INFORMATION TECHNOLOGY AND ECONOMIC CHANGE: THE IMPACT OF THE PRINTING PRESS*

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The printing press was the great innovation in early modern information technology, but economists have found no macroeconomic evidence of its impact. This article exploits city-level data. Between 1500 and 1600, European cities where printing presses were established in the 1400s grew 60% faster than otherwise similar cities. Cities that adopted printing in the 1400s had no prior advantage, and the association between adoption and subsequent growth was not due to printers choosing auspicious locations. These findings are supported by regressions that exploit distance from Mainz, Germany—the birthplace of printing—as an instrument for adoption. *JEL* Codes: N13, N33, N93, O11, O18, O33.

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I. Introduction

The movable type printing press was the great innovation in early modern information technology. The first printing press was established in Mainz, Germany, between 1446 and 1450. Over the next 50 years the technology diffused across Europe. Between 1450 and 1500, the price of books fell by two-thirds, 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]

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, they found no evidence of productivity gains associated with computer-based information technologies. A conventional 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

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1. For instance Roberts (1996), Braudel (1979), and Gilmore (1952). On prices see Zanden (2009) and Clark (2004).

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elasticities.[2] However, that argument makes no attempt to gauge the positive externalities historians argue were associated with the diffusion of printing. Historical research suggests that print media transformed the ways ideas were disseminated, promoted the accumulation of human capital, and played a key role in the evolution of business practices (Febvre and Martin 1958; Eisenstein 1979; Hoock 2008).

This article examines these spillovers by exploiting new, city-level data on the adoption of the movable type printing press in fifteenth-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 article compares cities where printers established presses with similar cities where they did not. The article uses ordinary least squares (OLS) estimators to document the magnitude and the timing of the association between printing and city growth. It then employs historical evidence and instrumental variable techniques to identify the impact of printing on city growth.

The instrumental variable (IV) analysis is motivated by historical evidence. Johannes Gutenberg established the first printing press in Mainz around 1450.[3] At that time only a small number of men in Mainz knew the secrets behind the technology. Between 1450 and 1500, the technology diffused in "concentric circles" (Barbier 2006) as printers set out to establish presses in other cities. Distance from Mainz was strongly and significantly associated with early adoption of the printing press, but not with city growth before the diffusion of the printing press or with other independent determinants of city growth. The geographic pattern of technology diffusion thus allows us to identify exogenous variation in adoption. Instrumenting for adoption with distance from Mainz, I find very large and significant estimates of the relationship between the adoption of the printing press and city growth.

The printing press fostered knowledge and skills that were valuable in commerce. Print media played a key role in the development of numeracy, the emergence of business education, and the adoption of innovations in bookkeeping and accounting. With access to cheap waterborne transport, port cities were positioned to

2. Clark (2001) argues that the macroeconomic impact was "unmeasurably small" for these reasons.

3. For details of Gutenberg's innovation and competing attempts to devise print media see Section V.D.

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profit from innovations in commercial practice. In the data, I find that printing delivered special benefits to port cities—beyond the advantages associated with printing or with port location alone.

These findings add a new dimension to arguments stressing the role of cities as sites where information was exchanged, ideas were produced, and the business practices and social groups that drove the rise of European capitalism developed.

II. Literature

Among economic historians, there is some difference of opinion about the extent to which the movable type printing press was a revolutionary innovation. Mokyr (2005) notes that innovation depends on the cost of accessing existing knowledge, and that the printing press was one of the most important access cost–reducing inventions in history. Jones (1981) also argues that "western progress owed much to the superior means of storing and disseminating information." Baten and van Zanden (2008) find a significant association between simulated national-level wages and observed differences in aggregate book production in European history.[4] However, Clark (2001) finds no evidence of aggregate productivity growth associated with the diffusion of movable type printing. Mokyr (2005) similarly argues that the aggregate effects were small.

Social historians have hailed the movable type printing press as a revolutionary innovation. Braudel (1979a) identifies printing as one of three great technological revolutions observed 1400–1800 (alongside advances in artillery and navigation). Gilmore (1952) states that printing drove "the most radical transformation in the conditions of intellectual life in the history of western civilization." Eisenstein (1979) argues that printing created revolutionary new possibilities for "combinatory intellectual activity." Roberts (1996) suggests the outcome was one "dwarfing in scale anything which had occurred since the invention of writing."

Macroeconomic research identifies the central role ideas play in technological change and growth (Romer 1990; Lucas 2009; Jones and Romer 2010). Economists observe that technological

4. Baten and van Zanden (2008) draw simulated country-level real wages from Allen (2003). This paper takes the city as the unit of analysis. Within economies, there was significant variation in printing and growth across cities. Observed data on economic outcomes is also available at the city level. Moreover, contemporary national boundaries did not define the historic economies of Europe.

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change is driven by sharing and recombining ideas (Romer 1990; Mokyr 1995; Weitzman 1998). These findings indicate that major changes in the ways ideas can be stored and transmitted may have far-reaching consequences.

Printing was an urban technology. The market for print media was overwhelmingly urban. Motivated by these facts, this article takes cities as the units of analysis.

European cities played a central role in the emergence of modern, idea-based capitalist economic growth. Urban life generated social contacts that fostered the circulation of information and innovation (Bairoch 1988). Cities were also seedbeds of capitalist business practices. Braudel (1979a) observes that historically, "Capitalism and towns were the same things."[5] 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.[6] These facts support the use of city growth as an indicator of economic vitality.

III. 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 benefited from localized spillovers in human capital accumulation, technological change, and forward and backward linkages. These spillovers contributed to city growth by exerting an upward pressure on the returns to labor, making cities culturally dynamic and attracting migrants. They were localized by high transport costs associated with intercity trade and because the printing press fostered important face-to-face interactions.[7]

Historically, urban death rates exceeded urban birth rates and migration drove city growth. Cities drew migrants to the

5. Historical research has qualified this generalization (e.g. Scott 2002) but confirms the importance of cities. For discussion see Dittmar (2010).

6. Acemoglu, Johnson, and Robinson (2005), DeLong and Shleifer (1993), Bairoch (1988), and Braudel (1979a, 1979c).

7. This article stresses the effects of print media on the development of economically useful skills and knowledge. The interplay between printing and religion is discussed in Section V.F. The historic association between printing and city growth is consistent with Glaeser and Saiz's (2003) finding that human capital predicts population and productivity growth at the city level in our day.

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extent that they offered relatively high wages, cultural amenities, and economic opportunities.[8] In the pre-industrial era, commerce was a more important source of urban wealth and income than tradable industrial production.[9] As a result, migration and city growth were typically contingent on commercial success.[10]

Print media played a key role in the acquisition and development of skills that were valuable to merchants.[11] The ability to calculate interest rates, profit shares, and exchange rates was associated with high returns for merchants engaged in large-scale and long-distance trade. Starting in the 1480s, European presses produced a stream of "commercial arithmetics." Commercial arithmetics were the first printed mathematics textbooks and were designed for students preparing for careers in business.[12] They transmitted commercial know-how and quantitative skills by working students through problems concerned with determining payments for goods, currency conversions, interest payments, and profit shares. 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)

Gaspar Nicolas, author of the first Portuguese arithmetic (1519), similarly explained: "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).

8. On migration and historical demography see Woods (2003), de Vries (1984), and Bairoch (1988).

9. See inter alia Nicholas (2003) and Braudel (1966).

10. Political capitals were exceptions to this rule.

11. A large share of print media was religious and less likely to generate positive spillovers. However, the availability of affordable religious and humanist works promoted literacy and, increasingly, norms favoring the exchange of ideas. Literacy is discussed later. Section V.F. discusses printing and religion.

12. They were employed in urban schools and by private teachers teaching commercial arithmetic. The schools teaching commercial arithmetic operated parallel to universities, which did not provide business-oriented preparation. See Rey (2006), Speisser (2003), Swetz (1987), and Goldthwaite (1972).

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Hundreds of commercial arithmetics were printed 1480–1550 (see Figure I below).

Print media were also associated with the development of cutting-edge business practice. Social scientists have identified double-entry bookkeeping as an important technological innovation since the early twentieth century, when Weber (1927) and Sombart (1957) argued that it played a key role in the emergence of rational, optimizing business practice. The first published description of double-entry bookkeeping appeared in 1494 (Luca Pacioli's *Summa*). Printed merchants' manuals then disseminated the key ideas. Generally, merchants' manuals combined instruction in accounting and arithmetic with non-quantitative guidance on business practice (Goldthwaite 1972; Hoock 2008). A subset contained tables that simplified the calculation of interest on loans, tariffs, and transport costs. Hoock (2008) observes that, "In some ways, [these handbooks] present the same characteristics as the modern pocket calculator with integrated routines." Figure I documents that hundreds of different merchants' manuals were printed 1480–1550. It shows that growth in the number of merchants' manuals printed declined from high initial rates and

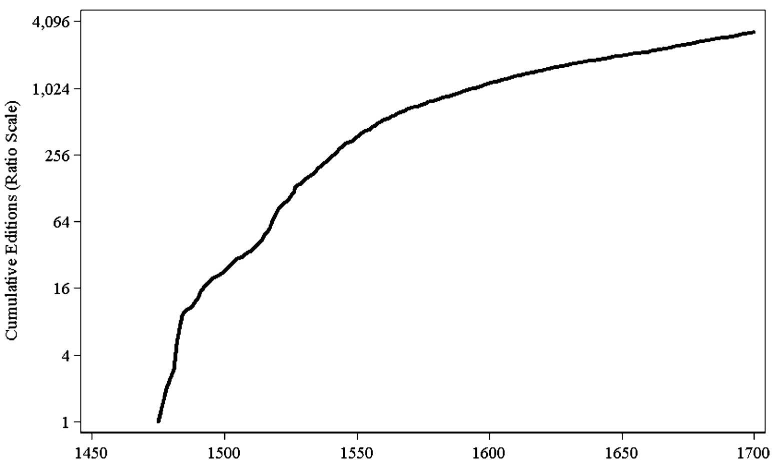

FIGURE I

Cumulative Output of Merchants' Manuals in Europe

Cumulative output (editions) of printed merchants' manuals in Europe, including commercial arithmetics, treatises on bookkeeping, guides to commercial law and business practice. Data from Hoock and Jeannin (1991, 2001, 2007).

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by the late 1500s stabilized at a constant rate (approximately 1% per year).

The observation that print media fostered the development of business practices employed in long distance trade raises a question: Did printing deliver special benefits to geographic locations that were propitious for commerce? Historically, transport over land was relatively expensive. Cities with access to cheap, waterborne transport were positioned to realize high returns to innovations in commerce. Section V.B. documents that the growth advantage enjoyed by cities that adopted printing in the late 1400s was largely driven by the growth of ports with printing presses—beyond advantages associated with the printing press or with being a port alone.

The availability of inexpensive texts was a key prerequisite for the spread of literacy in Renaissance Europe (Grendler 1990). School books generated high returns for Renaissance printers (Bolgar 1962; Nicholas 2003; Füssel 2005). Schooling in languages became part of a progression in which pupils went from "arts to marts." Cities began to run schools for children who were not going to learn Latin—using printed grammar school texts. In the fifteenth century, it became expected that the children of the bourgeoisie would attend school (Bolgar 1962). But print media also promoted opportunities for the less privileged to obtain education and raise their incomes. Brady (2009) observes that no document better captures the new opportunities than Thomas Platter's (1499–1582) autobiography (Platter 1839). After wandering penniless across Europe, Platter began his formal schooling at age 18. Having learned Latin, Platter took a job as a rope maker in Zurich to support his book-buying and reading habit, taught himself Hebrew and Greek, and rose to become a wealthy school master, professor, and printer.

Beyond literacy, print media fostered the development of new, bourgeois competences and the "social ascent of new professionals" (Scott 2002).[13] The urban middle classes were the principal purchasers of books. Printing spread to meet, "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

13. Mokyr (2005) defines competence as extending beyond the ability to read, interpret, and execute the instructions of a technique to include supplemental tacit knowledge. Nicholas (2003) and Eisenstein (1979) observe that print media transformed urban culture.

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order to manage their businesses and conduct civic affairs" (Rice 1994). The new technology underpinned an emerging culture of information exchange and the development of an urban, bourgeois public sphere (Smith 1984; Long 1991; Zaret 2000).

The role of print media in the diffusion of industrial innovations was probably more limited. Historically the diffusion of industrial technology was heavily dependent on the movement of skilled workers (Cipolla 1972). This is consistent with the emphasis this article places on localized spillovers from print media and the pattern of technology diffusion described shortly. Significantly, the knowledge required to successfully cast movable type remained quasi-proprietary for nearly one century after Gutenberg's innovation: Biringuccio's *Pirotechnia* (1540) provides the earliest known published blueprint.

Cities with printing presses derived benefits from the technology that others did not. The costs of information and human capital accumulation were significantly lower in cities with printing presses. In part, these advantages were due to transport costs.

Print media were costly to transport because they were heavy and fragile commodities, sensitive to damp (Febvre and Martin 1958; Barbier 2006). The trade in hardbound books was relatively extensive but still significantly limited. Outside printing cities, information on the range of available print media was incomplete and many books were not offered for sale. Flood (1998) observes, "Outside the towns where books were printed or which were main centers of the burgeoning book trade the public were dependent on what itinerant traders offered them and on word of mouth."[14] Booklets and ephemera termed "city printing" (*l'imprimerie de ville*) accounted for a large share of production and were even less widely traded.[15] Transport costs in early modern Europe were sufficiently high that print media often spread through reprinting rather than intercity trade.[16] Books were often shipped unbound

14. Contemporary accounts confirm that access to print media was limited outside printing centers. Platter (1839) described the constraints on his education in the early 1500s: "In the school at St. Elizabeth, indeed, nine Bachelors of Arts read lectures at the same hour, and in the same room. . . neither had any one printed books. . . What was read had first to be dictated, then pointed and constructed, and at last explained; so that the Bacchants had to carry away thick books of notes when they went home."

15. See Nieto (2003), Edwards (1995), Eisenstein (1979), and Section V for further discussion.

16. Edwards (1995) observes: "If, for example, there was an interest in Strasbourg for a work first published in Wittenberg, it was more common for a printer

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and in very small lots—a few copies of a few texts (Febvre and Martin 1958). 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 km raised the sale price of transported books by 20% (Febvre and Martin 1958). Records from the archives of the Ruiz merchant family indicate that insurance and transport costs for a shipment of 21 books from Lyon to Medina del Campo (280 km as the crow flies) were equivalent to 30 days' wages for a skilled craftsman (Febvre and Martin 1958). Archival holdings provide additional evidence on the limits on the trade in print media. The Bayerische Staatsbibliothek in Munich houses the largest and most comprehensive historic collection of books printed 1450–1500. Figure II shows that the proportion of the editions produced in a given city and held in the Munich archives declines sharply (and nonlinearly) in the distance between the printing city and the archive.[17]

Printing cities also enjoyed benefits due to agglomeration economies. The printing press produced new face-to-face interactions in addition to books and pamphlets. Printers' workshops brought scholars, merchants, craftsmen, and mechanics together for the first time in a commercial environment, eroding a preexisting "town and gown" divide (Eisenstein 1979). Bookshops and the houses of printers became meeting places and temporary residences for intellectuals. Print technology also produced, in 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" (Eisenstein 1979). Historical research indicates that these activities made printing cities attractive cultural and economic locations. Cities that were early adopters of the printing press attracted booksellers, universities, and students. Adoption of the printing press also fostered backward linkages: the printing press attracted paper mills, illuminators, and translators.[18]

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."

17. Language barriers do not explain this phenomenon: 72% of books printed 1450–1500 were printed in Latin and the pattern holds when the sample is restricted to Latin editions. That an unusually high proportion of books printed Venice and Rome was held in foreign collections is explained by the fact that Venice was the commercial hub and leading printing center of Europe 1450–1500 and Rome occupied a unique position as the seat of Roman Catholicism.

18. See Febvre and Martin (1958), Barbier (2006), Varry (2002), Fau et al. (2003), and Eisenstein (1979).

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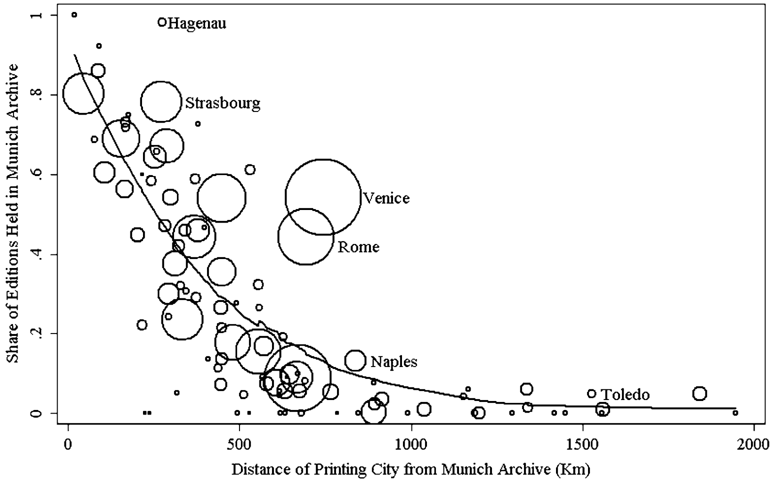

FIGURE II

Archive Holdings and Distance from Point of Production

This figure presents data for the 100 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. Markers are scaled to reflect the magnitude of city book production. Fitted values estimated with locally weighted regression. Data on total incunabula production from ISTC (1998).

IV. DATA

This article exploits data on the diffusion and output of printing presses over the technology's infant industry period (1450–1500). Between 1450 and 1500, entrepreneurs established printing presses across Europe and the real price of books fell by two-thirds (Zanden 2004; Clark 2004). Between 1500 and 1800, printing technology was largely unchanged and declines in the price of books were relatively modest (Febvre and Martin 1958; Füssel 2005).[19] Historical research emphasizes that the period 1450–1500 was the "first infancy" of printing. Books produced 1450–1500 are referred to as *incunabula*, from the Latin for

19. Clark (2004) finds that real book prices in England fell 75% between 1450 and 1530 and stabilized at one-third the pre-Gutenberg level through the late 1700s. Zanden (2009) examines Dutch data and estimates that real prices fell by two-thirds 1450–1500. Zanden estimates that between 1500 and 1800 book prices declined from approximately one-third to one-sixth of the pre-Gutenberg level.

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"cradle" or "infancy" (Febvre and Martin 1958; Clair 1976; Glomski 2001; Barbier 2006). Over the infant industry period supply-side constraints limited technology diffusion. As will be discussed, by the early to mid-1500s these constraints were relaxed.

I construct data on the location and output of printing presses over the infant industry period from three principal sources. The first source is the *Incunabula Short Title Catalogue* (ISTC 1998) maintained by the British Library. The ISTC (1998) "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. The ISTC catalogs fifteenth-century editions printed in 196 historic cities.[20] The second source is Febvre and Martin's (1958) *L'Apparition du Livre*, which documents 181 historic cities that adopted the printing press 1450–1500. The third source is Clair's (1976) *A History of European Printing*, which documents the establishment of printing presses in 188 historic cities 1450–1500. As shown in Table I, the historical sources identify 205 unique cities that adopted the printing press 1450–1500.[21]

Data on the locations and populations of Europe's historic cities are from Bairoch, Batou, and Chèvre (1988). Their approach is to identify the set of cities that ever reached 5,000 inhabitants between 1000 and 1800 and then search for population data for these cities in all periods. The data record (in thousands) the populations of urban agglomerations, not simply populations within administratively defined boundaries.[22] These data—henceforth the "Bairoch data"—are recorded every 100 years up to 1700, and then every 50 years to 1850. The data set contains a total of 2,204 historic European cities. Populations are observed every 100

20. Of the 27,873 records, 1,352 are either undated or are associated with dates outside 1450–1500 and 738 indicate only a regional location or possible city locations.

21. This figure comprises the 196 cities from the ISTC, four additional printing cities identified by Febvre and Martin, four identified by Clair, and one identified by Clair and Febvre and Martin. While presses operated in these nine additional cities, since we have no record of incunabula produced at these locations, they are not recorded in ISTC (1998). Results are not contingent on the inclusion of these cities.

22. Bairoch, Batou, and Chèvre (1988) include populations of "the 'fauborgs', the 'suburbs', 'communes', 'hamlets', 'quarters', etc. that are directly adjacent" to historic city centers. Bairoch, Batou, and Chèvre draw data from urban censuses, tax records, archaelogical work, as well as other primary and secondary sources. These data are examined in greater detail in Dittmar (2010).

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TABLE I
THE DIFFUSION OF THE PRINTING PRESS 1450–1500

(1) 20th-Century Polity	(2) Cities Adopting Printing Press	(3) Total Number of Historic Cities	(4) Share Adopting (%)
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

Notes. See text for the sources identifying printing cities. Data on total cities represent the historical cities identified in Bairoch, Batou, and Chèvre (1988).

years 1300–1800 for a balanced panel of 202 cities.[23] The leading alternate source of data on historic city populations is the panel in de Vries (1984). This article analyzes the Bairoch data because the de Vries (1984) data are restricted to 1500–1800 and cover only cities that reached a population of 10,000.[24]

The econometric work that follows also exploits a new database on the historical characteristics of European cities, including which cities were located on navigable rivers, sea ports, and the sites of Roman settlement; which were political or religious centers; and measures of economic institutions. These data are described in the Data Appendix.

23. 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 nonurban religious establishments (principally monasteries). Other “missing” print centers were adjacent to cities that did have presses and represent a sort of duplication. Westminster with its proximity to the city of London is an example. In keeping with the economic understanding of urban agglomeration, and the construction of the Bairoch data, this article treats production of print media at Westminster as London output.

24. Dittmar (2010) analyzes and compares these data in greater detail.

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V. Empirics

V.A. Overview

Per capita income data are not available at the city level and the existing data on urban wages are confined to a small number of cities.[25] 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.[26] Moreover, city growth may reflect technological progress. In modern economies with mobile labor, high-productivity cities are likely to draw migrants (Glaeser, Scheinkman, and Shleifer 1995). 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. For these reasons, this article 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 small subset cities, and because the available measures of output are coarse, I focus on adoption. 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 ephemera was less concentrated than the production of expensive books and the intercity trade in ephemeral forms of print media was relatively limited: historians designate these ephemeral media as "city printing" (l'imprimerie de ville).[27] These media played an important role in the development of literacy and print culture that measures of book production may not capture. These facts support an emphasis on the printing press itself.

V.B. Comparison of Average Outcomes

This section compares the population growth of cities that were early adopters of print technology with the growth of cities that were not. It documents that cites in which printing

25. Allen (2007) compiles data on real wages in 20 cities. These extend to the early 1400s for only eight cities, all of which adopted printing 1450–1500. Similar coverage is available in the data collected by the Global Price and Income History Group (UC Davis) and the International Institute for Social History.

26. See Acemoglu, Johnson, and Robinson (2005), Bairoch (1988), and de Vries (1984).

27. See Nieto (2003), Flood (1998), Edwards (1995), Eisenstein (1979), Febvre and Martin (1958), and Barbier (2006).

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presses were established in the late 1400s grew relatively quickly 1500–1600.[28]

Table II compares, by country, the growth 1500–1600 of cities that were early adopters with the growth of cities that were not. It includes all cities for which population data are available. It shows that on average, cities that adopted the press in the late 1400s grew 20 percentage points more than nonprinting cities 1500–1600. Table II also shows that the cities that adopted were unusually large: 30% of cities with population data adopted, but adopting cities accounted for 58% of total urban population in 1500. Moreover, the Netherlands stand out as an economy in which printing press cities grew relatively slowly 1500–1600. Table III shows that the print cities' growth advantage declined to a modest 7 percentage points 1500–1800. It also shows that in Germany print cities grew relatively slowly over long periods.[29]

For Germany the slow growth of print cities in the 1600s was associated with military conflict (the Thirty Years War, 1618–1648) in which flourishing cities were depopulated. In the Netherlands, the slow growth of print cities 1500–1800 is entirely accounted for by slow growth before 1700. The Netherlands were the site of military conflict through much of the sixteenth century and from 1621, following the expiration of the Twelve Years Truce.[30] These wars were confessional conflicts between Catholic and Protestant forces. Since print media were critical for the diffusion of the Reformation (Edwards 1995; Gilmont 1998), these wars cannot be viewed simply as "exogenous shocks." As discussed in Section V.F., the positive economic impacts of the printing press may have been offset the adverse consequences of the religious diversity and conflict it was used to promote.

28. It is natural to wonder whether the printing press impacted incomes at the city level. The data on wages are limited to a small number of cities almost all of which adopted the press 1450–1500. The Online Appendix documents that skill premia (the ratio of skilled wages to unskilled wages) increased after the establishment of printing presses and discusses the increases in urban wages observed 1500–1600.

29. The slow growth of former Czech print cities is due to Prague's demographic decline, which was associated with the reimposition of serfdom and the city ceasing to be a political capital.

30. 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 a third of its population.

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TABLE II
PRINT TECHNOLOGY AND LOG CITY GROWTH 1500–1600

	Press Adopted 1450–1500			Press Not Adopted 1450–1500			
(1) 20th-Century Polity	(2) No. of Cities	(3) Urban Pop. 1500	(4) Weighted Average Growth	(5) No. of Cities	(6) Urban Pop. 1500	(7) Weighted Average Growth	(8) Print City Growth Advantage
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

Notes. Urban populations are given in thousands. At the country level, weighted average growth (columns 4 and 7) is calculated using city populations in 1500 as the weights on log city growth. At the city level, log growth 1500–1600 is $\ln\left(\frac{POP_{1600}}{POP_{1500}}\right)$, where POP_t is city population in year t. The print growth advantage (column 8) is the difference between average growth for adopting and nonadopting cities (column 4 − column 7). Across all countries, total weighted average growth is calculated using urban populations in 1500 as the weights. Hungary is omitted because Buda was the lone Hungarian print city and the Bairoch data do not record Buda's population in 1600.

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TABLE III
PRINT TECHNOLOGY AND LOG CITY GROWTH 1500–1800

	Press Adopted 1450–1500			Press Not Adopted 1450–1500			
(1) 20th-Century Polity	(2) No. of Cities	(3) Urban Pop. 1500	(4) Weighted Average Growth	(5) No. of Cities	(6) Urban Pop. 1500	(7) Weighted Average Growth	(8) PrintCity Growth Advantage
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

Notes. Urban populations are given in thousands. At the country level, weighted average growth (columns 4 and 7) is calculated using city populations in 1500 as the weights on log city growth. At the city level, log growth 1500–1600 is $\ln\left(\frac{POP_{1800}}{POP_{1500}}\right)$, where POP_t is city population in year t. The print growth advantage (column 8) is the difference between average growth for adopting and nonadopting cities (column 4 − column 7). Across all countries, total weighted average growth is calculated using urban populations in 1500 as the weights.

V.C. Regression Analysis

Table IV presents regression estimates that examine log city growth over 100-, 200-, and 300-year periods. These estimates show that cities that adopted the printing press in the late 1400s grew no faster than other cities 1400–1500, but enjoyed very large and significant growth advantages after 1500. The estimates 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 historic presence of political and educational institutions (political capitals and historic universities); the nature of economic institutions securing protection against expropriation; and advantages associated with locations at sea ports, navigable rivers, and sites where Roman settlements were established (Hohenberg and Lees 1985; DeLong and Shleifer 1993; Acemoglu,

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TABLE IV

REGRESSION ANALYSIS OF PRINT MEDIA AND LOG CITY GROWTH

	Dependent Variable Is Log City Growth			
	Pre-Adoption	Post-Adoption		
(1)	(2)	(3)	(4)	(5)
Independent Variable	Growth 1400–1500	Growth 1500–1600	Growth 1500–1700	Growth 1500–1800
Print Adoption 1450–1500	0.07	0.19***	0.26***	0.30***
	(0.08)	(0.06)	(0.08)	(0.09)
Editions Per Capita	0.03	0.03*	0.04	0.05
	(0.03)	(0.02)	(0.03)	(0.03)
University	−0.12	0.02	0.17*	0.17*
	(0.11)	(0.07)	(0.09)	(0.09)
Roman Site	0.08	−0.01	0.09	0.04
	(0.06)	(0.05)	(0.08)	(0.07)
Capital	0.31**	0.95***	1.46***	1.98***
	(0.13)	(0.16)	(0.20)	(0.27)
Freedom Index	−0.23	0.27***	0.29**	−0.07
	(0.14)	(0.10)	(0.13)	(0.14)
Atlantic Port	0.16	0.34***	0.64***	0.76***
	(0.18)	(0.09)	(0.14)	(0.12)
Mediterranean Port	0.21*	0.15	0.57***	0.65***
	(0.13)	(0.12)	(0.15)	(0.17)
Baltic Port	−0.16	0.25**	0.55**	0.37
	(0.18)	(0.12)	(0.22)	(0.24)
Navigable River	0.14*	0.18***	0.23***	0.39***
	(0.08)	(0.06)	(0.09)	(0.09)
Log Population	−0.22***	−0.30***	−0.42***	−0.64***
	(0.04)	(0.04)	(0.05)	(0.05)
Country FE	Yes	Yes	Yes	Yes
Observations	291	495	515	622
R Squared	0.33	0.32	0.35	0.47

Note. The dependent variable in column (2) is $\ln\left(\frac{POP_{1500}}{POP_{1400}}\right)$, where POP_t is city population in year t. The dependent variable in column (3) is $\ln\left(\frac{POP_{1600}}{POP_{1500}}\right)$. The dependent variable is in column (4) is $\ln\left(\frac{POP_{1700}}{POP_{1500}}\right)$. The dependent variable in column (5) is $\ln\left(\frac{POP_{1800}}{POP_{1500}}\right)$. *Editions Per Capita* are measured as editions published 1450–1500 per 10,000 inhabitants in 1500. *University* is an indicator for the presence of a historic university. *Roman Site* and *Capital* are indicators for cities located on sites of Roman settlement and historic capitals. *Freedom Index* is the DeLong and Shleifer (1993) index of regional institutions securing property rights. *Atlantic Port*, *Mediterranean Port*, and *Baltic Port* are indicators for historic port cities on these bodies of water. *Navigable River* is an indicator for cities on historically navigable inland waterways. *Log Population* measures the log of city population at the beginning of the relevant period. All variables are described in the Data Appendix. City growth 1400–1500 is taken as a placebo (the average date of adoption was 1476). Heterskedasticity-robust standard errors are clustered at the country level and presented in parentheses. Significance at the 90%, 95%, and 99% confidence levels are indicated by *, **, and ***, respectively.

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Johnson, and Robinson 2005).[31] On average European cities grew by 0.27 log points 1500–1600. Table IV shows print cities grew an additional 0.19 log points over this period. This estimate implies that printing accounted for 18% of city growth 1500–1600.[32] In the balanced panel, the print effect is stronger (0.3 log points) 1500–1600 and the association between books per capita and growth vanishes. This suggests that city printing (pamphlets, price lists, and other nonbook materials) and the subject matter of print media were important (see the Online Appendix). The results also hold when we exclude the cities of Eastern Europe that were exposed to the institutions of the second serfdom post-1500.[33]

These results are supported by generalized difference-in-differences regression estimates that test whether and when cities that adopted printing in the late 1400s began to grow relatively quickly. The generalized difference-in-differences set-up estimates the association between city growth and the interaction between print status and time in the balanced panel of cities with populations observed every 100 years 1300–1800. The basic reduced-form model is:

$$Y_{i,t} = \theta_i + \delta_t + \sum_{t=1300}^{1700} \alpha_t D_t T_i + X'_{i,t}\gamma + \epsilon_{i,t}. \tag{1}$$

Here $Y_{i,t}$ is log city growth for city i in time t, the θ_i's are city fixed effects, the δ_t's time fixed effects, D_t is an indicator variable for each time period, T_i is an indicator variable capturing whether city i was an early adopter of print technology, $X_{i,t}$ is a vector of covariates, and $\epsilon_{i,t}$ is the error term. The coefficient of interest is α_t, which captures the growth advantage print cities enjoyed in each time period t. Covariates $X_{i,t}$ include controls for universities, political capitals, and country fixed effects; interactions between indicators for Atlantic ports and time fixed effects; indicators for Mediterranean ports and time fixed effects;

31. Results are robust to controls for Protestantism. For discussion of religion see Section V.F.

32. This calculation relies on the point estimate of 0.19, the fact that printing presses were established in 135 of the 495 cities in Table IV, and the assumption that the establishment of presses in printing cities did not depress the growth of cities without presses. Evidence for this assumption is discussed below and in the Online Appendix. The fact that the estimated print effect does not fall when controls are added may appear puzzling. The explanation is that printers tended to go to larger cities and big cities typically grew slowly. This nonrandom growth dynamic is analyzed in Dittmar (2010).

33. On the impact of the "second serfdom" see Dittmar (2010).

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interactions between country and year indicators; and between log population and year indicators to control for the negative association between intial city size and city growth identified in Dittmar (2010).

Table V documents that the cities that adopted the printing press in the late 1400s had no prior growth advantage but a highly significant advantage of over 30 percentage points after 1500. It shows that although print cities enjoyed growth advantages 1600–1700 and 1700–1800, the estimates do not cross the conventional thresholds for statistical significance in the complete sample. In Table V, the line "Print × Yr1400" presents the estimate of the relative growth advantage print cities enjoyed 1400–1500, the line "Print × Yr1500" presents the estimated print city growth advantage 1500–1600, and so on.

Table V shows that the print effect is not driven by the particular region in which cities were located, but was driven by the growth advantages enjoyed by ports that adopted printing.[34] Column (6) shows that when the sample is restricted to port cities, cities that adopted printing in the late 1400s had extremely large subsequent growth advantages. It also shows that—once the interaction between printing and ports is considered—Atlantic ports enjoyed no systematic advantages over non-Atlantic ports. Column (7) shows that among cities that were not ports, early adoption of the printing press was associated with a modest and statistically insignificant growth advantage. Interestingly, ports were *less* likely to get the printing press than other cities. In the balanced sample, printing presses were established by 1500 in 43% of nonport cities and 36% of sea ports. Controlling for city size, the presence of universities, country fixed effects, and measures of institutional quality, there is a significant negative association between ports and the adoption of the printing press 1450–1500.[35]

V.D. Technology Adoption

The printing press was not randomly assigned to cities. This section describes how the technology was brought to and adopted by the cities of Europe. It documents that the quasi-proprietary

34. The results are not driven by a "London effect." Excluding English cities does not change the results. The results are similarly robust to controlling for Protestantism. On religion, see Section V.F.

35. For this analysis, see the Online Appendix.

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TABLE V
LOG CITY GROWTH: THE TIMING OF THE PRINT ADVANTAGE

(1) Variable	(2) All Cities Balanced Sample	(3) Exclude German Cities	(4) Exclude Italian & Dutch Cities	(5) Exclude If East of Elbe River	(6) Only Port Cities	(7) Only Cities Without Ports
Print × Yr1400	0.09	0.10	0.09	0.11	0.27	−0.04
	(0.16)	(0.18)	(0.20)	(0.17)	(0.38)	(0.16)
Print × Yr1500	0.34**	0.39**	0.41**	0.34**	1.39***	0.10
	(0.15)	(0.17)	(0.18)	(0.16)	(0.42)	(0.15)
Print × Yr1600	0.13	0.22	0.08	0.16	0.73**	−0.01
	(0.16)	(0.17)	(0.20)	(0.16)	(0.34)	(0.17)
Print × Yr1700	0.19	0.25	0.16	0.22	0.84**	0.00
	(0.14)	(0.16)	(0.17)	(0.14)	(0.42)	(0.15)
Atlantic × Yr1400	0.12	0.27	0.13	0.12	−0.32	—
	(0.31)	(0.33)	(0.37)	(0.31)	(0.52)	—
Atlantic × Yr1500	0.43*	0.55**	0.38	0.44*	−0.24	—
	(0.25)	(0.28)	(0.28)	(0.25)	(0.52)	—
Atlantic × Yr1600	0.42*	0.49*	0.33	0.45**	0.47	—
	(0.22)	(0.25)	(0.24)	(0.22)	(0.38)	—
Atlantic × Yr1700	0.60***	0.73***	0.64***	0.62***	0.32	—
	(0.19)	(0.20)	(0.21)	(0.19)	(0.38)	—
R squared	0.55	0.57	0.58	0.54	0.77	0.53
Observations	1,010	875	710	850	225	785
Adopting Cities	83	71	53	78	16	67
Nonadopting Cities	119	104	89	92	29	90

Note. This table presents estimates of Equation (1) using the balanced panel of cities with population data observed every 100 years 1300–1800. The dependent variable is log population growth: $\ln\left(\frac{POP_{t+100}}{POP_t}\right)$, where POP_t is city population in year t and t = 1300, . . . , 1700. Print is an indicator variable for cities that adopted the printing press 1450–1500. The variables Yr1400,. . . , Yr1700 are indicators for 100-year periods starting 1400, . . . , 1700. Atlantic is an indicator variable for cities that were historic ports on the Atlantic Ocean. Regressions control for city, country, and year fixed effects; country cross year fixed effects; Mediterranean port cross-year fixed effects; and log population. See Data Appendix for details on the construction of the control variables. Heterskedasticity-robust standard errors clustered by city are in parentheses. Significance at the 90%, 95%, and 99% confidence levels are indicated by *, **, and ***, respectively.

nature of the technology limited diffusion on the supply side and how distance from Mainz was an important determinant of adoption 1450–1500.[36]

The movable type printing press was developed by Johannes Gutenberg in Mainz around 1450. In subsequent decades entrepreneurial printers spread the technology to other European

36. Section V.E. documents the negative relationship between adoption and distance within economies. It shows that distance from Mainz is a strong instrument for adoption and yields large, significant estimates of the technology's impact. For analysis of factors associated with adoption see also the Online Appendix.

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cities. Over the infant industry period, the printers who established presses in cities across Europe were almost exclusively Germans. Most had been apprentices of Gutenberg and his business partners in Mainz or had learned from former apprentices.[37] Figure III shows the pattern of diffusion. Figure IV shows that the proportion of cities adopting printing declined in distance from Mainz.

Over the period 1450–1500, entry was limited by the fact that the printing press was a quasi-proprietary technology. The key innovation in printing—the process used to cast movable metal type—was complex and semi-secret.[38] To produce suitable metal type, printers required a combination of alloys that was strong and ductile; hard and nonporous; noncorrosive and maintained the "plane-parallel" shape of the castings when cooled. These characteristics were obtained with a precise combination of lead, tin, and antimony that was a trade secret.[39] Although it proved impossible to maintain a strict monopoly on the intellectual property behind the printing press, the knowledge remained quasi-proprietary for almost a century. The first known "blueprint" manual on the production of movable type was only printed in 1540 (Biringuccio's *Pirotechnia*).

Supply-side restrictions meant that distance from Mainz was an important factor determining which cities were early adopters. Cities relatively close to Mainz were more likely to

37. Before he moved to Mainz, Gutenberg was developing the technology in Strasbourg. There were concurrent attempts to develop printing technology in Avignon and Haarlem, but the breakthrough was made in Mainz and the technology diffused from there. See Barbier (2006), Nieto (2003), Fuhrman (1978), Clair (1976), and Febvre and Martin (1958).

38. Recent research suggests that as of the 1450s, Gutenberg may not have entirely consolidated the breakthrough that enabled the mass production of movable metal type. Agüera y Arcas and Fairhall (2001) and Agüera y Arcas (2002) perform a computational analysis of the characters in the Papal Bull (Calixtus Bull) of 1456 printed by Gutenberg. Agüera y Arcas and Fairhall document that this bull was printed with hundreds of different versions of each letter. This finding suggests that Gutenberg may have been casting only a few letters at a time in the 1450s. It also raises the possibility that other printers played a role in developing techniques that permitted the mass production of movable type.

39. Documents from a lawsuit in which Gutenberg was the defendant reveal that when one of his original business partners died, Gutenberg sent a servant to the home of the deceased to dismantle a press, retrieve components, and destroy evidence of their collaboration lest these materials fall into the hands of the partner's heirs. See Clair (1976), Fuhrman (1978), and Febvre and Martin (1958).

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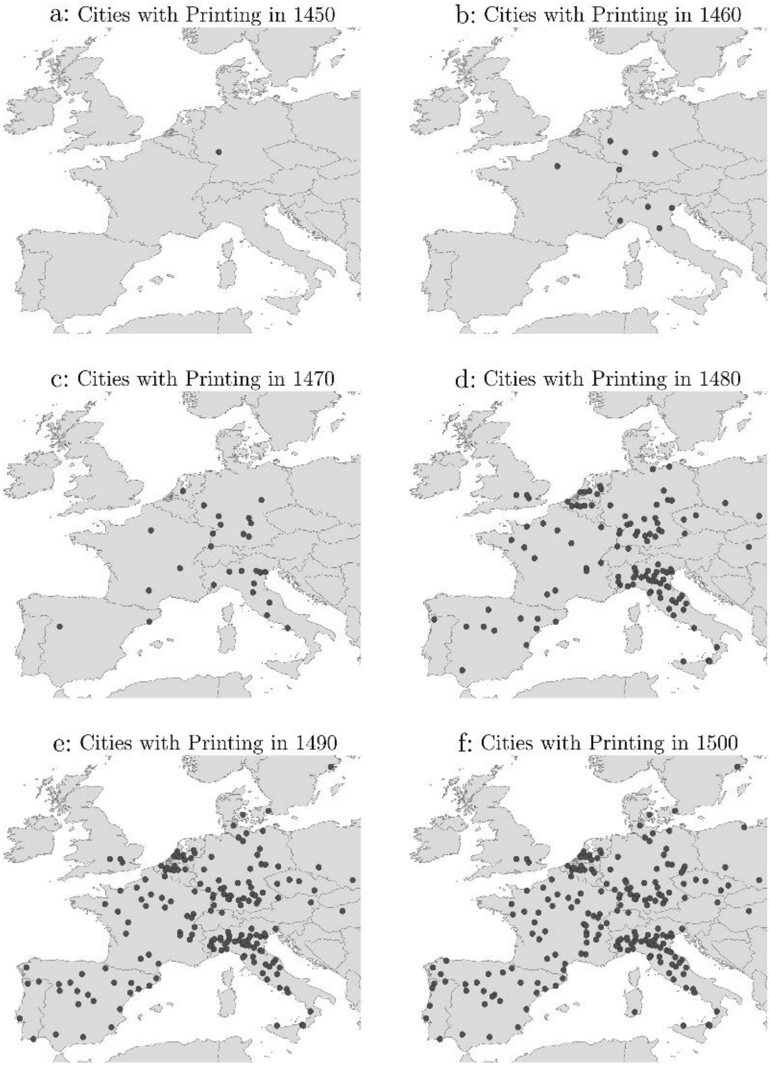

FIGURE III
The Diffusion of the Movable Type Printing Press

receive the technology other things equal (Barbier 2006). As Nieto (2003) notes, faced with high travel costs and the uncertainties associated with the matching process, printers who established a profitable press in a given city had few incentives to leave.

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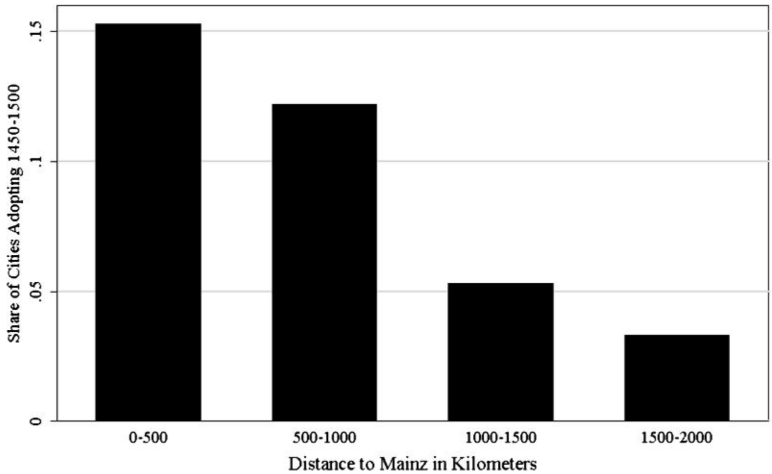

FIGURE IV

Distance from Mainz and Adoption of the Printing Press, 1450–1500

This figure documents the relationship between distance from Mainz, Germany and the proportion of historic cities that adopted the printing press 1450–1500. Historic cities are those identified in Bairoch, Batou, and Chèvre (1988).

Consistent with these observations, 40 of Europe's 100 largest cities did not have printing presses in 1500.

Regulatory barriers to diffusion and entry were minimal. Printing with movable type was a new occupation and fell outside existing guild regulations. Füssel (2005) 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), Nicholas (2003), Brady (2009), and Neddermeyer (1997) confirm that entry was free and unregulated.

In contrast, financial barriers to entry were notable. For those unable to manufacture movable type, 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.[40] In addition, paper was expensive, printers realized returns on print runs only over time,

40. Data from bequests show that the equipment required to establish a press cost 250–600 livres in the early 1500s (Gilmont 1998; Febvre and Martin 1958). A livre was worth 18.7 g of silver 1500–1550. The average wage earned by a craftsman in Paris was 4.4 g of silver per day 1500–1550 (the average wage across 18 cities was 4.7 g—see Allen 2007).

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and successful printing required a minimum efficient scale. As a result, printers typically required financial backing.[41]

Originating in Mainz, the technology diffused through a search process. The process was shaped by demand-side fundamentals but had an important random component. Printers sought two things: a backer to finance an establishment and a town with sufficiently large and stable demand for print media (Febvre and Martin 1958). 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) 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) identify the idiosyncratic interest of particular capitalists, patrons, and religious institutions had in making texts available as the dominant factor in the diffusion process.[42] Gilmont (1998) observes that technology diffusion was, "guided more by chance than by any assessment of profitable centers" in which to establish presses and that a set of early print centers maintained first mover advantages in subsequent centuries (Gilmont 1992).

The pattern of diffusion was shaped by the fact that printing exhibited characteristics associated with o-ring production

41. The main source of commercial credit 1450–1500 was the urban merchant class (Wright 1996). Over this period, only a handful of cities had organized exchanges and formal banking systems were only incipient. Many cities with significant merchant interests did not adopt printing 1450–1500. Sea port cities were commercial and financial centers. In the balanced sample, printing presses were established in 36% of port cities and in 43% of nonport cities. Important sea ports that did not get the printing press include Bari, Bordeaux, Bremen, Dordrecht, Dublin, Königsberg (Kaliningrad), Livorno, Malaga, Marseilles, Salerno, Santander, Salonika, and Toulon. As documented in the Online Appendix sea ports were less likely than other cities to get printing presses 1450–1500 even controlling for distance from Mainz. But many inland cities that were important industrial and financial centers also did not get printing presses 1450–1500 (e.g., Mechelen, Arras, and Lille). These facts suggest that unobserved city characteristics associated with technology adoption and subsequent growth are unlikely to explain the estimated printing effect. To further address concerns about missing determinants of technology adoption and city growth, Section V.E. exploits distance from Mainz as an instrument for adoption.

42. Printers were invited to Rome, Chartres, Erfurt, and Florence. The first press in Paris was not a business venture but a project initiated by two professors at the Sorbonne. Some years later, workers from this press set up the first commercial establishment in Paris. See Clair (1976).

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functions (Kremer 1993). Beyond the secret of movable type, printing required a complementary set of inputs and skills, each of which was required for successful production. Successful printing required movable type, a suitably oily ink, nontrivial skill in inking and press work, and in the printer a rare combination of mechanical and intellectual skills (Fuhrman 1978).[43]

The availability of paper was a prerequisite for the diffusion of the printing press, however, the locations of preexisting paper mills did not determine which cities adopted the printing press (Febvre and Martin 1958; Barbier 2006). In the tenth century paper mills were established in Islamic Europe (Palermo, Cadiz, Cordoba, Grenada, and Toledo). By 1300, there were mills at 20 locations in Catalunya and Italy. In the 1300s paper mills were established at 25 locations in France. Between 1390 and 1450, paper mills spread into Germany (Nürnberg, Ravensburg, Chemnitz, Köln, Frankfurt am Main, Würzburg, Esslingen, Munich), Switzerland (Basel and Marly), Bohemia (Königsaal), and Austria (Kremsmünster). There was no significant association between adoption of the printing press and proximity to paper mills.

V.E. Distance from Mainz as Instrumental Variable

Given the observed positive association between the adoption of print technology and city growth, the natural question is whether printers selected cities that were already bound to grow quickly. This section exploits distance from Mainz as an instrument for print adoption. It confirms that distance from Mainz was a significant determinant of technology adoption. It documents that there was no statistically significant relationship between distance from Mainz and city growth before the diffusion of the printing press, that a highly significant relationship emerged after Gutenberg, and that distance from Mainz was not correlated with other determinants of growth. It shows that instrumenting for adoption with distance yields estimates of the print effect that are significant and substantially larger than OLS estimates.

43. The oily ink and the skills in press work were developed for and by printing. However, it is natural to wonder whether cities with advanced metal-working industries were likely to both grow quickly independent of printing and to attract printers. The evidence does not support this hypothesis. Among German-speaking cities, printing presses were no more likely to be established in locations close to metal-working districts identified in Scott (2002) or iron mills identified in Lutz (1941).

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TABLE VI
DISTANCE FROM MAINZ AND ECONOMIC OUTCOMES BEFORE AND AFTER GUTENBERG

(1) Regression Model	(2) Log Growth 1400–1500	(3) University in 1450	(4) Log Size in 1500	(5) Log Growth 1500–1600
Log Distance to Mainz	−0.05	0.00	−0.11	−0.03***
	(0.04)	(0.01)	(0.08)	(0.01)
Observations	269	410	410	410
R Squared	0.23	0.12	0.31	0.22

Note. The dependent variable in column (2) is log city growth 1400–1500: $\ln\left(\frac{POP_{1500}}{POP_{1400}}\right)$. The dependent variable in column (3) is an indicator variable recording the presence of a historic university in 1450. The dependent variable in column (4) is log city population in 1500: $\ln(POP_{1500})$. The dependent variable in column (5) is log city growth 1500–1600: $\ln\left(\frac{POP_{1600}}{POP_{1500}}\right)$. Controls include city latitude, longitude, the interaction between latitude and longitude; the DeLong-Shleifer index of institutions; indicators for sea ports, navigable rivers, capitals, and cities on Roman sites; and log city population. (Log population is not a control for the regression reported in column 4.) Sample restricted to balanced panel of cities with population observed 1500–1800 in economies with at least one print city. Heteroskedasticity-robust standard errors clustered by country in parentheses. Significance at the 99% confidence level is indicated by ***.

Between 1450 and 1460 only a small number of men in Mainz knew the secrets of printing. Barbier (2006) observes that in subsequent decades the technology diffused in "concentric circles" (see also Febvre and Martin 1958; Nieto 2003). This section exploits distance from Mainz as an instrument to capture variation in adoption that was exogenous to the underlying determinants of city growth.

Ideally, we would employ a measure of economic distance that captured travel times, travel costs, and trade flows. However, data on travel times and intercity trade is exceedingly limited and fragmentary (Braudel 1966). For this reason, I employ great circle ("as the crow flies") distance as an instrument. Because great circle distance is not perfectly correlated with unobserved economic distance, we expect to find attenuated estimates of the association between distance from Mainz and adoption.

Table VI shows that highly significant relationship between distance from Mainz and growth emerged after Gutenberg's innovation (1500–1600), but that no significant relationship between growth and distance is observed before the diffusion of printing (1400–1500).[44] It also documents that cities that were close to Mainz not significantly larger or smaller than others

44. An earlier version of this paper reported results from a specification with country fixed effects which found that cities farther from Mainz in fact grew relatively quickly 1400–1500, although this estimate was also not statistically significant.

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TABLE VII

INSTRUMENTAL VARIABLE ANALYSIS OF PRINTING AND LOG CITY GROWTH

(1) Regression Model	(2) 1st Stage Adopt Print 1450–1500	(3) 2nd Stage City Growth 1500–1600
Log Distance to Mainz	−0.06***	
	(0.01)	
Adopt Print 1450–1500		0.58**
		(0.29)
Observations	410	410
R squared	0.34	0.15
F Statistic (IV)	20.74***	82.07***

Note. The dependent variable in the first stage is an indicator variable that takes the value of 1 for cities that adopted the printing press 1450–1500. The dependent variable in the second stage is log population growth: $\ln\left(\frac{POP1600}{POP1500}\right)$. Distance from Mainz in log kilometers is the instrumental variable for print adoption 1450–1500. Regressions control for: log city population in 1500, port location, navigable rivers, location on Roman sites, political capitals, city latitude, city longitude, the interaction between latitude and longitude, and the DeLong–Shleifer freedom index of regional institutions. The Data Appendix provides detailed descriptions of these variables. Sample restricted to balanced panel of cities with population observed 1500–1800 in economies with at least one print city. Heteroskedasticity-robust standard errors clustered by country in parentheses. Significance at the 90%, 95%, and 99% confidence levels are indicated by *, **, and ***.

were no more likely to have housed universities on the eve of Gutenberg's innovation. These results indicate that the diffusion of the printing press from Mainz provides a plausible means to obtain variation in adoption that is exogenous to preexisting economic and educational determinants of city growth. The estimates control for ports, navigable rivers, Roman sites, capitals, longitude, latitude, the interaction between longitude and latitude, the DeLong–Shleifer index of institutions, and log city population in the previous period.

Table VII reports the IV estimates of the impact of early print adoption on city growth. The first-stage results document that distance from Mainz is a strong instrument. There was a very significant negative association between distance and adoption, and the F statistics for the IV are highly significant: they cross the rule-of-thumb threshold of 10 and the weak instrument thresholds calculated by Stock and Yogo (2002). The second-stage results show that the IV estimate of the impact of adoption on city growth is a significant 0.58 log points for 1500–1600 or, equivalently, 78 percentage points.[45]

45. A model with country fixed effects yields slightly larger estimates of the effect of adopting printing 1450–1500 on city population growth 1500–1600.

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TABLE VIII
PLACEBO TEST OF INSTRUMENTAL VARIABLE IDENTIFICATION

(1) IV Employs Distance From	(2) IV Estimate of Print Effect	(3) IV Estimate t Statistic
Mainz	0.58	2.03**
Amsterdam	−3.00	0.95
London	1.20	0.34
Paris	−14.25	0.12
Venice	0.08	0.55
Wittenberg	2.21	0.64

Note. The dependent variable is log population growth 1500–1600: $\ln\left(\frac{POP_{1600}}{POP_{1500}}\right)$. All regressions have the controls noted in Table VII. The sample is restricted to balanced panel of cities with population observed 1500–1800. The t statistics are heteroskedasticity robust and clustered by country. Significance at the 95% confidence level is indicated by **.

Table VIII provides a falsification test of the IV estimates. It compares the estimate obtained using distance from Mainz as the IV with results obtained using distance from other important cities: Amsterdam, London, Paris, Venice, and Wittenberg. These other cities are placebos. Wittenberg is included because it has been identified as the location from which Protestant ideas diffused, because Protestantism may have been a demand shifter for literacy, and because Becker and Woessmann (2009) argue that distance from Wittenberg may identify exogenous variation in Protestantism (the next section examines the interplay between religion and printing in greater detail). Only in the case of Mainz does distance pick up a significant print effect on subsequent city growth. This evidence supports the singular importance of distance from Mainz.

The magnitude of the IV estimate is remarkable. For 1500–1600, the IV estimate ($\hat{\alpha}_{IV} = 0.58$) is more than twice the size of the OLS estimate and implies that printing accounted for 68% of total city growth.[46] There are several possible explanations for this result.

First, the OLS estimate may be attenuated by proxy measurement error. What mattered for city growth was not the physical presence of a printing press but its contribution to human capital

46. In the unbalanced sample examined in Table IV, $\hat{\alpha}_{OLS} = 0.19$ for 1500–1600. In the balanced panel examined in the Online Appendix, $\hat{\alpha}_{OLS} = 0.29$ for 1500–1600. The IV point estimate implies that printing accounted for 68% of total city growth under the assumption that the establishment of printing presses in some cities did not depress growth in cities without presses. See above and Online Appendix for supporting evidence.

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accumulation and intellectual exchange. An indicator variable capturing whether a given city was an early adopter of the printing press is a coarse proxy for these nuanced aspects of social life. It is likely that cities closer to Mainz were able to develop richer print cultures over the early modern period. In the OLS regressions, a binary indicator proxies for unmeasured "print culture." It follows that $\hat{\alpha}_{OLS}$ may be attenuated by a species of measurement error and that IV regression may pick up a "cleaner" measure of the impact of printing.[47]

Second, we cannot rule out a priori the possibility that the IV estimate is biased *upward* by differences implicit in the IV scheme. It is possible that there was underlying heterogeneity in the returns to technology adoption and that the IV approach recovers returns for a subset of cities likely to have high returns. For this to be the case, on average the cities likely to benefit most from the new technology would have to be the ones located close to Mainz. A plausible case could be made that this was the case for Italy. By the middle 1400s, cities in northern Italy arguably enjoyed institutional advantages over the southern Italian cities exposed to the institutions of the kingdoms of Naples and Sicily—and were closer to Mainz. However, when one excludes the Italian cities from the sample, one still gets large IV estimates: a print effect of over 0.67 log points for 1500–1600 that is significant at the 95% level.

V.F. *Printing and Religion*

Print media played a critical role in the diffusion of the Protestant Reformation 1517–1648.[48] Historians argue that the diffusion of the Reformation would not have been possible without the printing press (Brady 2009). However, religious sentiment also fostered demand for print media, notably through Protestant calls for laypersons to read the Bible. Recent economic research examines whether Protestantism was associated with variations in economic outcomes (Becker and Woessmann 2009;

47. One could imagine that distance from Mainz also captures adoption after 1500. The evidence does not support this hypothesis. As shown in the next section, cities close to Mainz were no more likely than others to adopt printing 1500–1600. Over this period, supply-side restrictions on diffusion were relaxed.

48. The Evangelical media campaign criticizing Catholic Church practices was the first major attempt to employ the printing press to shape a mass movement. Pamphlets published in the vernacular made Martin Luther the first best-selling author. See Edwards (1995) and Gilmont (1998).

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Cantoni 2009). This section examines the interplay between religion and printing.

Becker and Woessmann (2009) argue that Protestantism shifted the demand for literacy and impacted economic outcomes through a human capital channel. Becker and Woessmann use distance to Martin Luther's base in Wittenberg as an IV to identify exogenous variation in Protestantism within historic Prussia.[49] Given the associations Becker and Woessmann find between Protestantism, literacy, and prosperity, it is natural to wonder whether the print effects estimated in this article embody a Protestant demand shift for print media. It is also natural to wonder how the IV identification strategy in this article relates to the IV strategy in Becker and Woessmann (2009).

The historical chronology is important for an understanding of these IV strategies. This article examines the impact of printing presses established 1450–1500. Martin Luther's calls for the reform of the Church first appeared in Wittenberg in 1517. Wittenberg was not a particularly important city before 1517, and distance from Wittenberg was not associated with the drivers of growth prior to 1517 (Becker and Woessmann 2009).

Consistent with this sequence of events, the baseline instrumental variable estimate of the print effect reported in Table VII is robust to the inclusion of distance to Wittenberg as an additional control variable. In Table IX, column (2) documents that the magnitude and significance of the relationship between distance to Mainz and adoption of the printing press is the same when we control for distance to Wittenberg as in the the baseline estimate presented in Table VII (this relationship is the first stage in the IV regression, $\beta_{FS} = -0.06$). Column (3) similarly documents that the relationship between distance to Mainz and city growth 1500–1600 is the same when we control for distance to Wittenberg as in the baseline estimate presented in Table VI (this is the reduced form, $\beta_{RF} = -0.03$). Columns (4) and (5) show that among German-speaking cities there was also no significant relationship between distance to Wittenberg and the establishment of printing presses 1450–1500 or between distance to Wittenberg and city growth 1500–1600.[50] These results are consistent with Cantoni's (2009) finding that there

49. Wittenberg is 370 km northeast of Mainz. Proximity to Wittenberg predicts Protestantism.

50. The German-speaking cities comprise cities in Germany, Austria, and parts of Alsace, Poland, Switzerland, and Bohemia.

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TABLE IX
DISTANCE TO MAINZ (GUTENBERG) AND WITTENBERG (LUTHER)

	All Cities		German-Speaking Cities	
(1)	(2)	(3)	(4)	(5)
Regression Model	Adopt Print 1450–1500	Log Growth 1500–1600	Adopt Print 1450–1500	Log Growth 1500–1600
Log Distance to Mainz	−0.06***	−0.03**	−0.04***	−0.03***
	(0.01)	(0.01)	(0.01)	(0.00)
Log Distance to Wittenberg	0.03	−0.03	−0.05	0.10
	(0.02)	(0.02)	(0.04)	(0.07)
Observations	410	410	85	85
R squared	0.34	0.22	0.41	0.29

Note. The dependent variable in columns (2) and (4) is an indicator variable that records whether a printing press was established in a given city 1450–1500. The dependent variable in columns (3) and (5) is log city growth 1500–1600: $\ln\left(\frac{POP_{1600}}{POP_{1500}}\right)$. Controls and t statistics are as in Table VII. European sample restricted to balanced panel of cities with population observed 1500–1800. German sample restricted to cities with population observed 1500 and 1600. Heterskedasticity-robust standard errors clustered by country in parentheses. Significance at the 95%, and 99% confidence levels are indicated by ** and ***.

was no positive association between Protestantism and city populations among German cities 1300–1800.

The data also provide only qualified support for the hypothesis that Protestantism was a positive demand shifter for the printing press. Table X exploits data on printing presses founded in German-speaking cities after Luther disseminated his famous 95 theses in 1517. Columns (2) and (4) show that there is no clear evidence that German-speaking cities close to Wittenberg were more likely to adopt the printing press after 1517.[51] The weakness of these estimates does not, however, rule out a Protestant demand shift for print media from existing printing presses. Columns (2) and (4) also show that distance from Mainz was no longer negatively associated with the adoption of the printing press 1517–1600. Over this period, the first blueprints describing how to create movable type were printed, and the technology ceased to be a trade secret controlled by printers emanating from Mainz. Columns (3) and (5) show that the proximity to Wittenberg was not associated with city growth 1600–1700. In fact, cities farther from Wittenberg grew relatively quickly. However, the standard errors on the estimates are large and the association is not statistically significant.

51. In fact, examining cities in the unbalanced panel. I find that distance from Wittenberg was positively associated with adoption of the printing press 1517–1600 (Table X, column (4)).

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TABLE X

PROTESTANTISM AS DEMAND SHIFTER FOR PRINT MEDIA IN GERMANY

	Cities from Balanced Panel		Cities from Unbalanced Panel	
(1)	(2)	(3)	(4)	(5)
Regression Model	Adopt Print 1517–1600	Log Growth 1600–1700	Adopt Print 1517–1600	Log Growth 1600–1700
Log Distance to Mainz	0.33***	−0.05***	0.16*	−0.05***
	(0.07)	(0.01)	(0.08)	(0.01)
Log Distance to Wittenberg	−0.08	0.04	0.02***	0.06
	(0.05)	(0.05)	(0.00)	(0.05)
Observations	54	86	106	87
R Squared	0.28	0.33	0.18	0.33

Note. The dependent variable in columns (2) and (4) is an indicator variable that records whether a printing press was established in a given city 1517–1600. The estimates in these columns examine cities without printing presses in 1517. The dependent variable in columns (3) and (5) is log city growth 1600–1700: $\ln\left(\frac{POP_{1700}}{POP_{1600}}\right)$. The balanced sample comprises German-speaking cities with population observed 1500–1800. The unbalanced sample comprises cities with population observed in 1500. Controls and t statistics as in Table VII. Significance at the 90%, 95%, and 99% confidence levels are indicated by *, **, and ***. Data on post-1517 presses from Reske (2007). Among German cities adopting the press 1517–1700, the mean adoption year was 1591.

Two related facts may explain why Protestantism may have been associated with a demand shift for print media, but Protestant cities did not grow quickly 1600–1700. First, presses in Protestant cities concentrated on producing agitational pamphlets and religious propaganda (Febvre and Martin 1958) without immediate economic spillovers. Second, while a Protestant demand shift could be expected to show up in city growth 1600–1700, the Thirty Years War (1618–1648) led to massive disruptions in economic activity and demographic shocks that hit Protestant cities harder than Catholic cities (Cantoni 2009). During the war, the output of German printing presses declined by roughly 80% (Febvre and Martin 1958). Moreover, war-related demographic declines were pronounced in northeastern Germany, running as high as 30% of the population (Scott 2002). The Thirty Years War was a religious conflict and appears to have offset any printing-related advantage among Germany's Protestant cities. This suggests that the economic impact of information technologies may operate through their effects on the transmission of economically useful ideas and the evolution of beliefs and ideologies.

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VI. 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 article 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 78 percentage points—more than similar cities that did not over the period 1500–1600. These estimates imply that the impact of printing accounted for at least 18% and as much as 68% of European city growth between 1500 and 1600.

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

Data Appendix

Data on city populations. City populations are from Bairoch, Batou, and Chèvre (1988) and de Vries (1984). City locations are from Bairoch, Batou, and Chèvre (1988) and http://www.gpsvisualizer.com/.

Data on print media. The locations of printing presses established 1450–1500 are from Febvre and Martin (1958), Clair (1976), and ISTC (1998). Data on the number of editions published in each city 1450–1500 are from ISTC (1998). Data on printing presses established after 1500 in German-speaking cities are from Reske (2007). Data for the Bayerische Staatsbibliothek are online at http://mdzx.bib-bvb.de/bsbink/treff2feld.html (accessed March 2009). The Bayerische Staatsbibliothek holds historical collections acquired by Duke Albrecht V. In 1558, Albrecht acquired the private library of Johann Widmannstetter. In 1571, Albrecht also purchased the private library of international banker Johann Fugger. Additional acquisitions were made as German monasteries were dissolved in the 1802–1803 period. Data on merchants' manuals are from Hoock and Jeannin (1991, 2001, 2007).

Control variables. The data sources for the control variables are as follows.

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University is an indicator variable taking the value 1 in a given period if a university was present in a given city at the beginning of that period. For instance, the University of Ferrara (Italy) was founded in 1391. For Ferrara, *University* = 0 in 1300 and *University* = 1 in 1400. Data on the historical location of universities are from Darby (1970) and Jedin, Latourette, and Martin (1970).

Roman Site is an indicator variable taking the value of 1 for cities located on the sites of Roman settlements. Data on Roman settlements are from Stillwell, MacDonald, and McAllister (1976).

Port is an indicator variable taking the value 1 for cities located on historic sea or ocean ports. Data on the historical location of ports are from Acemoglu, Johnson, and Robinson (2005), supplemented by data in Magosci (1993) and Stillwell, MacDonald, and McAllister (1976), and the sources cited in Dittmar (2010). The data in this article supplements Acemoglu, Johnson, and Robinson (2005) by coding for cities that were historically ports on the Baltic (e.g., St. Petersburg, Gdańsk, Kaliningrad, Szczezin, Rostock, and Lübeck) and Mediterranean and Black Sea ports omitted in Acemoglu, Johnson, and Robinson (2005): Durres, Fano, Gaeta, Iraklion, Kerch, Korinthos, Malaga, Pozzuoli, Trapani, and Vlora. Similarly, the coding here reflects the fact that Rota and Sanlúcar de Barrameda had Atlantic ports.

Atlantic Port, *Mediterranean Port*, and *Baltic Port* are indicators taking the value of 1 for cities with ports on these bodies of water. Black Sea ports are classed as Mediterranean.

Navigable River is an indicator variable taking the value 1 for cities located on historically navigable inland waterways. Data on navigable rivers are drawn from Magosci (1993), Pounds (1979, 1990), Livet (2003), Cook and Stevenson (1978), Graham (1979), Stillwell, MacDonald, and McAllister (1976), and de Vries, Jan and van der Woude (1997). The coding captures the principal historically navigable waterways and does not class as "navigable" waterways that required substantial improvements and became navigable only over the early modern era. Some cities on navigable rivers were also sea or ocean ports.

Freedom Index is the DeLong and Shleifer (1993) index of regional institutions. DeLong and Shleifer class institutions as either promoting relatively unrestrained and autocratic rule (prince, index value 0) or as securing relative freedom (free, index value 1). The DeLong–Shleifer coding is here extended to Poland and the Ottoman Europe, neither of which meet the criteria for

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classification as free between 1300 and 1850 (this is confirmed by DeLong).

Capital is an indicator variable taking the value 1 for cities that were historically national capitals. For instance, Madrid was not a capital through 1500 (Phillip II moved the court to Madrid and made it his capital only in 1561). Similarly, Berlin is taken as a capital from 1700 (Berlin became the capital of Prussia in 1701). Likewise, Kraków was Poland's capital through 1596, when Sigismund III moved the capital of the Polish-Lithuanian Commonwealth to Warsaw. In contrast, London and Paris were capitals in all periods examined in the econometric analysis.

Executive Constraint is the historical coding of the Polity-IV index of constraints on arbitrary executive authority. The data are from Acemoglu, Johnson, and Robinson (2002, 2005).

Table A.1 provides summary statistics for these variables for all cities and for the balanced panel of cities with population data observed every 100 years 1300–1800.

APPENDIX TABLE A.1
SUMMARY STATISTICS

	Unbalanced Panel		Balanced Panel	
(1) Variable	(2) Mean	(3) s.d.	(4) Mean	(5) s.d.
Adopt Print 1450–1500	0.09	0.29	0.41	0.49
Editions Per Capita	11.59	121.90	102.41	377.19
Roman Site	0.15	0.36	0.41	0.49
Atlantic Port	0.05	0.22	0.11	0.31
Mediterranean Port	0.03	0.18	0.09	0.29
Baltic Port	0.00	0.07	0.03	0.17
Navigable River	0.06	0.24	0.25	0.44
Distance to Amsterdam	983.53	590.26	778.81	470.92
Distance to London	1,101.86	653.11	879.86	560.77
Distance to Mainz	1,192.21	711.41	989.34	577.05
Distance to Paris	1,045.17	668.84	849.23	505.06
Distance to Venice	1,011.99	531.73	856.86	433.06
Distance to Wittenberg	1,093.61	564.61	912.31	487.20
Population 1300	11.84	16.47	18.53	22.77
Population 1400	11.97	21.00	18.83	27.10
Population 1500	10.73	15.83	19.92	24.20
Population 1600	11.60	20.91	27.39	38.58
Population 1700	10.56	28.49	32.78	62.16
Population 1800	12.02	31.10	44.92	89.98
Ln Population Growth 1300–1400	−0.04	0.63	0.01	0.57
Ln Population Growth 1400–1500	0.18	0.53	0.13	0.55
Ln Population Growth 1500–1600	0.27	0.53	0.26	0.55

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APPENDIX TABLE A.1
(CONTINUED)

	Unbalanced Panel		Balanced Panel	
(1) Variable	(2) Mean	(3) s.d.	(4) Mean	(5) s.d.
Ln Population Growth 1600–1700	0.00	0.61	0.06	0.57
Ln Population Growth 1700–1800	0.56	0.66	0.31	0.50
Capital 1300	0.01	0.10	0.02	0.16
Capital 1400	0.02	0.12	0.02	0.16
Capital 1500	0.01	0.09	0.02	0.16
Capital 1600	0.01	0.09	0.02	0.16
Capital 1700	0.01	0.08	0.03	0.17
Capital 1800	0.00	0.06	0.02	0.16
University 1300	0.04	0.19	0.06	0.25
University 1400	0.07	0.25	0.12	0.32
University 1500	0.10	0.30	0.18	0.39
University 1600	0.09	0.29	0.24	0.43
University 1700	0.08	0.27	0.26	0.44
University 1800	0.06	0.24	0.29	0.45
Freedom Index 1300	0.41	0.49	0.47	0.50
Freedom Index 1400	0.42	0.49	0.47	0.50
Freedom Index 1500	0.17	0.38	0.21	0.41
Freedom Index 1600	0.11	0.31	0.21	0.41
Freedom Index 1700	0.17	0.37	0.15	0.36
Freedom Index 1800	0.11	0.31	0.15	0.36

Note. The balanced panel comprises 202 cities with populations observed every 100 years 1300–1800. The unbalanced panel comprises 498 cities with population observed in 1300, 400 cities in 1400, 631 cities in 1500, 897 cities in 1600, 1,169 cities in 1700, and 2,113 cities in 1800. For time-invariant city characteristics, summary statistics for the unbalanced panel are calculated over 2,202 cities. City populations are in thousands. Distances are in kilometers. Editions per capita measures editions published 1450–1500 per 10,000 inhabitants in 1500.

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SUPPLEMENTARY MATERIAL

An Online Appendix for this article can be found at QJE online (qje.oxfordjournals.org).

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