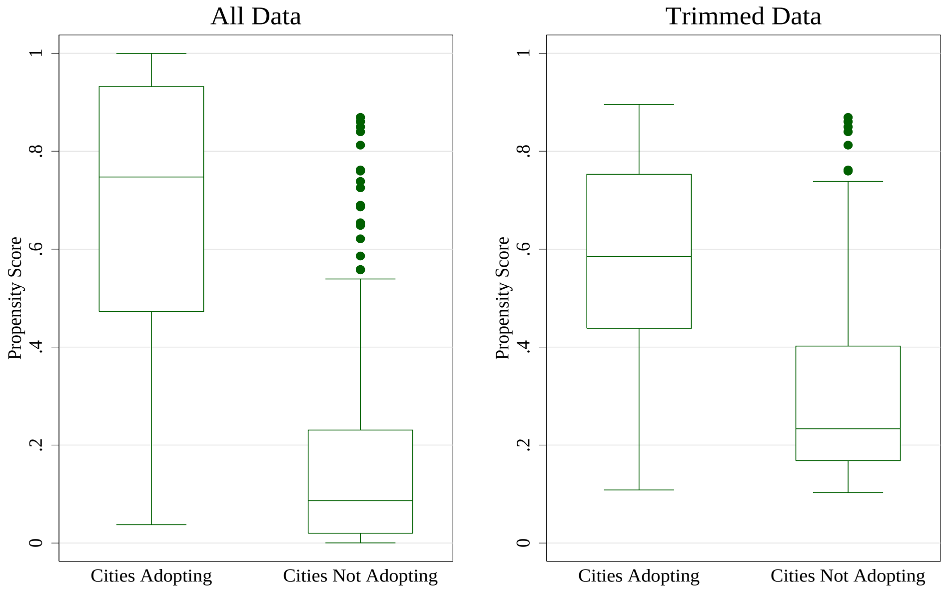
The estimated propensity scores can be used to examine possible endogenity (selection) effects in technology adoption. An endogeneity problem would arise if (i) adoption is associated with above par growth in future years, and (ii) adoption is associated with the accurate expectation of above par growth – 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 is consistent with the narrative evidence emphasizing the random dimension of the search and matching process behind print adoption. It suggests that adoption was not driven by correct expectations about future city growth.[39]

[37] 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.

[38] Evidently the treatment effect over the set $\mathbb{A}$ is not identical to the ATE.

[39] Between 1450 and 1500 entrepreneurs established presses in the sorts of cities that – other things equal – ended up growing relatively slowly. Initially, the technology spread to cities that were already very large and most extensively through Italy, France, and Germany. From 1500 through 1850, the most dynamic city growth was in Holland, England, and along the Atlantic coast. Similarly, once

Figure 2: 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.

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:

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

Here the treatment effect is captured in α_2, the coefficient on technology adoption. The estimate of α_2 is consistent assuming (i) $\mathbb{E}\left[Y(1) - Y(0)|X_i\right]$ is uncorrelated with $\text{Var}(T|X_i)$ and (ii) unconfoundedness (sometimes called "selection on observables").[40] Because $\text{Var}(T|X_i)$ is a nonmonotonic quadratic in $P(X_i)$ and $\mathbb{E}\left[Y(1) - Y(0)|X_i\right]$ will likely be linear in several elements of X_i, zero correlation may hold approximately.[41]

Table 6 reports results estimating the model in equation (1) over several different

one controls for access to navigable water, small cities tended to grow faster than the big cities that were over-represented among the early adopters of print technologies.

[40]Formally, the unconfoundedness assumption is that $\mathbb{E}[Y(j)|T, X] = \mathbb{E}[Y(j)|X]$, for $j \in 0, 1$.

[41]See Wooldridge (2002: 617-618) for discussion.

periods. Panel A shows the baseline results associated with propensity scores esti-

Table 6: The Printing Press and City Growth – Propensity Score Analysis

Variable	City Growth 1400-1500	City Growth 1500-1600	City Growth 1500-1700	City Growth 1500-1800
(1)	(2)	(3)	(4)	(5)
Panel A: Baseline Propensity Score				
Propensity	0.30 **	-0.49 **	-0.63 **	-0.96 **
	(0.13)	(0.09)	(0.16)	(0.18)
Print	-0.22 **	0.20 **	0.19 *	0.19 *
	(0.08)	(0.06)	(0.11)	(0.11)
Panel B: Alternative Propensity Score				
Propensity	-0.17	-0.43 **	-0.43 **	-0.69 **
	(0.12)	(0.13)	(0.20)	(0.24)
Print	0.00	0.33 **	0.19	0.18
	(0.09)	(0.10)	(0.15)	(0.17)

Note: This table reports parameter estimates from city growth regressions of the form: $\ln POP_{i,t} - \ln POP_{i,s} = \alpha_0 + \alpha_1 PROPENSITY_i + \alpha_2 ADOPTION_i + \epsilon_{i,t}$, where $POP_{i,t}$ is city i's population at time t, $ADOPTION_i$ is an indicator capturing whether city i adopted the printing press by 1500, and $PROPENSITY_i$ is the estimated propensity score capturing the probability of adoption. Significance at 90 and 95 percent confidence denoted "*" and "**", respectively.

mated over the large sample of cities on which population data for 1500 is available. The baseline estimate of 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), but negative and statistically significant after adoption (1500-1800). Controlling for this likelihood, cities that adopted printing suffered a significant growth disadvantage prior to adoption (1400-1500) and enjoyed a very large and significant growth advantage after adoption (1500-1800). The estimates in Panel A suggest that technology adoption with an increase in growth of 0.2 log points (23 percentage points). For comparison, mean city growth for all cities was 0.27 log points (31 percentage points) both 1500-1600 and 1500-1700.[42]

Table 6 Panel B shows alternative results associated with the small sample of cities on which population data is available for both 1400 and 1500. These results differ in several interesting ways. First, in these estimates printing cities are at no significant growth disadvantage prior to adoption. Second, the estimate of the growth advantage in the century after adoption (1500-1600) is highly significant and substantially larger at 0.33 log points (39 percentage points). Third, the estimated print growth advantage 1500-1700 and 1500-1800 is in magnitude the same as in the

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

baseline calculation, however with substantially larger standard errors the estimates are no longer statistically significant over these longer time periods.[43] These results suggest that the association between early technology adoption and city growth was concentrated in the 1500-1600 period, immediately following the invention of the printing press.

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[44]:

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

Estimates of equation (2) show no evidence of selection into treatment. Table 7 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 scores close to 0 or 1 (Panel B restricts to observations with $\hat{P} \in [0.1, 0.9]$).

Table 7: 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 later 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

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

[44] 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 $\hat{P}$.

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.

4.5 Difference-in-Differences

Difference in difference estimators account for the effects of unobserved confounding variables provided the latter are constant over time. Difference-in-difference estimates confirm the significance and magnitudes of the propensity score and OLS results.

The difference-in-difference estimator can be estimated:

$$Y_{it} = \alpha_0 + \alpha_1 PRINT_i + \alpha_2 TIME_t + \alpha_3 (PRINT_i \cdot TIME_t) + \beta' X_{it} + \epsilon_{it}$$

Here Y_{it} is log growth, $PRINT_i$ is an indicator capturing whether a city was an early adopter, $TIME_t$ captures whether or not an observation is from before or after the intervention, and X_{it} is a vector of additional city characteristics.[45] The parameter of interest is α_3, which captures any time-specific growth advantage printing cities may have enjoyed. Table 8 presents results from difference-in-difference regressions estimated over data for 1400-1600 (i.e. examining growth 1400-1500 and 1500-1600).

Consistent with the results above, Table 8 shows that across specifications we find estimates of $\hat{\alpha}_3 \approx 0.18$. 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.[46] 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.[47] Model 4 adds city fixed effects. Under this specification, $\hat{\alpha}_3 = 0.15$ and is only significant at the 90 percent confidence level. However, 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 A and suggests that print cities were growing relatively slowly before adoption.

[45] As discussed above, the average city adopted the printing press in 1476. The identifying assumption here is that $TIME_{1400} = 0$ and $TIME_{1500} = 1$.

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

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

Table 8: 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)
Time	0.02	0.05	0.00	0.19 *
	(0.07)	(0.07)	(0.07)	(0.10)
Print	-0.07	0.16 **	0.13 **	-0.27 **
	(0.06)	(0.06)	(0.04)	(0.12)
Print x Time	0.17 **	0.15 **	0.18 **	0.15 *
	(0.06)	(0.05)	(0.05)	(0.09)
Log Size		-0.20 **	-0.28 **	-1.06 **
		(0.04)	(0.04)	(0.11)
University			-0.06	-0.17
			(0.07)	(0.13)
Catholic Site			-0.01	0.06
			(0.06)	(0.10)
Roman Site			0.09 **	2.18 **
			(0.04)	(0.33)
Med Port			0.35 **	0.22
			(0.11)	(0.19)
Atlantic Port			0.52 **	0.40 **
			(0.09)	(0.18)
River			0.14 **	0.76 **
			(0.05)	(0.13)
Capital			0.62 **	0.21
			(0.13)	(0.33)
Freedom Index			0.03	0.15
			(0.12)	(0.13)
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.

4.6 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.[48] A synthetic control group is a weighted average of available control units. Synthetic control group methods generalize the difference-in-differences model.

[48] Abadie et al. (2007), Hainmueller (2008), and Imbens and Wooldridge (2008) introduce synthetic control group methods.

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:

$$\hat{\alpha}_{\text{sc}} = Y_{1t} - \sum_{k=2}^{K+1} \omega_k^* Y_{kt} \tag{3}$$

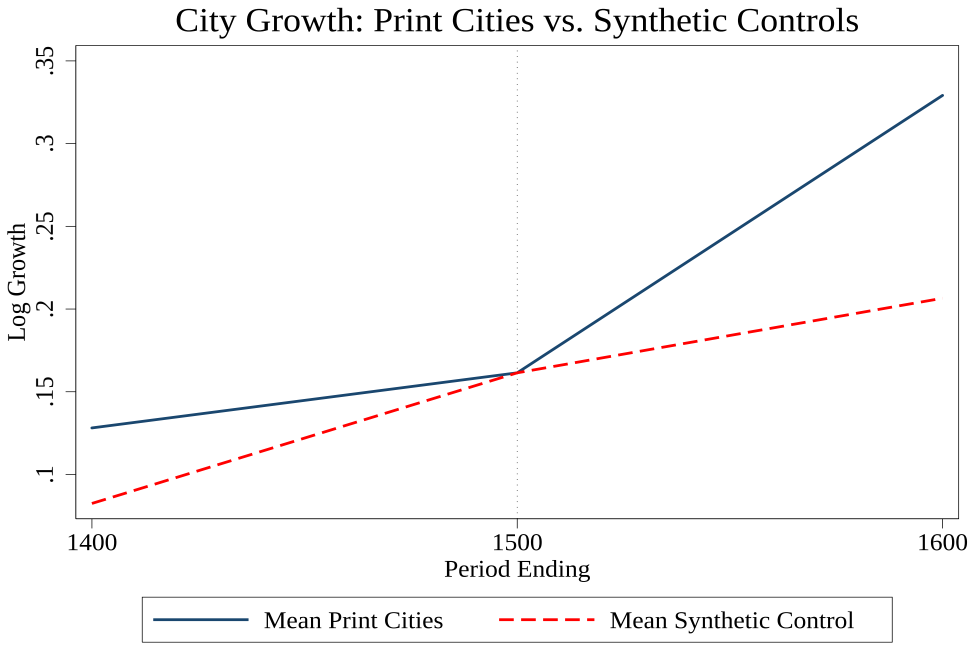
Here Y_{1t} is the outcome for a treated unit at time t and there are potential control units with outcomes Y_{kt} indexed with $k = 1, \ldots, K$. The weights ω_k^* are computed to minimize the distance between pre-intervention outcomes and other predictors of post-interventions outcomes for the treated observation and the control group.[49] 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 3 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. However, following the introduction of the printing press, on average print cities grew 12 percentage points faster than their synthetic controls 1500-1600.

4.7 Spillovers

The estimates presented in Table 6 (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

[49] 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. See Abadie et al. (2007) and Hainmueller (2008) for details. This exercise is implemented using the `synth` routine discussed in Hainmueller (2008).



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).[50] 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. 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:

$$Y_i = \alpha_0 + \alpha_1 P_i + \alpha_2 T_i + \alpha_3 P_i^* + \alpha_4 T_i^* + e_i \tag{4}$$

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

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

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.[51]

Table 9 presents the estimates of equation (4) 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

Table 9: 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.

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.

[51] Ideally, we would have a measure of distance that reflected actual travel times and costs and/or trade flows between cities. Data on inter-city trade is exceedingly limited. The available data on travel times is also sparse. On this see Braudel (1966), which provides limited data on travel times between Venice and a small set of European cities, 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.

5 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 suggest that cities that adopted print technologies in the late 1400s grew at least 20 percentage points – and as much as 35 percentage points – more than similar cities that did not over the period 1500-1600. Between 1500 and 1600, mean city growth was 32 percentage points. Broadly, I find that print cities 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 a considerable growth advantage 1500-1700 and even 1500-1800. Moreover, cities that adopted the printing press enjoyed no growth advantages prior to adoption.

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

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 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 4.2 (above) describes city growth in economies with at least 5 cities that adopted the printing press over the infant industry period. Table B1 presents the data for all economies.

Table B1: Print Technology and City Growth

Panel A: City Growth Between 1500 and 1600

	Press Adopted			Press Not Adopted			
20th Century Polity	No. of Cities	Urban Pop. 1500	Weighted Average Growth	No. of Cities	Urban Pop. 1500	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	25	174	-0.27	0.19
Czechoslovakia	4	109	0.23	7	29	0.25	-0.02
Denmark	1	10	1.39	1	3	0.51	0.88
England	3	60	1.16	52	213	0.21	0.95
France	26	700	0.20	48	440	0.04	0.16
Germany	30	374	0.16	83	400	0.12	0.04
Hungary	1	12	0.00	4	29	0.16	-0.16
Italy	34	1119	0.26	67	463	0.24	0.02
Netherlands	11	118	0.34	22	142	0.53	-0.19
Poland	3	77	0.60	15	100	0.08	0.52
Portugal	5	90	0.56	22	118	0.04	0.52
Spain	19	359	0.37	57	561	-0.15	0.51
Sweden	1	7	0.25	17	27	0.06	0.20
Switzerland	3	27	0.25	8	26	0.00	0.25
Totals	150	3,284	0.27	435	2,768	0.07	0.20

Panel B: City Growth Between 1500 and 1800

	Press Adopted			Press Not Adopted			
20th Century Polity	No. of Cities	Urban Pop. 1500	Weighted Average Growth	No. of Cities	Urban Pop. 1500	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	83	400	0.44	-0.18
Hungary	1	12	0.73	4	29	1.15	-0.41
Italy	34	1119	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	5	90	1.05	22	118	0.26	0.79
Spain	19	359	0.30	57	561	-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	150	3,284	0.43	435	2,768	0.36	0.07

Section 4.2 (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 B2 shows that analysis of a balanced panel of cities on which we observe population data in all relevant periods yields very similar results.

Table B2: Regression Analysis of Print Media and City Growth
Dependent Variable is Log City Growth

Independent Variable	Pre-Adoption 1400-1500	Post-Adoption 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.

To be completed (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. J. Batou, and P. Chèvre (1988), *La Populations 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] Brenner, R. (1976), "Agrarian Class Structure and Economic Development in Pre-Industrial Europe," *Past and Present*, Vol. 70, pp. 30-75.

[14] Butler, P. (1940), *The Origin of Printing in Europe*, Chicago; University of Chicago Press.

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

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

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

[18] Clark, G. (2007), "Genetically Capitalist?" UC Davis working paper.

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

[20] 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.

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

[22] 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.

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

[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] 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.

[27] 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.

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

[29] 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

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

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

[32] 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.

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

[34] Hirano, K., G. Imbens, and G. Ridder (2003), "Efficient Estimation of Average Treatment Effects Using the Propensity Score," *Econometrica*, Vol. 71, No. 4, pp. 1161-1189.

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

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

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

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

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

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

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

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

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

[44] 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.

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

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

[47] McMurtrie, D. (1944), *The Book: The Story of Printing and Bookmaking*, Oxford; Oxford University Press.

[48] Mellot, J-D (2002), "Rouen and its printers from the 15th to the 19th century," in M. Gee and T. Kirk eds., *Printed Matters: Printing, Publishing and Urban Culture in Europein the Modern Period*, Aldershot; Ashgate Press.

[49] Merrington, J. (1978), "Town and Country in the Transition to Capitalism," in R. Hilton ed., *Transition from Feudalism to Capitalism*, London; Verso.

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

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

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

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

[54] Monro, J. (2001), "Money, Wages, and Real Incomes in the Age of Erasmus," University of Toronto Working Paper.

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

[56] Rhodes, N. and J. Sawday (2000), *The Renaissance Computer*, London; Routledge.

[57] 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.

[58] Tilly, C. (1994), "Entanglements of European Cities and States," in Tilly, C. and W. Blockmans eds., *Cities and the Rise of States in Europe*, Boulder; Westview.

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

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

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

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

[63] 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.

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