# A Time to Print, a Time to Reform

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Copenhagen Business School
HANDELSHØJSKOLEN

# Department of Economics

**Copenhagen Business School**

## Working paper 05-2019

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# A Time to Print, a Time to Reform*

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March 2019

**Abstract**

The public mechanical clock and the movable type printing press were two of the most important and complex general purpose technologies of the late medieval period. We document two of their most important, yet unforeseeable, consequences. First, an instrumental variables analysis indicates that towns that were early adopters of clocks were more likely to also be early adopters of presses. We posit that towns with clocks became upper-tail human capital hubs—both technologies required extensive technical know-how that had many points of overlap. Second, a three-stage instrumental variables analysis indicates that the press influenced the adoption of Lutheranism and Calvinism, while the clock's effect on the Reformation was indirect (via the press).

**Keywords**: mechanical clock, printing press, technology, Reformation, human capital, Calvinism, Lutheranism, instrumental variables

**JEL codes**: N33, N73, O33, O34, P48, Z12

*We are grateful for comments received from participants at workshops at the University of Colorado, University of Copenhagen, UC Irvine, Copenhagen Business School, Northwestern University, the 2017 ASREC meetings in Boston and the workshop on Martin Luther's Heritage in Modern Economics and Social Sciences in Rome. Jeanet Bentzen, Luigino Bruni, Davide Cantoni, Greg Clark, Brad DeLong, Jeremiah Dittmar, Phil Hoffman, Joel Mokyr, Luca Nunziata, and Jan Luiten van Zanden provided extremely useful comments. All errors are ours.

# 1 Introduction

This paper addresses two related issues that are key for understanding the rise of the modern economy. First, to what extent did general purpose technologies spill over into the spread of other technologies *prior to* industrialization? Second, what were the unforeseeable consequences of technological agglomeration on the social and political equilibria of the pre-modern period? These issues are far from trivial historical footnotes: technology agglomeration and political and social upheaval have long been viewed as key elements of Europe's economic rise (Weber 1905 [2002]; Mokyr 1990a, 2016; Allen 2009; Greif 2006; Acemoglu and Robinson 2012).

We contribute an answer to these questions by analyzing the causes and consequences of the spread of the two most important technologies of the late medieval period: the public mechanical clock and the movable type printing press. We proceed to analyze the effect these technologies had on the spread of the Protestant Reformation, which was arguably the most important social, political, and religious movement of the early modern period. In short, we find strong evidence of technological agglomeration (those places with clocks were more likely to later adopt the press) and a direct (indirect) role for printing (clocks) in the spread of the Reformation.

Both clocks and printing presses required an immense amount of mechanical knowledge to build and operate, and the production of both required precision, technical skills, and dexterity in using different metals. For these reasons, clockmakers and printers often belonged to guilds of the smiths: approximately 60% of medieval and Renaissance clockmakers came from the ranks of blacksmiths, goldsmiths, and locksmiths (Dohrn-van Rossum 1996, p. 193; Zanetti 2017, p. 113-122), while Johann Gutenberg (the inventor of the press) himself was a blacksmith and goldsmith, as were many of the early printers (Febvre and Martin 1958, p. 49-51, 168, 201). Clockmakers and early printers were the knowledge elites of their day, and the historical record notes numerous spillovers between the two professions. Were such spillovers of actual economic significance, as was the case in England and France on the eve of industrialization (Mokyr 2005, 2009; Squicciarini and Voigtlaender 2015, 2016)?

The most obvious candidates for locating those synergies were European cities prior to the Industrial Revolution. Cities were the best place for stimulating and developing innovation. On the demand side, better transportation technologies and organized markets facilitated the availability of cheaper inputs for producing new products. On the supply side, cities facilitated the exchange of ideas and the availability of skilled artisans who were able to create final products derived from the inventors' blueprints (Mokyr 1990b). Furthermore, in cities there is an endogenous element of technology adoption (as found in modern American cities by Moretti (2012)).The clustering of skilled workers and smart inventors enabled new learning processes for the next generation of new ideas.

If the connection between clocks and the press is an open empirical question, such questions have been largely answered about the connection between the printing press and the Reformation. Indeed, Martin Luther himself viewed the press as one of the key reasons why his reform movement succeeded. The major problem for the initial reformers in early 16th-century northern Germany was information dissemination (of propaganda). Previous attempts at reform (e.g., the Hussite movement of the early 15th century) were unable to get off the ground, in part because there was no printing press to spread propaganda rapidly enough before the Church could react. The Lutherans were able to overcome this problem by spreading propaganda via printed pamphlets. The early Lutheran leaders, led by Luther himself, wrote thousands of anti-papal pamphlets in the Reformation's first decades and these works spread rapidly through reprinting in various print shops throughout central Europe. The connection between printing and the Reformation was confirmend by Rubin (2014) and Dittmar and Seabold (2016), both of whom provide empirical evidence linking the spread of the printing press and print workshops to the spread of the Reformation.

The role the clock played in the spread of the Reformation has been the subject of much less study. There is reason to believe the clock may have played a role in the spread of the Reformation, as it served as a coordinating device which created a sense for time, punctuality, and discipline that was key to the ideas of the Calvinist movements. In fact, Calvin himself was inspired by the opportunities the clocks offered, and he embedded rules of order and discipline in his religious beliefs following the newly available precise time measurement (Engammare 2010). In this vein, Gorski (2003) claims that the Calvinist spirit towards a new culture of punctuality, order, and social-disciplining facilitated the success of the Dutch Revolt (1568–1648) by a well-organized minority and let Calvinism succeed to become the dominant religion, and it later enabled successful state formation.

Testing these conjectures is an empirical challenge for many reasons. First, neither mechanical clocks nor printing presses were randomly assigned to towns, indicating that any econometric specification must consider the endogeneity of the primary independent variables of concern. Second, it is possible that the spread of clocks affected the spread of the printing press. Such spillovers could have been facilitated by guilds (de la Croix et al. 2018), but to our knowledge there are no empirical tests of general purpose technology spillovers in the late medieval period. This suggests that the determinants of the spread of clocks and the printing press must be estimated sequentially, with the spread of clocks being estimated first, its effect on the spread of printing second, and the spread of both on the Reformation third.

We address these data and econometric issues using data from Rubin (2014) on printing presses and the Reformation (and various other town characteristics) and data from Boerner and Severgnini (2019) on the early spread of mechanical clocks. These data allow us to test whether the spread of the press and the spread of clocks affected the adoption of Lutheranism and Calvinism. We address potential endogeneity and omitted variable biases by instrumenting for the presence of a clock with the town's past experience with solar eclipses. The idea behind this instrument, which is also used by Boerner and Severgnini (2019), is based on the fact that eclipse activities stimulated the construction of astronomical tools such as astrolabes, which were the prototype of mechanical clocks. In other words, we posit that eclipses were events which lasted in the psyche and the lore of the population (as did earthquakes; see Belloc et al. 2016; Bentzen 2018), and this encouraged experimentation to understand the world better. We instrument for the spread of the printing press with the town's distance to Mainz, the birthplace of Gutenberg's press. This instrument is used in Dittmar (2011) and Rubin (2014), and it works intuitively as an instrument because printing spread out over time in relatively concentric circles emanating from Mainz, and Mainz was not an important enough of a city where distance from Mainz should have had an independent impact on other outcomes of interest.

We report results from numerous two-stage and three-stage regressions. In our most robust three-stage estimations, we jointly estimate the determinants of the spread of the clock, printing press, and Reformation. We find evidence that the adoption of the printing press is positively and highly significantly related to the spread of the mechanical clock: towns with mechanical clocks were around 16 percentage points more likely to adopt the printing press, all else equal. Further, we find that the spread of the printing press is a strong, positive predictor of a town being early adoptors of both Lutheranism and Calvinism: press towns were 29 (67) percentage points more likely to adopt Lutheranism (Calvinism) by 1530 (1600). On the other hand, the presence of a mechanical clock is not related to the spread of Lutheranism or Calvinism in any statistically meaningful way, although its *indirect* effects, via the press, were substantial: around 8 percentage points of the effect of the printing press variable on the spread of the Reformation can be explained by the prior existence of a clock. Moreover, our results cannot preclude the existence of a direct causal link between clocks and Calvinism, since nation fixed effects obscure most of the variation in the adoption of Calvinism. Indeed, the historiography of the Dutch Reformation suggests that clocks may have played a role, via coordination, in its success. Since our empirical framework cannot speak to this possibility, we provide a short narrative laying out why clocks may have played a causal role in the spread of Dutch Calvinism.

This paper therefore provides an additional technology link to the thesis that the Protestant movement led to capitalism and economic development in the long run, an idea most prominently argued by Weber (1905 [2002]). Weber's argument that a new work ethic propagated by the Reformation is closely linked to Calvinist ideas, which were embedded in the new use of time. Furthermore, Gorski (2003) outlined that the new Calvinist culture of social-discipline led to successful state formation, for instance in the Netherlands, and paved the way for colonialism and Western development.[1] Thus the introduction of new general purpose technologies might have helped trigger cultural revolutions which shaped economic development and growth in the long run. Moreover, the sequential nature of the events we analyze—clocks spread prior to the press, which spread prior to the Reformation—allows us to avoid reverse causality. A large literature suggests that religion and religious authorities can both inhibit the spread of technology (Mokyr 1990a, p. 200–206; Bénabou et al. 2016; Chaney 2016; Coşgel et al. 2012) or facilitate its spread (White 1972, 1978; Davids 2013, chs. 2–3). The argument presented in this paper focuses on the other side of this self-enforcing pattern, revealing how certain types of technological change can affect religious change.

The rest of this paper is structured as follows. Section 2 provides the historical background and the role played by clocks and printing presses during the Reformation. Section 3 describes the data collected for this study. Section 4 illustrates the different empirical strategies adopted, while Section 5 reports the empirical results. Finally, Section 6 concludes.

# 2 Historical Background: Clocks, Printing, and the Reformation

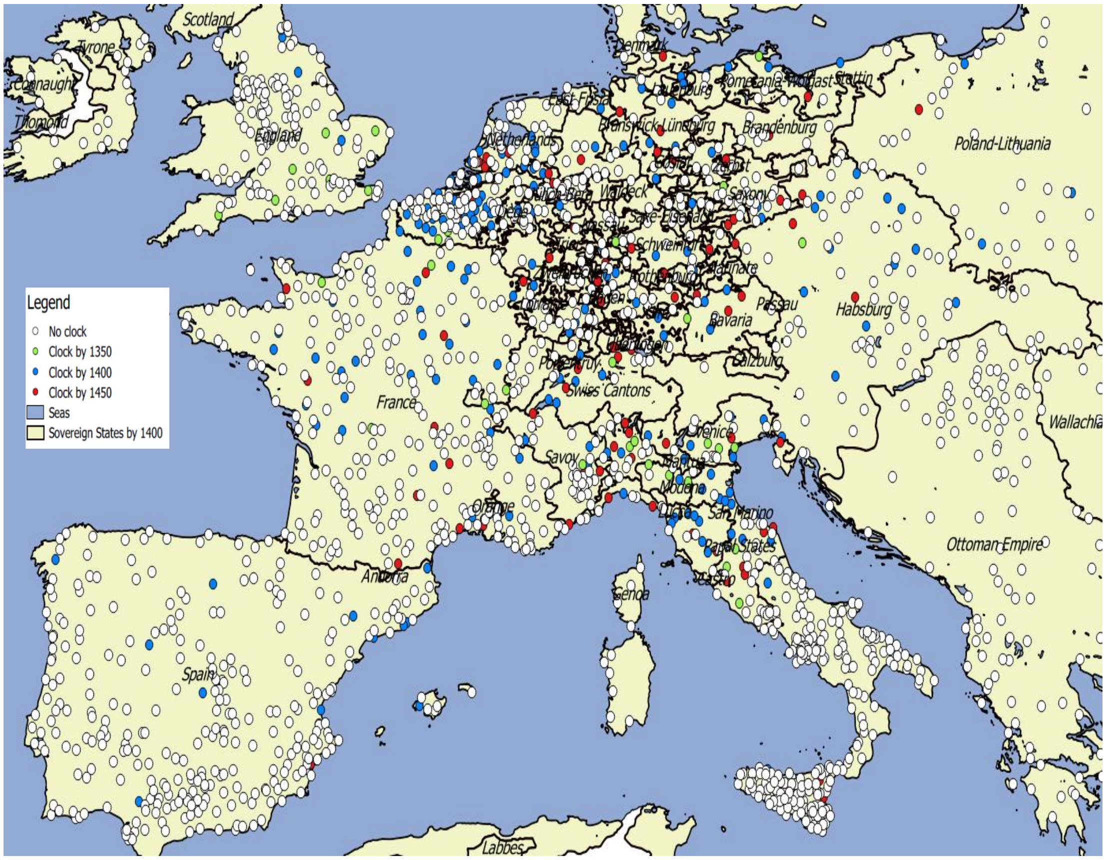
## 2.1 The Mechanical Clock

Public mechanical clocks first arrived in Europe at the end of the 13th century. Clocks appeared simultaneously around the turn of the century in northern Italy, southern England, and southern Germany. During the 14th century, clocks spread in towns all over Western Europe, penetrating further into Germany, Italy, and England, and for the first time into Belgium, the Netherlands, France, Spain, Switzerland, Austria, and neighboring Central European territories (see Figure 1). During the 15h century clocks first appeared in Eastern Europe and Scandinavia (Dohrn-van Rossum 1996). The spread of clocks followed an S-shape diffusion curve, which is typical for the spread of a general purpose technology, beginning with a very slow adoption rate, followed by a steep increase, and finally reaching a saturation point where the relative adoption rate declines. As seen in Figure 2, the inflection point of this S-shaped curve was around 1450.

The public measurement of time was something completely new in the late medieval period. Clocks existed before in the form of sand, sun, or water clocks, but they were not previously used for daily activities because they were not very reliable or functional. As a result, one's sense of time was mainly defined by the position of the sun. However, soon after the initial spread of public mechanical clocks, clocks were used to coordinate activities such as fixing market time or agreeing on public town hall meetings (Dohrn-van Rossum 1996). Indeed, a salient feature of public mechanical clocks was that they were publicly accessible

[1] Andersen et al. (2017) provide a different cultural explanation for the "Protestant ethic" that, like our paper, places its roots prior to the Reformation. They show that parts of England that were exposed to Cistercian monasteries prior to the Reformation grew faster than those that did not.

Figure 1: The Diffusion of the Mechanical Clock in Europe, 1283–1450.



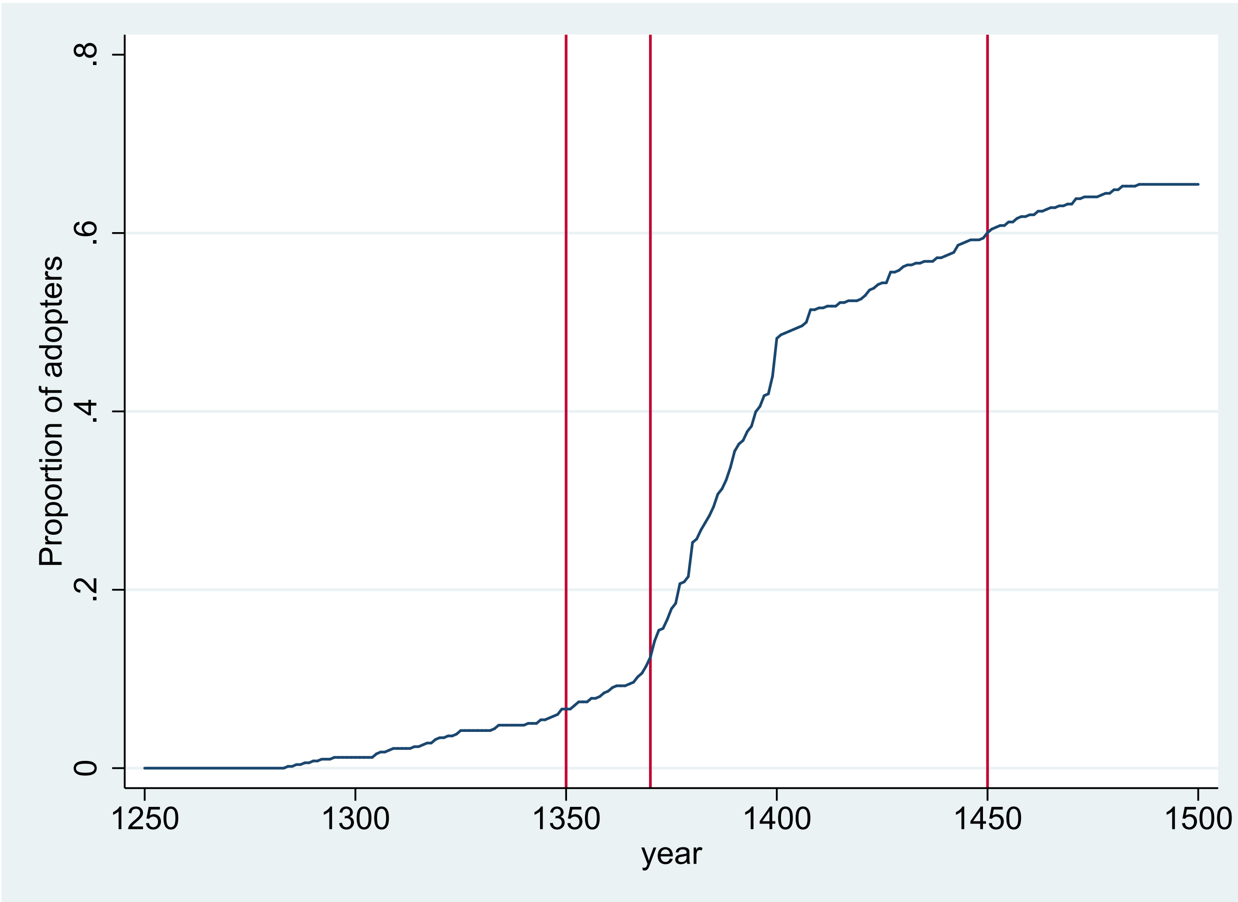

Sources: Boerner and Severgnini (2019) for the mechanical clock and GIS border from Nuessli (2011).

focal points that created common knowledge for anyone within listening distance—one only had to listen to the chime and have the ability to count in order to know the time. In addition, publicly-available time began to affect the measurement of working time, and in general created a new attitude of punctuality, discipline, and order (Thompson 1967; Glennie and Thrift 1996, 2009).

The original motivation behind the commissioning of clock construction was generally not economic. The building of a clock was a sign of prestige, openness, and progressiveness of a city (Boerner and Severgnini 2019). Clocks were typically built on church towers or the communal tower of the town hall.[2] They were mechanical devices that produced a weight-driven acoustic signal every hour. The construction and maintenance of a clock was not that costly compared to other public expenses—although it was not negligible either—and it was typically mentioned in the town account books. The following example from the city of Duisburg (in western Germany) in 1401 supports this claim. Duisburg was a rather small town. Its town

[2]It is worth noticing that, despite the contrast between the "Church's time" and the "merchant's time" observed by Le Goff (1970 [1980]), Dohrn-van Rossum (1996, pp. 231–232) rejects any hypothesis of Church resistance to the public mechanical clocks. Supported by several historical sources, he argues that churches and monasteries "did not hesitate in introducing and making practical use of the new technology as soon as it was available."

Figure 2: Cumulative Distribution of the Mechanical Clock, 1250-1500




Cumulative distribution of mechanical clock based on the cities available in Bairoch et al. (1988). Source: Authors' calculations based on the authors' dataset of clocks. The vertical red lines represent the end of the three phases of early adoption (i.e., 1350, 1370, and 1450). Source: Boerner and Severgnini (2019).

account books note that construction and installation of the first clock cost 10 Gulden. The daily maintenance costed 2 Gulden per year (paid as yearly wage to the local sexton) and a general overhaul, which took place every couple of years (normally carried out by a foreign expert), cost about 10 Gulden. In comparison the complete renovation of the church tower roof in the year 1401 cost 60 Gulden. The new church cross cost 35 Gulden in 1365.[3] Yet, the construction of mechanical clocks, while not incredibly expensive relative to other major expenses incurred by medieval towns, was a difficult task which could not easily be learned. Moreover, a profession or guild of clockmakers did not exist. The first clockmakers came from various backgrounds which brought knowledge and expertise from various theoretical and practical disciplines. For instance, some clockmakers had an education in astronomy. Such knowledge was learned in monastic education, university studies, or elite circles of the Jewish scientific culture, where Islamic scientific knowledge was preserved.

[3]This information, along with much more about medieval Duisburg, is available in Mihm and Mihm (2007).

These clockmakers typically had a theoretical knowledge of astronomy, and they would also learn to build astronomic instruments, and thus had some mechanical skills (Dorhn-van Rossum 1996). Indeed, clocks were often astronomic instruments and the dials indicated (beside the time) the movements of the celestial bodies. The acquisition of such knowledge was quite advanced and placed such individuals among the upper-tail of human capital during the late medieval period. Another group of clockmakers were engineers. They did not have any theoretical training, but developed a technical-artisanal versatility which enabled them to draw, design, and construct all kind of machines, including clocks (Dorhn-van Rossum 1996; Zanetti 2017). Finally, a large share of clockmakers were specialized smiths, in the form of locksmiths or goldsmiths. These crafts were among the most advanced in terms of artisanal skill of the time. Early locksmiths and goldsmiths were specialized fine mechanics who were able to build clocks based on experimentation, imitation, and learned professional skills (Dorhn-van Rossum 1996). In the case of engineers and smiths, their skills were based on tacit knowledge. In other words, much of their skill was the result of "learning by doing" based on transmission from their colleagues and masters rather than any abstract theoretical knowledge formation (Mokyr 2002; de la Croix et al. 2018).[4]

Given the need for theoretical astronomical knowledge and the practical expertise of a smith constructing clocks, it is not obvious how both knowledge streams interacted to become the skill base for mechanical clocks. The life and career of Richard of Wallingford, Abbot of St. Albans and an early clockmaker, may provide some answers (North 2004). Wallingford was the son a of a blacksmith, but he received a university education at Oxford which included (beside theology) mathematical and astronomic education, before he started constructing clocks and other astronomical calculation devices at St. Albans. His expertise was based on both theoretical university knowledge and practical skills picked up from his family environment. Even though the life and career of Wallingford was exceptional, the frequent admission of children from wealthy artisanal families to universities, such as Oxford, Cologne, or Heidelberg can be documented back to the early 14th century (Miethke 2004). Thus a general exchange of theoretical knowledge and practical skills, which likely generated new human capital, can be observed back to the late medieval period.

## 2.2 The Printing Press

Johann Gutenberg invented the movable type printing press in his workshop in Mainz, Germany circa 1450.[5] By 1455, Gutenberg and his assistants produced the first major work using the new invention, the famous Gutenberg bible. There were significant barriers to entry in the early printing business, most of which were

[4]It can debated if these skills belonged to the upper-tail of human capital or not. At least some scholars have claimed that the evolution of highly specialized artisanal skills during the late Middle Ages and Renaissance triggered or even anticipated the Scientific Revolution of the 17th century (Zilsel 2000; Long 2011; Zanetti 2017).

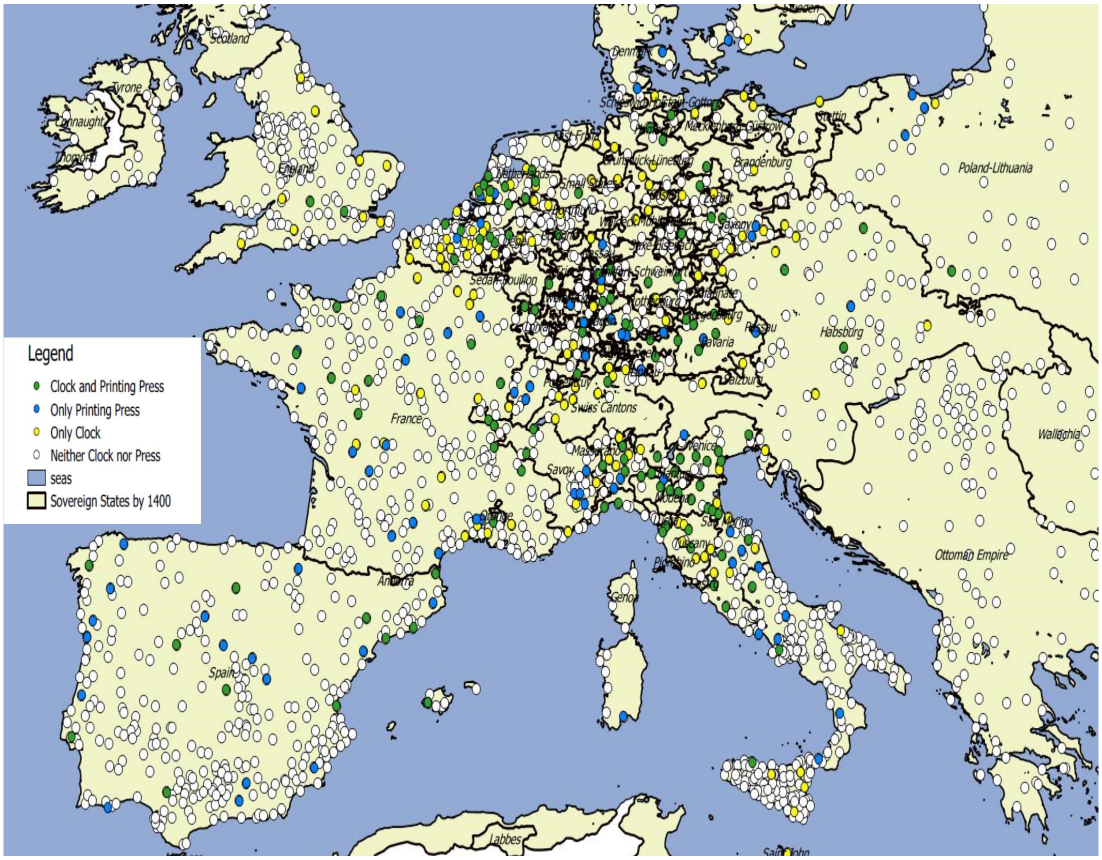
[5]Much of this section is a condensed version of printing history found in Rubin (2014, 2017).

due to the intricacies of the new technology. Gutenberg's primary breakthrough was casting the metal type with a specific combination of alloys that permitted the blocks to be used repeatedly without breaking. The secrets of the new technology were closely guarded by Gutenberg and his assistants, many of whom eventually set up their own shops (Dittmar 2011). This small group had a near monopoly on printing. Indeed, the art of printing took such a large amount of skill-specific human capital that its initial spread was enabled only by those who had previous experience in a print workshop.

These early printers went first to where demand was highest: commercial centers, university towns, and monasteries, where literacy rates were much higher than elsewhere in Europe (Eisenstein 1979). Religious works were the most popular, comprising 45 percent of all books published by the end of the century (Febvre and Martin 1958, p. 249). Religious men were not the only ones who desired books; merchants were an important source of demand, especially in Northern Italy, where books of mathematics were highly desired. For instance, the *Treviso Arithmetic*, printed in 1478, was the first known printed book of mathematics in the West, and the works of Euclid first appeared in Venice in 1482 (Swetz 1987). Indeed, the large print centers in Europe were among the most important commercial towns; the top 10 print cities, in terms of volume of printed works prior to 1500, were Venice, Paris, Rome, Cologne, Leipzig, Lyons, Augsburg, Strasbourg, Milan, and Nuremberg.

By the end of the 15th century printing spread well beyond Mainz—nearly eight million books were printed across the continent (Eisenstein 1979). Sixty of the 100 largest cities in Western and Central Europe had presses, as did 30 percent of cities with population of at least 1,000 (Dittmar 2011; Rubin 2014, 2017). Printing spread throughout the continent by 1500, with printers establishing shops in (modern day) Austria, Belgium, Czech Republic, Denmark, France, Germany, Italy, the Netherlands, Poland, Portugal, Spain, Switzerland, and the United Kingdom (see Figure 3). The outward supply shift in the market for books resulted in an 85 percent decrease in their price by the end of the century (Spitz 1985; Buringh and van Zanden 2009). This made books affordable to people well outside the merchant elite and monastic cloisters, and it was a key reason that literacy increased dramatically in subsequent centuries, particularly in Great Britain, the Netherlands, Germany, and Sweden (Buringh and van Zanden 2009). Presses also made financial information much more readily available. News-sheets containing price and exchange rate information were printed in large quantities soon after the spread of the press, facilitating the integration of financial markets and opening up new trade routes (McCusker 2005; Chilosi and Volckart 2010). Ultimately, early adopting cities grew much faster in the long run than non-adopting cities, all else equal (Dittmar 2011).

Figure 3: The Diffusion of Clocks by 1450 and the Movable Type Printing Press by 1500




Sources: Rubin (2014) for the printing press, Boerner and Severgnini (2019) for the mechanical clock, and GIS border from Nuessli (2011).

## 2.3 The Reformation

The Protestant Reformation was one of the most transformative events of the last millennium. It undermined the power of the Church, altered political power structures across Europe, and triggered over a century of violent religious wars. It began on October 31, 1517, when a little-known professor named Martin Luther nailed his Ninety-Five Theses to the door of the All Saints Church in Wittenberg. His words found a sympathetic audience in northern Europe, and Luther quickly became the leader of the Protestant movement.

Print editions of Luther's theses quickly spread to nearby cities in the Holy Roman Empire, including Leipzig, Magdeburg, Nuremberg, and Basel. In the early 16th century Holy Roman Empire, local lords maintained purview over small, decentralized regions and numerous independent cities ruled themselves, ostensibly free from outside interference. These were ideal conditions for Luther's ideas to spread. Powerful lords, seeking to undermine the power of the Church, offered Luther and his cadre protection, and they appointed preachers sympathetic to reform ideas. Luther's message was particularly attractive in the free cities, of central Germany. In Switzerland and southern Germany, a similar movement led by Huldrych

Zwingli (1484-1531) undermined Church influence throughout the 1520s. It was especially effective in free cities such as Strasbourg and Constance (Cameron 1991). This movement laid the groundwork for the much more effective and long-lasting Calvinist movement of the 1550s.

The Reformation spread throughout the Holy Roman Empire through a variety of ways. The most important was through literate preachers, who went from town to town spreading the Reformation message. These preachers had positions in the established Church and directly questioned congregations about the nature of worship and the practices of the Church hierarchy. Luther wrote numerous pamphlets in support of their arguments. Between 1517 and 1520 alone, he wrote 30 treatises which sold over 300,000 copies. These copies quickly spread throughout Europe via re-printing (Blickle 1984; Spitz 1985; Pettegree 2015).

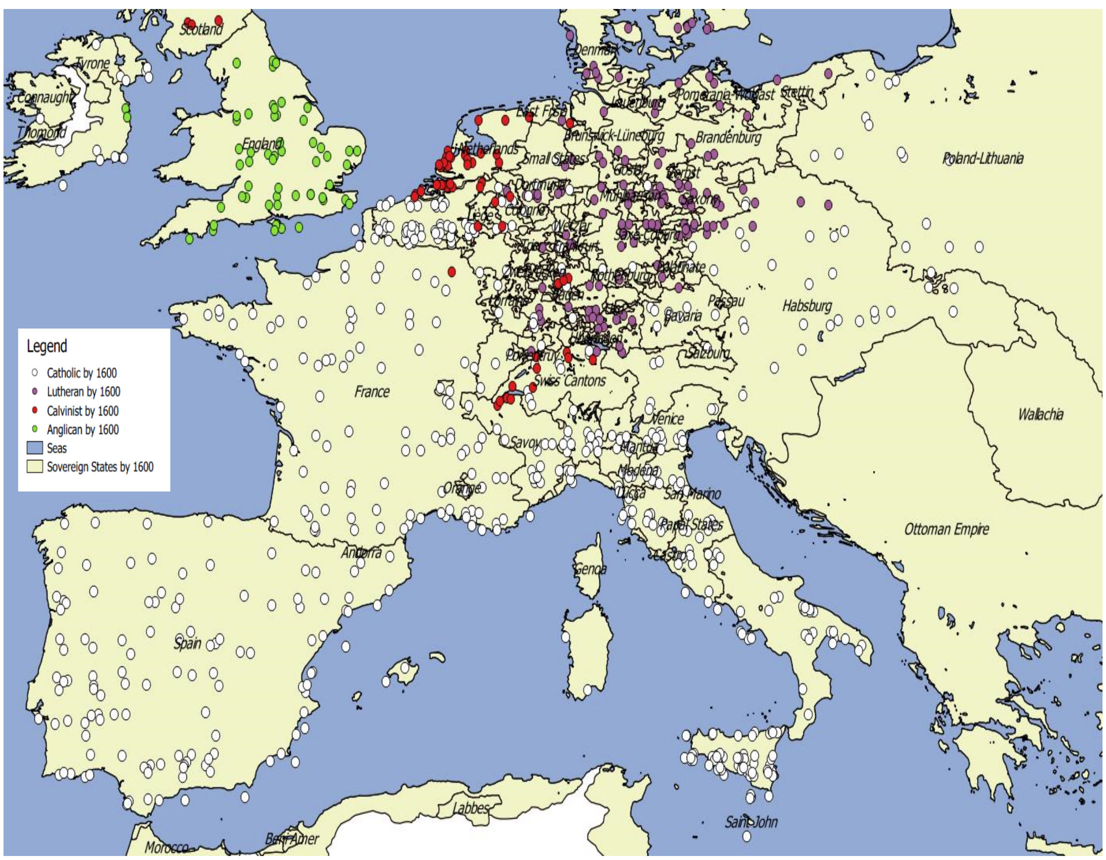
A second, and complementary, manner in which the Reformation spread was through broadsheets and pamphlets, most of which were written by Luther and other lead reformers. Even though literacy rates were low, it was common for pamphlets to be read in the public square. The accompanying broadsheets were often graphic, and their anti-papal message was unmistakable to the intended audience. A third key to the success of the Reformation was pre-existing networks associated with the Protestant epicenters of Wittenberg and Basel. Kim and Pfaff (2012) show that cities with more students attending university in Wittenberg and Basel were much more likely to adopt the Reformation, while those with more students attending university in Cologne and Louvain—two Catholic strongholds—were less likely to become Protestant. A fourth, and related, mechanism encouraging the adoption of the Reformation was proximity to other reformed polities. Cantoni (2012) shows that those parts of the Holy Roman Empire that had more close neighbors adopt the Reformation were themselves more likely to adopt the Reformation, likely because they were more insulated from pushback from the emperor.[6]

After its early spread in the Holy Roman Empire, the Reformation eventually spread throughout much of Europe, although it ultimately splintered into multiple groups (see Figure 4). The largest non-Lutheran group were the Calvinists, who followed the teachings of the French theologian John Calvin (1509–64). In the early 1530s, Calvin fled to Basel, Switzerland and was recruited to reform the church in Geneva. His brand of Protestantism, which departed from Lutheranism largely on theological grounds, such as transubstantiation, spread throughout Switzerland, southern Germany, and parts of eastern and southern France. The French Calvinists, known as Huguenots, were violently suppressed until a series of peace edicts were agreed upon in

[6]Plenty of other causes of the Reformation exist in the literature. These are overviewed in Becker et al. (2016). Beyond printing, these causes include aristocratic patronage (Kim and Pfaff 2012), urbanization (Dickens 1974), the presence of monasteries (Pfaff and Corcoran 2012), agricultural potential (Curuk and Smulders 2016), and ideological influence via proximity to a Protestant hub (Becker and Woessmann 2009). The Reformation did receive some push back from the Church and the Holy Roman Empire in its first two decades, but not enough to contain its spread. One reason is that the Reformation coincided with the height of Ottoman power. The Habsburg Holy Roman Emperor Charles V did not quickly crush the Protestant alliances in part due to Ottoman incursions into central Europe. The Ottoman threat diverted resources that could have fended off the Reformation, and when the Ottoman threat was starkest, conflict between Catholics and Protestants was rare (Iyigun 2008).

the 1570s–1590s (Cameron 1991). Calvinism also caught on in the Low Countries, which was an early hotbed of Protestant activity until it was violently suppressed by the Spanish Habsburgs (who burned nearly 2,000 Protestants between 1523 and 1555). Beginning in the 1560s, Calvinist thought played an important role in instigating the Dutch Revolt against Spanish rule (van Gelderen 1992). William of Orange co-opted the new religion and, regardless of his personal convictions, employed it as effective propaganda in the early stages of the Revolt. England also adopted its own unique brand of Protestantism during the reign of Henry VIII. The Anglican Church formed in the wake of Henry VIII's confiscations of the monasteries and the removal of all Church institutions from England, and was formalized under the reign of Elizabeth I (r. 1558–1603). Since the Anglican Church, along with the various state churches of Scandinavia, was imposed largely from the top down, we do not focus on it in our analyses.[7]

Figure 4: The Diffusion of Lutheranism and Calvinism through 1600




Sources: Rubin (2014) for the printing press and GIS border from Nuessli (2011).

[7]For more on the economic consequences of Henry VIII's removal of the Catholic Church, see Rubin (2017) and Greif and Rubin (2018). They cite the secularization of politics as a key consequence of England's Reformation. Empirical evidence of post-Reformation secularization in the Holy Roman Empire is provided by Cantoni et al. (2018), who employ an extensive data set and find that the places that adopted the Reformation invested less in religious buildings, had fewer university students earn degrees in theology, and had more university graduates take (secular) bureaucratic roles after graduation.

### 2.4 Causal Channels: Linking the Clock, Printing Press, and the Reformation

In this section, we provide suggestive historical support for three causal channels tested in this paper: i) the spread of clocks and the spread of printing; ii) the spread of clocks and the spread of the Reformation (particularly Calvinism), and iii) the spread of the printing press and the spread of the Reformation (particularly Lutheranism).

#### 2.4.1 Causal Channel #1: the Clock and the Press

The evolution of high-tech skills was embedded in the larger development of technological and cultural change beginning in the late Middle Ages and further evolving during the Renaissance. Several scholars (Zilsel 2000; Mokyr 2009; Long 2011; Zanetti 2017) have claimed that during this period artisans not only became increasingly specialized, but also started combining practical skills and expertise with theoretical knowledge. This enabled the spread of upper tail human capital, which triggered and potentially even anticipated the Scientific Revolution of the early modern period.

In addition, this period can be characterized by a new conscious perception of technological innovation and recognition of innovators by contemporary writers. Towns started to actively support the immigration of artisans and helped to protect their skills and innovations (Dohrn-van Rossum 2005). Contemporary witnesses also started to identify and characterize some towns, for instance Nuremberg, as centers for high skilled artisans and innovation (Schremmer 1997; von Stromer 2000; Diefenbacher 2000). Indeed, our data reveals that Nuremberg was both a very early adopter of the clock and the printing press.

These cultural and technological developments affected the spread of both clocks *and* the printing press. As outlined earlier, clockmakers came from various backgrounds and expertise. They had skills in astronomy, engineering, or fine mechanics and metal processing. The early clockmakers passed on their knowledge directly to other skilled artisans, engineers, and astronomers. While no formal process (e.g., guild membership) was documented from this period, by the 15th century some clockmakers were occasionally mentioned as members and a sub-group belonging to various guilds of smiths (i.e., gold, silver, and lock smiths). Nevertheless, many clockmakers were independent experts and part of "non-corportative elites" of towns (Sasson 1961; Dohrn-van Rossum 1996). Thus the profession of the clockmaker became at least partly institutionalized over time. In accordance with this development, the invention of the movable type printing press by Gutenberg, a goldsmith, can be directly linked to both the highly specialized technical skills of fine mechanics and the institutional frame of the guild of the smiths. Consequently, it is possible that towns with a tradition and expertise in fine mechanics, engineering, and related skills had the capacity to absorb the new technology of the printing press relative to other towns missing such a cluster of upper tail human capital.

In what follows we test whether such agglomerations of upper-tail human capital manifested themselves in a connection between the spread of the mechanical clock and the spread of the movable type printing press.

### 2.4.2 Causal Channel #2: the Clock and the Reformation

The construction of the first public mechanical clock in Geneva dates to 1406. Thus, when Calvin started developing his religious and worldly guidelines in the late 1540s, while residing in Geneva, he must have been exposed to an urban life which had been shaped by a more than hundred years of using and following the beat of the clock (Engammare 2010). Although we are only familiar with a few details of the daily use of clocks in Geneva, we can assume based on sources from other towns that the clock affected the daily life of people—for instance when gathering in markets for business transaction, for administrative town meetings, or by shaping and monitoring labor activities (Dorn-van Rossum 1996). This point is important: our hypothesis is that *if* the clock is causally linked to the spread of the Reformation, it was more through a culture of coordinating around time emerging in the long-run in the presence of a public mechanical clock rather than the clock itself being used to coordinate activities.

Based on personal notes and private communications, it can be derived that time management played an important role in Calvin's daily life. Calvin used the division of time for his daily routine, and he recognized time scarcity as a major problem which could only be solved by punctuality, discipline, and order. Calvin even used the expression "minutes" in his writings, which was for the middle of the 16th century extremely unusual (Engammare 2010). Calvin introduced his personal daily routine into public recommendations in his sermons, where he approached the scarcity of time, asking his church-members to regularly and punctually attend and to not waste time. His new religious spirit of discipline and order was adopted in many local church regulations and these served as blueprint for the further dissemination of the Calvinist doctrine (Engammare 2010).

Beyond Calvin himself, clocks may have played a role in the spread of the Reform movements. Within the Holy Roman Empire, cities had considerable political, economic, and cultural independence and thus a greater freedom to develop and change. Accordingly, the early construction of a public mechanical clock in a town and the steady beat of the clock it entailed shaped the social behavior of the city, affecting order, discipline, and communal life (Thomson 1967; Glennie and Thrift 1996, 2009). It is possible that this paved the way for the success of the Reformation, as towns with clocks had at least a century of culture which centered around coordinating activities via time.

This process was most thoroughly exemplified in the Netherlands, where Calvinist preachers spread in towns throughout the mid-16th century. Citizens formed around these preachers in revolutionary groups which followed the discipline and order preached by Calvin. There is much historical evidence on revolutionary movements in Dutch cities which inform us about well-coordinated and punctual revolutionary activities (Mack Crew 1978; Arnade 2008). Typically, Calvinist groups marched in ordered groups from outside into the city center singing psalms. Sometimes they walked into the city from opposite sides in two separate groups at the same time. Parallel to the church mess, they organized their own worship services. Moreover, iconoclasm, which spread extremely quickly throughout the Netherlands, seemed to have been well-organized, even though we do not have detailed evidence how these actions were coordinated. Finally, an interesting (if not anecdotal) piece of evidence suggests that Calvinists seem to have used the clock as a signal for revolutionary action: in 1566 a Catholic spy reported that Calvinists intended to sack the city of Lille and for this purpose they organized a chain of cities in Artois and French Flanders, which communicated by the sequential ringing of bells the start of the revolutionary activity (Mack Crew 1978, p. 15). Once the Calvinist movement settled, either temporarily as in the case of Antwerp (Marnef 1994), or permanently as in the case of the freed Dutch territories after 1672 with the success of the Dutch Revolt (Pettegree 1994), there was an organized and systematic overtaking of all the parishes. In these towns, the new doctrine was generally employed by local municipal governments in order to establish religious change (Pettegree 1994). Thus, this anecdotal evidence supports the claim by Gorski (2003) that a highly organized and disciplined group of Calvinists not only succeeded in revolting but also took immediate action after the Revolt to organize the new structures of the state, and in this way implemented a new state culture backed by Calvinist doctrine.

### 2.4.3 Causal Channel #3: the Press and the Reformation

The connection between the printing press and the Reformation is among the oldest and well-known linkages in Reformation historiography. Even Luther himself noted that "[The printing press is] God's highest and ultimate gift of grace by which He would have His Gospel carried forward."(quoted in Spitz 1985). Rubin (2014) econometrically tested the connection between the spread of printing and the Reformation and found that cities that adopted the printing press were 29.0 percentage points more likely to adopt the Reformation by 1600 than those that were not. Similarly, Dittmar and Seabold (2016) find that Protestant ideas spread to a much greater extent in cities with pre-existing print competition.

The primary connection given in the literature connecting the printing press and the Reformation is the reformers' use of the press in their anti-papal propaganda. Indeed, Febrve and Martin (1958, p. 288) describe the Reformation as the "first propaganda campaign conducted through the medium of the press," while Edwards (1994, p. 1) begins his book on Luther and the printing press by noting that "the Reformation saw the first major, self-conscious attempt to use the recently invented printing press to shape and channel a mass movement." Rubin (2014) shows that the top print centers in the Holy Roman Empire were much more likely to adopt the Reformation (8 of the top 10 print centers in each of the last three decades of the 15th century), and those cities producing religious pamphlets in the 16th century were likewise much more likely to have adopted the Reformation.

The proposed connection is thus a supply-side one: cities that had access to inexpensive pamphlets were much more likely to be exposed to the new Protestant ideas before the Catholic Church had time to respond.[8] Such access to cheap, printed material was crucial for the traveling preachers disseminating the newest pamphlets written by Luther and other top reformers. There was no copyright at this time; given high transport costs, important printed works (like Luther's) most commonly spread via reprinting in a nearby print shop (Edwards 1994). In short, the historical record provides plenty of reason to believe that there is a causal linkage connecting proximity to printing with adoption of the Reformation.

# 3 Data

Most of the data are from Rubin (2014) and Boerner and Severgnini (2019).[9] In this section, we overview and summarize the data we use for the primary variables of interest.

The universe of observations is all cities in Central and Western Europe which had some population by 1500 according to Bairoch et al. (1988). Bairoch et al. (1988) collected population data for every European city that reached 5,000 inhabitants at some point by 1800, and thus some cities in Bairoch et al. are not included in our data set. We collected a panel, where each observation is a city at a specific point in time, set at 100 year intervals, 1000–1500.

The three dependent variables in our study are dichotomous variables which take a value of one if a city had a clock by 1450, a city had a printing press by 1500, and a city was either Lutheran or Calvinist by time $t \in \{1530, 1560, 1600\}$. As seen in Table 1, which presents summary statistics of all data used in the analysis, 30 percent of cities had a mechanical clock by 1450, 21 percent had a printing press by 1500, 16 percent were Lutheran by 1600, and 7 percent were Calvinist by 1600.

Our clock data comes from Boerner and Severgnini (2019). Clocks spread through many of the larger cities in Europe, although they were by no means uniformly dispersed. Figure 1 indicates that clocks were widespread in the wealthier areas of Europe, such as the Low Countries, northern Italy, and the independent cities of the Holy Roman Empire. Yet their reach was limited. Few cities in the Iberian Peninsula or southern Italy had clocks, and even well-off France contained relatively few cities with clocks.

[8]The press may have also increased demand for the Reformation by elevating the desires of the bourgeoisie or enhancing vicarious participation in far away events (Eisenstein 1979, p. 132). Our analysis does not permit us to disentangle the supply and demand-side channels.

[9]For details of the underlying data sources, please consult these papers.

Table 1: Summary Statistics

| Variable | Mean | Std Error | Min | Max |
|---|---|---|---|---|
| | *Endogenous Variables* | | | |
| Clock by 1450 | 0.30 | 0.46 | 0 | 1 |
| Printing Press in 1500 | 0.21 | 0.41 | 0 | 1 |
| | *Religion Variables* | | | |
| Protestant in 1530 | 0.10 | 0.31 | 0 | 1 |
| Protestant in 1560 | 0.27 | 0.45 | 0 | 1 |
| Protestant in 1600 | 0.32 | 0.47 | 0 | 1 |
| Lutheran in 1530 | 0.09 | 0.29 | 0 | 1 |
| Lutheran in 1560 | 0.17 | 0.38 | 0 | 1 |
| Lutheran in 1600 | 0.16 | 0.37 | 0 | 1 |
| Calvinist in 1560 | 0.02 | 0.14 | 0 | 1 |
| Calvinist in 1600 | 0.07 | 0.25 | 0 | 1 |
| Anglican in 1560 | 0.07 | 0.26 | 0 | 1 |
| Anglican in 1600 | 0.07 | 0.26 | 0 | 1 |
| Catholic in 1530 | 0.90 | 0.31 | 0 | 1 |
| Catholic in 1560 | 0.73 | 0.45 | 0 | 1 |
| Catholic in 1600 | 0.68 | 0.47 | 0 | 1 |
| | *Control Variables* | | | |
| Calories | 107,846 | 27,074 | 11,506 | 165,531 |
| Independent City | 0.05 | 0.23 | 0 | 1 |
| Lay Magnate | 0.89 | 0.32 | 0 | 1 |
| University | 0.06 | 0.24 | 0 | 1 |
| Bishop | 0.29 | 0.45 | 0 | 1 |
| Hanseatic | 0.10 | 0.30 | 0 | 1 |
| Water | 0.65 | 0.48 | 0 | 1 |
| Market Potential | 19.20 | 6.49 | 5.92 | 85.90 |
| Log (distance to Wittenberg) | 6.22 | 0.74 | 3.04 | 7.27 |
| Log (distance to Zürich) | 6.02 | 0.63 | 2.52 | 7.04 |
| | *Instruments* | | | |
| Eclipse | 0.34 | 0.48 | 0 | 2 |
| Log (distance to Mainz) | 6.01 | 0.74 | 0 | 7.09 |

Notes: Total number of observations: 743. Although the data are a panel, most variables do not vary over time. Hence, we report only the cross-section. Some control variables vary over time: we report values in 1500, except for university (1450) and bishop (1517). All distance variables are in miles. We only include observations for which we have data for all covariates, which is similar to the universe of observations in Rubin (2014).

Our printing and Reformation data come from Rubin (2014). Printing spread outward from Mainz soon after its invention in 1450. Printers generally moved to places where demand for printed works was greatest: large population centers, university towns, and bishoprics contained a disproportionate share of presses. As with clocks, there was a spatial component to the spread of the printing press. As Figure 3 makes apparent, areas such as northern Italy, Germany, and the Low Countries were printing centers, whereas there were few press cities in England and the Iberian Peninsula. Moreover, many of the early print cities were *also* clock cities. This suggests that any analysis connecting the diffusion of clocks or printing to the Reformation must account for the possibility that one cause is mediated by the other. In other words, it is possible that clocks are correlated with the spread of the Reformation via the spread of printing, while it is also possible that the press is correlated with the Reformation due to the fact that clock towns were more likely to adopt the press. Of course, both clocks and the printing press may have had independent direct causal effects on the spread of the Reformation, as well.

Data collected for early versions of Rubin (2014) delineated when cities adopted the Reformation (by 1530, 1560, and 1600), and whether it adopted Lutheranism or Calvinism. As can be seen in Figure 4, there is a strong spatial component to the spread of the Reformation. The Netherlands turned Calvinist between 1560–1600, northern Germany adopted Lutheranism early, and Protestantism barely penetrated southern Europe. Indeed, much of the geographical variation is found in modern-day Germany, Switzerland, western Poland, and eastern France.

We also include a host of city-level variables that control for the supply and demand for the Reformation, the printing press, and mechanical clocks. In place of a population variable from Bairoch et al. (1988), we employ the number of calories consumed by the town from Galor and Özak (2016).[10] Calories are a good proxy for population size because it provides the maximum amount of potential calories attainable from the cultivation before and after 1500, allowing us to control for potential changes due to the Columbian exchange. Other demand controls include indicators for whether the city was independent (indicating it was economically important), belonged to a lay magnate (it was neither free nor subject to an ecclesiastical lord), housed a university, housed a bishop or archbishop, and was a member of the Hanseatic League (and thus had better access to information flows and greater wealth). Supply controls include indicators for whether the city was on water (ocean, sea, large lake, or river connected to another city), its market potential (the sum of other city's population divided by their distance to the city in question), and its distance to Wittenberg and Zürich.[11]

# 4 Empirical Strategies

## 4.1 Instrumenting for the Spread of Clocks and the Printing Press

The primary empirical challenge in linking general purpose technologies such as the mechanical clock and the movable type printing press to widespread social-political movements is the many unobservable variables that may affect both. Clocks and printing presses were not randomly assigned to towns. For instance, a town with high pre-press literacy—a variable for which practically no data exist from the Middle Ages—may have

[10] All results are robust to replacing the calories variable with a log of population variable. These results are found in the Appendix. The calories variable has the benefit of having fewer missing observations prior to 1500.

[11] As in Rubin (2014), all of the "distance to" variables are calculated "as the crow flies." Becker and Woessmann (2009) show that distance to Wittenberg is strongly correlated with the spread of Protestantism in Prussia, while followers of Zwingli spread from Zürich to the Swiss cantons and southern Germany.

been more likely to adopt the printing press *and* the Reformation. Demand for printed works were almost certainly higher in more literate towns, such as university towns or those with monasteries, while literacy may have also aided the reformers' efforts to spread its anti-papal message.[12] Indeed, literacy may have *also* contributed to the spread of the mechanical clock, since clocks were particularly useful for coordinating merchant and commercial activities, and those engaged in such activities were more likely to be literate. Another possible omitted variable is the "capitalist" or "entrepreneurial" spirit that may have encouraged the spread of both the clock and the press to a town. Mokyr (2009, 2016) and McCloskey (2010) suggest that precisely such a "spirit" was essential to the Enlightenment ideals that fostered economic growth in early modern England and the Dutch Republic. Yet another potential unobserved variable is a town's attitudes towards public good provision. On the one hand, public mechanical clocks were one of the quintessential public goods of the late medieval period. Meanwhile, Dittmar and Meisenzahl (2019) provide evidence that public good provision had a greater association with towns that eventually adopted the Reformation than with those that remained Catholic.

Due to these (and potentially other) omitted variables, a straight-forward econometric test linking mechanical clocks and movable type printing presses to the Reformation may contain biased coefficients. Reasonable stories can be told that the bias may be positive or it may be negative, but there is no reason to believe that these opposing forces necessarily cancel each other out. To account for these biases, we estimate the determinants of the spread of clocks and the press separately using instrumental variables. Fortunately, instruments for both clocks (Boerner and Severgnini 2019) and the printing press (Dittmar 2011; Rubin 2014) exist in the literature. We briefly review these instruments below and explain why they are correlated with the variable of interest while also satisfying (to a reasonable degree) the exclusion restriction.

We instrument for clocks with the number of solar eclipses a town experienced from 800 to 1241.[13] The use of solar eclipses as an instrument follows the approach introduced by Boerner and Severgnini (2019), who study the impact of mechanical clocks on the long-run growth dynamics of European cities. For our data set, we consider astronomical episodes in which the sun is completely obscured by the moon (total solar eclipses) or the moon seems smaller and at the same time covers the sun (annular solar eclipses); the regions of Europe that experienced at least two eclipses in 100 year interval are shown in Figure 5.[14]

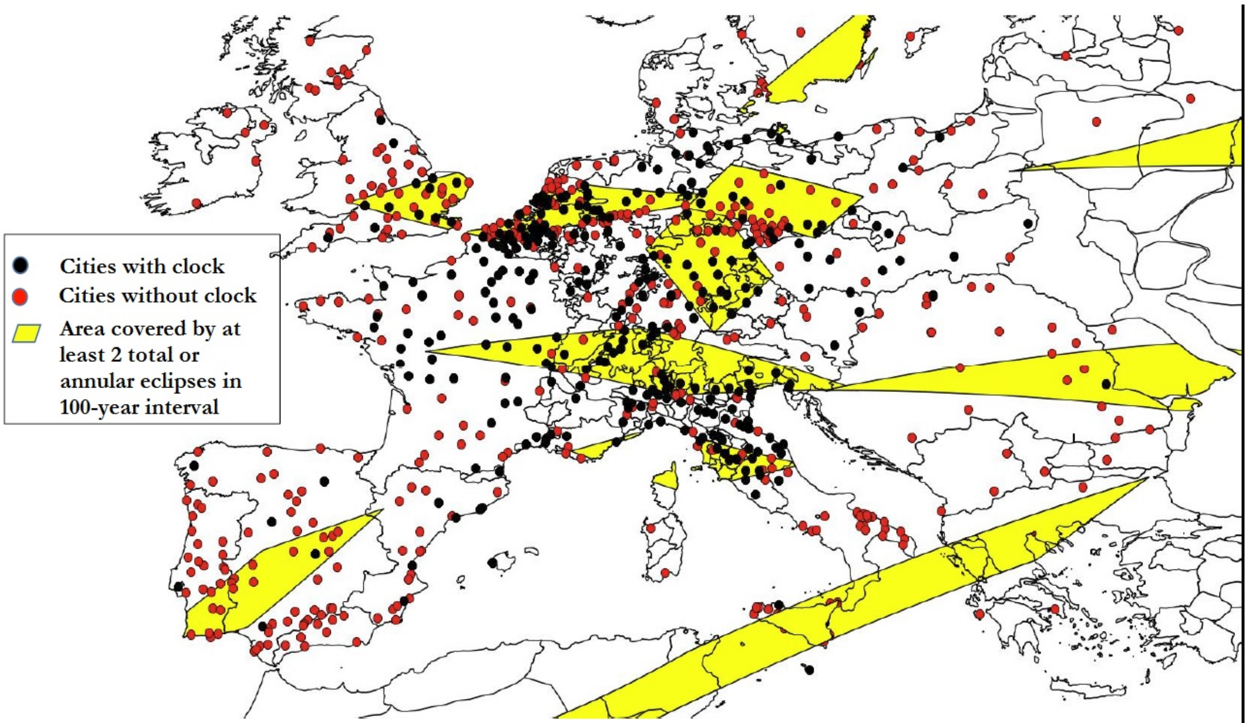
The rationale for using eclipses as an instrument for mechanical clocks follows from two relationships: i) the relationship between solar eclipses and astronomic instruments (astrolabes), and ii) the relationship between astrolabes and clocks. Regarding the first connection, the observation and documentation of the

[12] Universities may have also been associated with unobersved economic activity that is not picked up by a simple university dummy. See Cantoni and Yuchtman (2014) for more.

[13] This period covers all eclipses after 800 and before the implementation of the first clock in 1283. Before 800 no solar eclipses appeared in Europe for an extensive time.

[14] We do not consider lunar eclipses because they can be easily confused with other type of weather conditions.

Figure 5: European Cities that Experienced at Least Two Eclipses during the Period 800–1241




Source: Boerner and Severgnini (2019).

course of the celestial bodies and in particularly solar eclipses have elicited a special fascination. They could be observed by everyone, and due to their rare appearance, they were perceived as sudden, irregular, and often supernatural events (Stephenson 1997). The movements were seen as God's plan. Eclipses were in particular perceived this way by the European medieval society, where contrary to Middle Eastern and Chinese societies, hardly any recently compiled astronomic knowledge existed (the ancient Greek knowledge was almost forgotten). Thus the appearance of solar eclipses created curiosity to understand and predict these movements. This encouraged not only the further development of astronomy but also astrology, where personal astrologers advised political leaders on the optimal timing of decision-making (Borst 1989; Mentgen 2005). This broad interest created a demand in the development and use of astronomic instruments to measure and predict the movement of the heavenly bodies. In particular, astrolabes and in some cases astronomic water clocks were built (Price 1956; King 2011). The places where astrolabes were found in Europe seem to overlap with areas where solar eclipses frequently appeared.[15]

[15] An astrolabe was able to measure and simulate astronomic constellations and to measure time in equinoctial hours. King (2011) documents places where astrolabes were found in Europe. However, due to the fragmented nature of the source material, further quantification is not possible.

The second link is based on the idea that the construction of clocks was motivated by astronomic instruments (Cipolla 1967; Dohrn-van Rossum 1996), and that the timekeeping function was stressed in European astrolabes (McCluskey 1998). For instance, Cipolla (1967) states that medieval scholars were only interested in the development of machines that were related to astronomy. Cipolla takes the clock as a prime example of such a machine. Therefore a direct evolutionary path between astronomic instruments and first mechanical clocks is evident. The fact that most early mechanical clocks were also astronomic clocks (and instruments) supports this argument further.

The link between the frequent appearance of eclipses, astronomic (and astrological) curiosity and development of astronomic instruments, and finally the implementation of clocks with astronomic functions is neatly documented in the city of Mechelen. Mechelen, a Flemish city, was covered several times by total solar eclipses prior to the 13th century. The astronomer and philosopher Henry Bate of Mechelen both elaborated tables for predicting eclipses (the so-called *Tabulae Mechlinenses*) and claimed to have built an astrolabe containing a time component at the end of the 13th century (White 1978; Zanetti 2017). Finally, this same city was one of the first adopter of the public mechanical clock, which also had an astronomical component. More town case studies and a more detailed analysis can be found in Boerner and Severgnini (2019).

In short, there is little doubt that a correlation exists between the historical presence of eclipses and the spread of the mechanical clock. For reasons given above, there is reason to believe that this relationship is causal, even if the causal pathway is indirect. As long as pre-1450 eclipses did not directly affect the spread of printing or the Reformation—and we have little reason to believe this was the case—we can use the appearance of solar eclipses as an instrument for the implementation of public mechanical clocks. To investigate this point, in Table 2 we reintroduce the exogeneity tests in Boerner and Severgnini (2019), where different cities' characteristics are related to the the eclipses controlling for the set of regressors suggested by Rubin (2014). The results show that eclipses did not explain either institutional or geographical characteristics, with the only exception of being part of the Hanseatic league.[16] More precisely, we consider regions and cities where solar eclipses appeared as places with a higher likelihood of building clocks.[17]

We instrument for the spread of printing by using a town's distance from Mainz, the birthplace of printing. For reasons argued in Dittmar (2011) and Rubin (2014), a town's distance to Mainz should be related to the spread of printing but *not* to a town's eventual adoption of the Reformation (except through the printing

[16] In the econometric analysis in Section 5, we find a strong positive correlation connecting both eclipses to clocks and clocks to printing presses. The fact that we get an insignificant coefficient of eclipses on the printing press suggests that, if anything, there is a negative direct relationship between the variable related to the eclipses and the printing press.

[17] One might wonder why we use cities and regions rather than the location of monasteries as the crucial geographical point. First, we are interested in the implementation of public mechanical clocks in cities and their effect on the spread of printing and the Reformation. Second, most medieval cities that we study had at least one monastery inside their town walls and all of them had one in their immediate vicinity. Finally, in some monasteries, there existed opposition to the study of astronomy because it was not willed by God.

Table 2: Exogeneity test

| | (1) | (2) | (3) | (4) | (5) | (6) | (7) | (8) | (9) |
|---|---|---|---|---|---|---|---|---|---|
| Dependent variable: | *Clock* | *Press* | *Imperial city* | *Bishop* | *Water* | *Hansa* | *Log Dist. to Wittenberg* | *Log 16c Growth* | *Log 15c Growth* |
| *Eclipse* | 0.24** | -0.01 | 0.03 | 0.02 | 0.03 | 0.16*** | -0.04 | -0.08 | 0.03 |
| | (0.09) | (0.05) | (0.03) | (0.03) | (0.08) | (0.05) | (0.07) | (0.08) | (0.11) |
| *Log Dist to Mainz* | -0.01 | -0.14*** | -0.01 | -0.01 | 0.01 | 0.00 | 0.00 | -0.06 | 0.01 |
| | (0.06) | (0.04) | (0.05) | (0.05) | (0.04) | (0.03) | (0.12) | (0.09) | (0.04) |
| Adjusted $R^2$ | 0.40 | 0.40 | 0.69 | 0.14 | 0.47 | 0.44 | 0.82 | 0.02 | 0.18 |
| Observations | 193 | 318 | 318 | 318 | 318 | 175 | 318 | 175 | 122 |

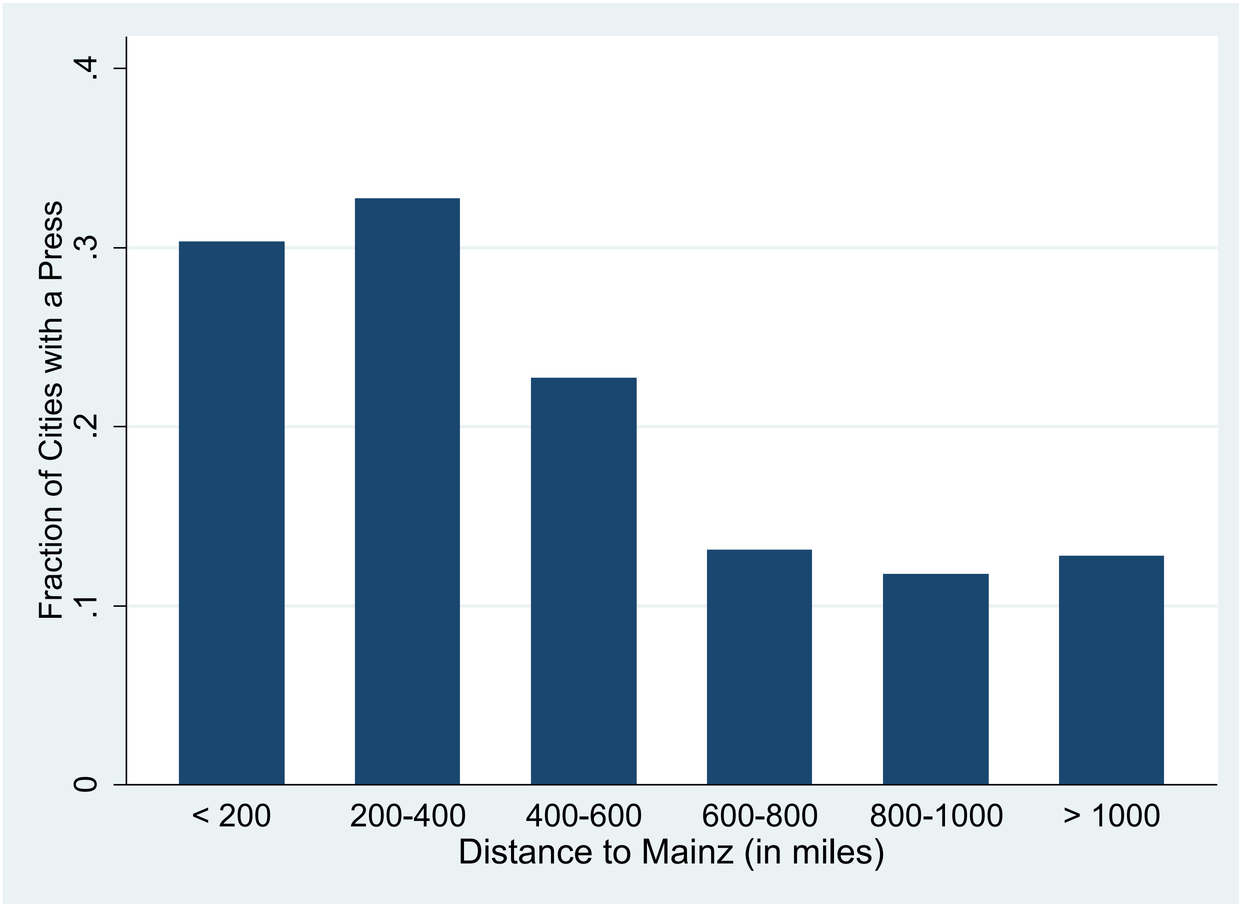
Notes: ***p < 0.01, **p < 0.05, *p < 0.1. OLS regression based on the dataset and specification provided by Rubin (2014). Population in 1300 instead of 1500 is used in the first column.

channel). Distance to Mainz is highly correlated with the early spread of printing because the first printers were either apprentices or business associates of Gutenberg in Mainz. The secrets of the new technology—most importantly, the process used to cast movable metal type, which required a specific combination of alloys—was closely guarded among this small group for the first few decades of print. This small group of printers were capitalists, and they consequently spread to cities where demand for the technology was greatest (larger cities, university cities, and bishoprics, although none of these would qualify as instruments since they may have been independently related to the acceptance of the Reformation). Printers also weighed cost when considering where to spread, and they therefore broadly spread out in concentric circles emanating from Mainz (Dittmar 2011; Rubin 2014). This stylized fact is apparent in Figure 6, which shows the share of cities that adopted printing, broken down by distance from Mainz. The trend is clear: cities that were further away from Mainz were less likely to have a press than cities closer to Mainz. Moreover, Rubin (2014) shows that distance to Mainz is not statistically related to any observable characteristics than influence Reformation adoption, such as whether the town was an independent city, had a bishop, is located on water, was a member of the Hanseatic league, and its 15th and 16th century population growth.

## 4.2 Empirical Strategies

We test the connections between clocks, printing presses, and the Reformation using various econometric specifications. We first test whether the spread of the mechanical clock had an impact on the spread of the printing press. There is reason to believe the two may be connected. If the clock encouraged goldsmiths and blacksmiths to congregate together or served as a focal point for literates (such as merchants), there would be a causal connection between the two. If there is indeed a causal connection between the two, any analysis attempting to connect the spread of printing to the Reformation would be biased unless it also accounts for

Figure 6: Share of Cities with a Printing Press by 1500, by Distance to Mainz




Source: Rubin (2014).

the spread of the clock (should the clock also have an independent effect on the spread of the Reformation). Therefore, we first test the following equation using a probit model:

$$\text{Press}_{i,j,1500} = f(\alpha_0 + \beta_0 \text{Clock}_{i,j,1450} + \gamma_0 \text{X}_{i,j,1450} + \text{D}_j + \varepsilon_0). \tag{1}$$

$\text{Press}_{i,j,1500}$ is a dichotomous variable equaling one if town $i$ in nation $j$ had a press by 1500, and $\text{Clock}_{i,j,1450}$ is a dichotomous variable equaling one if town $i$ in nation $j$ had a clock by 1450. $\text{X}_{i,j,1450}$ is a set of city-specific covariates (from 1450) including calories (a proxy for population), whether it was an independent city, whether it was ruled by a lay prince, whether it had a university, whether it had a bishop, whether it was a member of the German Hansa, whether it is on water, and its log distance to Mainz. $\text{D}_j$ is a set of "nation" fixed effects, which are more properly called regional fixed effects due to the shifting nature of borders in the early modern period. These dummies include: Denmark, England, Finland, France, Ireland, Italy, Norway, Poland, Portugal, Scotland, Spain, Sweden, and Switzerland, with the Holy Roman Empire as the omitted dummy.[18]

Clocks were not randomly assigned to cities. It is conceivable that towns adopted both general purpose technologies—the clock and the press—for reasons unobserved in our data, such as innovative "culture." To address this possibility, we instrument for the presence of a mechanical clock with the variable $\text{Eclipse}_{i,j,1450}$. This variable is a sum of the number of times a city in nation $i$ experienced multiple eclipses within the span of a century prior to 1450. In other words, we estimate the following set of equations (with equation (2) estimated by a linear probability model):

$$\text{Clock}_{i,j,1450} = \alpha_1 + \beta_1 \text{Eclipse}_{i,j,1450} + \gamma_1 \text{X}_{i,j,1450} + \text{D}_j + \varepsilon_1, \tag{2}$$

$$\text{Press}_{i,j,1500} = f(\alpha_2 + \beta_2 \widehat{\text{Clock}}_{i,j,1450} + \gamma_2 \text{X}_{i,j,1450} + \text{D}_j + \varepsilon_2). \tag{3}$$

Before proceeding to the three stage test, we analyze the effect of the spread of the mechanical clock and, separately, the spread of the movable type printing press on the Reformation. This latter is largely a replication of Rubin (2014), with a larger data set.[19] Moreover, for reasons noted previously, it is possible that the mechanical clock and the printing press affected the spread of Lutheranism and Calvinism. Hence we estimate equation (4):

$$\text{Religion}_{i,j,t} = f(\alpha_3 + \beta_3 \text{Tech}_{i,j,1500} + \gamma_3 \text{X}_{i,j,1450} + \text{D}_j + \varepsilon_3). \tag{4}$$

In these equations, $\text{Religion}_{i,j,t}$ is a dichotomous variable equaling one if town $i$ in nation $j$ adopted Religion $\in$ {Lutheranism, Calvinism} by year $t \in \{1530, 1560, 1600\}$, although we do not test for Calvinism in 1530 or 1560 because it had not yet spread significantly. $\text{Tech}_{i,j,1500}$ is a dichotomous variable equaling one if town $i$ in nation $j$ adopted either the clock by 1450 or the press by 1500, depending on the specification in consideration. The set of city-specific covariates $\text{X}_{i,j,1450}$ is the same as in previous equations with the exception that log distance to Mainz is replaced by the log of distance to Wittenberg and Zürich, the birthplaces of Luther's and Zwingli's reformations. We also include a city's market potential in 1500 as a covariate, since Cantoni (2012) suggests that there was a spatial element to Reformation adoption.

[18] The fixed effects include the Netherlands and Belgium as part of the Holy Roman Empire. This makes sense in the context of the 14th and 15th centuries, when the clock and press initially spread. However, it makes less sense in the 16th century, when the Netherlands and Belgium came under Spanish purview and, beginning in 1568, attempted to breakaway during the Eighty Years' War. Hence, in the Reformation regressions we include a separate fixed effect for both the Netherlands and Belgium.

[19] Most of Rubin's (2014) regressions only include data from the Holy Roman Empire and France, since these were the only regions with variation in adoption of the Reformation. One benefit of the conditional mixed-process (cmp) technique (Roodman 2015) employed in this paper is that it permits the inclusion of data from countries where all towns chose one religion. This is important in the context of the present paper, but not in Rubin (2014), because it permits the testing of the effects of clocks on the spread of printing in those regions with only one religion. Since there is variation in the spread of clocks and the spread of printing in these regions, including these data points provides a clearer picture for the three stage analysis.

Clocks and printing presses were not randomly assigned to cities. Hence we instrument for the presence of a mechanical clock with the eclipse variable described previously and we instrument for the presence of a printing press with the city's log distance to Mainz. In other words, we estimate the following set of equations (with equation (5) estimated by a linear probability model and equation (6) estimated via probit):

$$\text{Tech}_{i,j,1500} = \alpha_4 + \beta_4 \text{Z}_{i,j} + \gamma_4 \text{X}_{i.j,1450} + \text{D}_j + \varepsilon_4, \tag{5}$$

$$\text{Religion}_{i,j,t} = f(\alpha_5 + \beta_5 \widehat{\text{Tech}}_{i,j,1500} + \gamma_5 \text{X}_{i,j,1450} + \text{D}_j + \varepsilon_5), \tag{6}$$

where $\text{Z}_{i,j}$ is the instrument $\{\text{Eclipse}, \log\text{ (Distance to Mainz)}\}$ corresponding to the appropriate technology $\{\text{Clock, Press}\}$.

Next, we test for the presence of clocks *and* the printing press on the spread of the Reformation. We permit clocks to affect the spread of the printing press independently, and thus employ a three-stage technique. Since these events happened sequentially—first clocks spread throughout Europe, then the printing press, then the Reformation—the main variables of concern do not suffer from reverse causation and therefore do not need to be estimated simultaneously. Since omitted variables may exist, however, we employ the instruments used above for clocks and the printing press. In other words, we estimate the following set of equations (with equations (7) and (8) estimated by a linear probability model and equation (9) estimated via probit):

$$\text{Clock}_{i,j,1450} = \alpha_6 + \beta_6 \text{Eclipse}_{i,j,1450} + \gamma_6 \text{X}_{i,j,1450} + \text{D}_j + \varepsilon_6, \tag{7}$$

$$\text{Press}_{i,j,1500} = \alpha_7 + \beta_7 \widehat{\text{Clock}}_{i,j,1450} + \delta_7 \log\left(\text{distance to Mainz}\right)_{i,j} + \gamma_7 \text{X}_{i,j,1450} + \text{D}_j + \varepsilon_7, \tag{8}$$

$$\text{Religion}_{i,j,t} = f(\alpha_8 + \beta_8 \widehat{\text{Clock}}_{i,j,1450} + \delta_8 \widehat{\text{Press}}_{i,j,1500} + \gamma_8 \text{X}_{i,j,1450} + \text{D}_j + \varepsilon_8). \tag{9}$$

Finally, we test whether there is an indirect effect of the public mechanical clock through the printing press.[20] We consider a formal mediation analysis, estimating an average causal mediation effect (ACME).[21] In practice, we consider the three structural equations represented by (7)–(9). This allows us to disentangle the direct impact of clock on religion, represented by $\hat{\beta}_8$ and the indirect effect, given by $\hat{\beta}_7 * \hat{\delta}_8$, thus providing an estimate for the fraction of the direct effect of the press that is explainable by the spread of the clock (MacKinnon 2008).[22] In the following section we report the estimation results for each of these specifications.

[20] In Appendix Figure A.1, we report the path diagram of our mediation analysis.

[21] See Imai et al. (2011), Heckman and Pinto (2015), and, for an empirical application, Dippel, Gold, and Heblich (2015).

[22] These estimates hold under two assumptions. First, there is no observable confounding variables that could affect mechanical clocks, the printing press, and the religious variables we consider. Second, the printing press is ignorable on the treatment status and controls.

# 5 Empirical Analysis

## 5.1 Connecting the Clock to Printing

We begin the empirical analysis by estimating the effect of the spread of the mechanical clock on the spread of the printing press. That is, we estimate equation (1), which does not account for endogeneity or omitted variables, along with the system of equations (2) and (3), which addresses these issues.[23] There is reason to believe that the spread of the mechanical clock affected the spread of printing. Most importantly, as we have noted, is the possibility of agglomeration effects of individuals with upper-tail human capital. Both clock-makers and printers belonged to this elite group and had similar skills, and if agglomeration effects existed in late-medieval Europe, the spread of clocks could be causally related to the spread of printing. Moreover, to the extent that the clock contributed to the wealth of a city, it would have also increased demand for printed works; although Boerner and Severgnini (2019) find that clocks did not affect city growth (a proxy for wealth) until after the 15th century. Clocks also may have been focal points for individuals more likely to demand presses (i.e., merchants). In short, there are numerous possible channels through which the spread of the mechanical clock positively affected the spread of printing. We test this conjecture in Table 3. Column (1) reports the probit estimation of equation (1) while columns (2) and (3) report the two-stage estimation of equations (2) and (3), with (3) estimated via probit and (2) estimated via OLS. In all regression equations we cluster standard errors by country code, as in Nunn and Qian (2011), and we report average marginal effects in probit regressions.

The results in column (1) indicate that cities with clocks were 19 percentage points more likely to adopt the printing press than cities without clocks. The other statistically significant covariates—population (as proxied for by calories), university, bishopric, bordering water, and distance to Mainz—all have the expected coefficient; the first four are indicative of greater demand for printed works, and all enter positively, while distance to Mainz enters negatively for reasons previously elaborated.

In the two-stage regressions, the magnitude of the coefficient on the clock variable increases while remaining highly statistically significant. These results indicate that cities with a clock by 1450 were 32 percentage points more likely to adopt printing, all else equal. The eclipse instrument is strong (F-stat = 24.73, well above the threshold of 10 suggested by Staiger and Stock [1997] and Stock and Yogo [2005]), suggesting that the increased standard error on the clock coefficient in column (3) is not simply a result of a weak instrument.[24]

[23] We analyzed each regression using the Stata *cmp* command (Roodman 2015). In the Appendix, we report regressions replacing the "calories" variable with population data from Bairoch et al. (1988). These results are reported in the Appendix Tables A.2, A.5, A.8, and A.9. We report regressions using 2SLS and the Stata ivprobit command in Tables A.1, A.3, A.4, A.6, and A.7.

[24] For more on tests of weak instruments under various assumptions regarding the variance of the sample, see Andrews et al. (2018).

Table 3: Connecting the Spread of the Mechanical Clock to the Spread of the Printing Press

| | (1) | (2) | (3) |
|---|---|---|---|
| | | First Stage | Second Stage |
| Regression Technique: | Probit | OLS | Probit |
| Dependent Variable: | Press by 1500 | Clock by 1450 | Press by 1500 |
| Eclipse | | 0.13*** | |
| | | [0.03] | |
| Clock by 1450 | 0.19*** | | 0.32*** |
| | [0.03] | | [0.12] |
| Calories in 1450 (by 10,000) | 0.02** | 0.04** | 0.01 |
| | [0.01] | [0.02] | [0.01] |
| Independent City in 1450 | -0.05 | 0.08** | -0.05* |
| | [0.04] | [0.03] | [0.03] |
| Lay Magnate in 1500 | -0.05 | -0.08 | -0.03 |
| | [0.04] | [0.06] | [0.04] |
| University by 1450 | 0.26*** | 0.38*** | 0.16* |
| | [0.05] | [0.04] | [0.09] |
| Bishop by 1450 | 0.09*** | 0.17*** | 0.05 |
| | [0.03] | [0.04] | [0.04] |
| Hanseatic | 0.05 | 0.12** | 0.02 |
| | [0.05] | [0.05] | [0.05] |
| Water | 0.13*** | 0.09*** | 0.10** |
| | [0.03] | [0.03] | [0.04] |
| Log(Distance to Mainz) | -0.10** | | -0.08** |
| | [0.04] | | [0.04] |
| Mean of Dep. Var. | 0.21 | 0.30 | 0.21 |
| Nation Fixed Effects | YES | YES | YES |
| Observations | 718 | 743 | 743 |
| No. of Clusters | 18 | 18 | 18 |
| R-squared | | 0.27 | |
| Log (pseudo-)likelihood | -259.5 | | -614.5 |
| F-stat on instrument | | 24.73 | |

Notes: ***$p < 0.01$, **$p < 0.05$, *$p < 0.1$. Robust standard errors clustered by country code in brackets. Regressions calculated using the Stata cmp command from Roodman (2015), with first stage as OLS and second stage as probit. Average marginal effects reported in columns (1) and (3). All regressions include a constant term (not reported). Distance to Mainz is in miles. Nation fixed effects include Denmark, England, Finland, France, Ireland, Italy (outside of the Holy Roman Empire), Norway, Poland, Portugal, Scotland, Spain, Sweden, and Switzerland, with the Holy Roman Empire as the omitted nation.

In short, there is strong evidence of a positive association between the spread of the mechanical clock and the spread of the printing press. These results suggest that agglomeration of elite human capital in certain European cities was enhanced by (or perhaps initiated by) the spread of the public mechanical clock. This result sheds additional light on the the findings of Boerner and Severgnini (2019), who find that the spread of the clock had long run consequences for city growth, but not short-run consequences (i.e., cities with clocks started to grow faster beginning in the 16th century). If the mechanism underlying their findings is (in part) the agglomeration of elite human capital spurred on by the clock—a possibility suggested by our results—then we would expect this effect to arise over a longer time horizon and not necessarily immediately.

But how did the spread of these general purpose technologies affect the spread of the Reformation? Given their positive (and plausibly causal) relationship, can we separate their effects? Did they affect the spread of Lutheranism and Calvinism differently, a possibility suggested by the historical record overviewed in Section 2? We turn to these questions in the remainder of this section.

## 5.2 Connecting the Clock to Calvinism and Lutheranism

Next, we test whether a connection exists between the spread of mechanical clocks and the spread of the Reformation. While we know of no work suggesting that clocks might be associated with the spread of Lutheranism, we noted in Section 2 that the conception of time and order was important in Calvinism. This suggests the possibility that the clock was positively associated with the spread of Calvinism. We test this connection by analyzing the system of equations (5) and (6), where clocks are the technology in question. Results are reported in Table 4. As before, the first stage (column (1)) is estimated via OLS and the second stage (columns (2)–(6)) is estimated via probit.

The first stage estimates the determinants of the adoption of the clock. In columns (2) through (4) of Table 4, clocks enter positively and significantly for Lutheranism. In column (5), clocks enter negatively and significantly for Calvinism. There is no obvious explanation for these results; indeed, they are counter to our ex ante hypotheses that, if anything, there may be a positive association with clocks and Calvinism. Yet, one upshot of including nation fixed effects is that all identification in the Calvinism regressions comes from the Holy Roman Empire and Switzerland, the only two "nations" with variation in Calvinism adoption. Hence, we can say nothing about the determinants of *Dutch* Calvinism in this analysis, despite the fact that there is reason to believe the clock may have played a role in its spread (as laid out in Section 2). While we know of no natural experiment that would allow us to test the effect of clocks on the Dutch Reformation, some insight is gained in the regression reported in column (6). In this regression, the Dutch and Belgian fixed effects are dropped, meaning that for the sake of the regression they are part of the Holy Roman Empire.

Table 4: Connecting the Spread of the Mechanical Clock to the Spread of the Reformation

| | (1) | (2) | (3) | (4) | (5) | (6) |
|---|---|---|---|---|---|---|
| | First Stage | Second Stage | | | | |
| | Clock | Lutheran | Lutheran | Lutheran | Calvinist | Calvinist |
| Dependent Variable: | by 1450 | by 1530 | by 1560 | by 1600 | by 1600 | by 1600 |
| Eclipse | 0.13*** | | | | | |
| | [0.03] | | | | | |
| Clock by 1450 | | 0.18** | 0.37*** | 0.35*** | -0.65*** | 0.26 |
| | | [0.07] | [0.10] | [0.08] | [0.16] | [0.39] |
| Calories in 1450 (by 10,000) | 0.04** | -0.03* | -0.03 | -0.03** | 0.01 | -0.08*** |
| | [0.02] | [0.02] | [0.02] | [0.01] | [0.02] | [0.03] |
| Independent City in 1450 | 0.08** | 0.05*** | 0.19*** | 0.19*** | 0.15 | 0.20*** |
| | [0.03] | [0.01] | [0.05] | [0.04] | [0.13] | [0.07] |
| Lay Magnate in 1500 | -0.08 | -0.09*** | 0.10** | 0.10** | 0.02 | 0.15 |
| | [0.06] | [0.02] | [0.04] | [0.04] | [0.15] | [0.12] |
| University by 1450 | 0.38*** | -0.07* | -0.07 | -0.17*** | 0.36*** | 0.05 |
| | [0.04] | [0.04] | [0.04] | [0.03] | [0.04] | [0.17] |
| Bishop by 1450 | 0.17*** | -0.05** | -0.15*** | -0.13*** | 0.18*** | 0.00 |
| | [0.04] | [0.02] | [0.03] | [0.02] | [0.05] | [0.11] |
| Hanseatic | 0.12** | -0.02 | -0.00 | 0.03 | 0.05 | -0.05 |
| | [0.05] | [0.04] | [0.06] | [0.05] | [0.04] | [0.05] |
| Water | 0.09*** | -0.00 | -0.01 | -0.02 | 0.05 | 0.13*** |
| | [0.03] | [0.02] | [0.02] | [0.02] | [0.05] | [0.04] |
| Market Potential in 1500 | | -0.01** | -0.01 | 0.00 | 0.01 | 0.01 |
| | | [0.01] | [0.01] | [0.00] | [0.01] | [0.01] |
| Log(Distance to Wittenberg) | | -0.09*** | -0.16*** | -0.15*** | | |
| | | [0.01] | [0.03] | [0.02] | | |
| Log(Distance to Zürich) | | | | | 0.05 | 0.13*** |
| | | | | | [0.04] | [0.04] |
| Mean of Dep. Var. | 0.30 | 0.10 | 0.27 | 0.32 | 0.07 | 0.07 |
| Nation Fixed Effects | YES | YES | YES | YES | YES | YES |
| Dutch/Belgium FE | NO | YES | YES | YES | YES | NO |
| Observations | 743 | 743 | 743 | 743 | 743 | 743 |
| No. of Clusters | 18 | 18 | 18 | 18 | 18 | 18 |
| Log (pseudo-)likelihood | | -444.8 | -450.5 | -434.2 | -402.7 | -437.7 |
| F-stat on instrument | 24.73 | | | | | |

Notes: ***$p < 0.01$, **$p < 0.05$, *$p < 0.1$. Robust standard errors clustered by country code in brackets. Regressions calculated using the Stata cmp command from Roodman (2015), with first stage as OLS and second stage as probit. Since the regressions are jointly determined, the first stage results are not always exactly the same, although they are always close. The results reported in column (1) are from the joint regression with column (2). Average marginal effects reported in columns (2) through (6). All regressions include a constant term (not reported). Distance to Wittenberg and Zürich are in miles. In all regressions, nation fixed effects include Denmark, England, Finland, France, Ireland, Italy (outside of the Holy Roman Empire), Norway, Poland, Portugal, Scotland, Spain, Sweden, and Switzerland, with the Holy Roman Empire as the omitted nation. In regressions (2)–(5), Netherlands and Belgium fixed effects are also included.

This is not unreasonable; both were formally territories of the Holy Roman Empire prior to the Dutch Revolt of 1568. This regression thus includes much more variation within the Holy Roman Empire with respect to the adoption of Calvinism. Clocks enter positively, although statistically insignificantly, suggesting the possibility that clocks played an important role in the Dutch Calvinist movement.

We refrain from interpreting the results in this section as causal, since it is possible that the clock coefficient is picking up the effect of the press on the Reformation. In other words, the regressions presented in Table 4 do not provide us with enough information to discern between a direct and indirect effect of the clock on the Reformation. We will attempt to discern between these effects in the following sections.

### 5.3 Connecting the Printing Press to Calvinism and Lutheranism

Before turning to the three stage estimates, we estimate the connection between the spread of printing and the two major early strands of Protestantism: Lutheranism and Calvinism. This is similar to the analysis conducted in Rubin (2014), although that analysis combined Lutheranism and Calvinism into a more general "Protestantism" variable. The primary connection proposed in the literature between the two is that the printing press facilitated the propaganda efforts of the reformers. Unlike previous attempts at Church reform, the Protestants were therefore able to entrench their movement before the Church and sympathetic lay rulers could respond. As noted previously, we hypothesize that the press should have had more of an effect on the spread of Lutheranism than Calvinism for two related reasons. First, Luther's supporters were widely known for using printed pamphlets to spread their reform message (Holborn 1942; Edwards 1994; Rubin 2014; Pettegree 2015). This also indicates that the effect of the press should have waned over time, as other factors, such as politics, became more vital for the success of the Reformation (this result is also found in Rubin 2014). Second, by the time Calvinism spread in the 1550s and 1560s, the features that led to the initial success of the Reformation, such as the printing press, played a smaller role in its continued spread relative to politics. Hence, it is possible that printing played little—or zero—role in the spread of Calvinism.

We test the connection between printing and the Reformation by analyzing the system of equations (5) and (6), where the press is the technology in question. Results are reported in Table 5. As before, the first stage (column (1)) is estimated via OLS and the second stage (columns (2)–(5)) is estimated via probit.

These results suggest a strong role for printing in the spread of both Lutheranism and Calvinism. As seen in columns (2)–(4) of Table 5, the magnitude of printing on the spread of Lutheranism by 1530 and 1560 is large: 30 and 43 percentage points, respectively, although the effect of printing of Lutheranism is 1600 is smaller (but still statistically significant). The results reported in column (5) likewise suggest that the spread of printing played a large and significant role in the spread of Calvinism. Since much of the

Table 5: Connecting the Spread of the Printing Press to the Spread of the Reformation

| | (1) | (2) | (3) | (4) | (5) |
|---|---|---|---|---|---|
| | First Stage | Second Stage | | | |
| | Press | Lutheran | Lutheran | Lutheran | Calvinist |
| Dependent Variable: | by 1500 | by 1530 | by 1560 | by 1600 | by 1600 |
| Log(Distance to Mainz) | -0.10*** | | | | |
| | [0.03] | | | | |
| Press by 1500 | | 0.30*** | 0.43*** | 0.16** | 0.48*** |
| | | [0.11] | [0.10] | [0.07] | [0.12] |
| Clock by 1450 | 0.25*** | -0.06* | -0.14*** | -0.06*** | -0.10* |
| | [0.04] | [0.03] | [0.04] | [0.02] | [0.05] |
| Calories in 1450 (by 10,000) | 0.01 | -0.03* | -0.02 | -0.02 | -0.03** |
| | [0.01] | [0.02] | [0.03] | [0.01] | [0.01] |
| Independent City in 1450 | -0.04 | 0.07*** | 0.26*** | 0.24*** | 0.10 |
| | [0.06] | [0.02] | [0.06] | [0.04] | [0.06] |
| Lay Magnate in 1500 | -0.07 | -0.10*** | 0.11** | 0.09*** | 0.12 |
| | [0.05] | [0.02] | [0.04] | [0.03] | [0.09] |
| University by 1450 | 0.39*** | -0.12** | -0.08 | -0.10** | -0.08 |
| | [0.05] | [0.06] | [0.08] | [0.04] | [0.07] |
| Bishop by 1450 | 0.11*** | -0.06 | -0.15*** | -0.10*** | 0.04 |
| | [0.03] | [0.04] | [0.04] | [0.01] | [0.04] |
| Hanseatic | 0.04 | -0.01 | 0.05 | 0.09*** | -0.07* |
| | [0.05] | [0.03] | [0.04] | [0.03] | [0.04] |
| Water | 0.12*** | -0.03 | -0.03 | -0.01 | -0.08 |
| | [0.02] | [0.02] | [0.02] | [0.02] | [0.05] |
| Market Potential in 1500 | | -0.02*** | -0.01* | 0.00 | 0.00 |
| | | [0.01] | [0.01] | [0.00] | [0.01] |
| Log(Distance to Wittenberg) | | -0.10*** | -0.19*** | -0.18*** | |
| | | [0.01] | [0.03] | [0.03] | |
| Log(Distance to Zürich) | | | | | 0.05 |
| | | | | | [0.04] |
| Mean of Dep. Var. | 0.21 | 0.10 | 0.27 | 0.32 | 0.07 |
| Nation Fixed Effects | YES | YES | YES | YES | YES |
| Observations | 743 | 743 | 743 | 743 | 743 |
| No. of Clusters | 18 | 18 | 18 | 18 | 18 |
| Log (pseudo-)likelihood | | -333.9 | -340.6 | -325.5 | -292.3 |
| F-stat on instrument | 9.77 | | | | |

Notes: ***p < 0.01, **p < 0.05, *p < 0.1. Robust standard errors clustered by AISO code in brackets. Regressions calculated using the Stata cmp command from Roodman (2015), with first stage as OLS and second stage as probit. Since the regressions are jointly determined, the first stage results are not always exactly the same, although they are always close. The results reported in column (1) are from the joint regression with column (2). Average marginal effects reported in columns (2) through (5). All regressions include a constant term (not reported). Distance to Mainz, Wittenberg, and Zürich are in miles. In all regressions, nation fixed effects include Belgium, Denmark, England, Finland, France, Ireland, Italy (outside of the Holy Roman Empire), Netherlands, Norway, Poland, Portugal, Scotland, Spain, Sweden, and Switzerland, with the Holy Roman Empire as the omitted nation.

identification in this regression comes from the Holy Roman Empire and Switzerland, it is possible that this is a reflection of Zwingli's efforts in the early stages of the Reformation.

Moreover, clocks enter negatively in all of the Protestant regressions, in contrast to Table 4. Yet, these coefficients might be biased, since clocks were not randomly placed in European cities (as we have extensively discussed). Hence, we refrain from over-interpreting these results at this point. In the following section, we attempt to address this concern by instrumenting for *both* the clock and the press.

### 5.4 Connecting the Clock to Calvinism and Lutheranism via Printing

Finally, we turn to the three-stage estimation which accounts for both the spread of mechanical clocks *and* the spread of the printing press on the adoption of Lutheranism and Calvinism. Although clocks were shown to be a strong predictor of the spread of printing in Table 3, it is likely that the correlation between the assignment of clocks and printing to towns was not completely independent. Hence, an appropriate specification would instrument for both the presence of clocks and printing presses. In other words, we should jointly estimate the system of equations (7), (8), and (9). We report the results of these estimations in Table 6.

These results confirm most of the primary hypotheses suggested earlier in the paper. First, note that the two instruments, eclipse and log distance to Mainz, remain strong in the three-stage framework. Second, clocks do not have a statistically significant effect on the early adoption of Lutheranism, although it is positively associated with the adoption of Lutheranism by 1600. Third, the result from Table 3 holds with respect to the connection between clocks and Calvinism: clocks are negatively associated with Calvinism when Dutch and Belgian fixed effects are included (column (6)), but this effect goes away when these fixed effects are not included (column (7)). This indicates a plausibly positive role for clocks in the Dutch Reformation, as our earlier narrative in Section 2 suggests.

Finally, the coefficients on the printing press variable are similar to those reported in the two stage regressions in Table 5. This suggests that even after controlling for the presence of the clock, the press played an important role in the spread of both Lutheranism and Calvinism, especially in the early stages of the Reformation, as suggested in Rubin (2014).[25] Meanwhile, the second stage coefficient connecting the spread of the clock to the spread of printing remains positive and highly significant, re-confirming the previous results regarding agglomeration of elite human capital. Again, this confirms the possibility that a channel underlying Boerner and Severgnini's (2019) results linking the spread of the clock to long-run

[25] In Appendix Table A.10, we drop Belgian and Dutch fixed effects in the Lutheran regressions. The results indicate a strong and positive role for the press and no statistically significant role for clocks for Lutheranism in 1530, 1560, and 1600. Moreover, in Appendix Tables A.11–A.12, we run the regressions reported in Table 6 using different metrics for the eclipse instrument. Results are largely similar.

Table 6: Connecting the Spread of the Clock and the Printing Press to the Spread of the Reformation

| | (1) | (2) | (3) | (4) | (5) | (6) | (7) |
|---|---|---|---|---|---|---|---|
| | First Stage | Second Stage | | | Third Stage | | |
| | Clock | Press | Lutheran | Lutheran | Lutheran | Calvinist | Calvinist |
| Dependent Variable: | by 1450 | by 1500 | by 1530 | by 1560 | by 1600 | by 1600 | by 1600 |
| Eclipse | 0.13*** | | | | | | |
| | [0.03] | | | | | | |
| Log(Distance to Mainz) | | -0.10*** | | | | | |
| | | [0.03] | | | | | |
| Clock by 1450 | | 0.42** | 0.02 | 0.21 | 0.30*** | -0.68*** | -0.11 |
| | | [0.18] | [0.09] | [0.14] | [0.10] | [0.15] | [0.25] |
| Press by 1500 | | | 0.29** | 0.36*** | 0.12 | 0.42* | 0.67*** |
| | | | [0.12] | [0.10] | [0.07] | [0.23] | [0.09] |
| Calories in 1450 | 0.04** | 0.01 | -0.04** | -0.03 | -0.03** | 0.00 | -0.07*** |
| | [0.02] | [0.01] | [0.02] | [0.02] | [0.01] | [0.01] | [0.01] |
| Independent City in 1450 | 0.08** | -0.05 | 0.06*** | 0.20*** | 0.20*** | 0.12* | 0.17*** |
| | [0.03] | [0.06] | [0.02] | [0.05] | [0.04] | [0.07] | [0.06] |
| Lay Magnate in 1500 | -0.08 | -0.05 | -0.09*** | 0.12*** | 0.11*** | 0.06 | 0.16** |
| | [0.06] | [0.05] | [0.01] | [0.05] | [0.04] | [0.14] | [0.08] |
| University by 1450 | 0.38*** | 0.33*** | -0.14*** | -0.18*** | -0.21*** | 0.15 | -0.18* |
| | [0.04] | [0.07] | [0.05] | [0.06] | [0.04] | [0.12] | [0.10] |
| Bishop by 1450 | 0.17*** | 0.09** | -0.07** | -0.18*** | -0.14*** | 0.13** | -0.05 |
| | [0.04] | [0.03] | [0.03] | [0.03] | [0.01] | [0.06] | [0.06] |
| Hanseatic | 0.12** | 0.02 | -0.02 | -0.01 | 0.03 | 0.03 | -0.05 |
| | [0.05] | [0.06] | [0.03] | [0.05] | [0.05] | [0.06] | [0.06] |
| Water | 0.10*** | 0.10*** | -0.03 | -0.05*** | -0.04** | -0.01 | 0.02 |
| | [0.03] | [0.03] | [0.02] | [0.02] | [0.02] | [0.08] | [0.04] |
| Market Potential in 1500 | | | -0.02*** | -0.01** | -0.00 | 0.01 | 0.01 |
| | | | [0.01] | [0.01] | [0.00] | [0.01] | [0.01] |
| Log(Dist to Wittenberg) | | | -0.10*** | -0.16*** | -0.16*** | | |
| | | | [0.01] | [0.02] | [0.02] | | |
| Log(Dist to Zürich) | | | | | | 0.05 | 0.14*** |
| | | | | | | [0.04] | [0.04] |
| Mean of Dep. Var. | 0.30 | 0.21 | 0.10 | 0.27 | 0.32 | 0.07 | 0.07 |
| Nation Fixed Effects | YES | YES | YES | YES | YES | YES | YES |
| Dutch/Belgium FE | NO | NO | YES | YES | YES | YES | NO |
| Observations | 743 | 743 | 743 | 743 | 743 | 743 | 743 |
| No. of Clusters | 18 | 18 | 18 | 18 | 18 | 18 | 18 |
| F-stat on instrument | 24.73 | 8.96 | | | | | |
| Log (pseudo-)likelihood | | | -688.8 | -694.7 | -679.2 | -646.3 | -679.4 |

Notes: ***p < 0.01, **p < 0.05, *p < 0.1. Robust standard errors clustered by country code in brackets. Regressions calculated using the Stata cmp command from Roodman (2015), with first and second stages as OLS and third stage as probit. Since the regressions are jointly determined, the first and stage results are not always exactly the same, although they are always close. The results reported in column (1) and (2) are from the joint regression with column (3). Average marginal effects reported in columns (3) through (7). All regressions include a constant term (not reported). Distance to Mainz, Wittenberg, and Zürich are in miles. In all regressions, nation fixed effects include Denmark, England, Finland, France, Ireland, Italy (outside of the Holy Roman Empire), Norway, Poland, Portugal, Scotland, Spain, Sweden, and Switzerland, with the Holy Roman Empire as the omitted nation. In regressions (3)–(6), Netherlands and Belgium fixed effects are also included.

city growth could have been elite human capital agglomeration: places with clocks were more likely to have presses but *not* any more likely to adopt the Reformation, at least in its early stages. This entails that the long-run economic benefits associated with the Reformation (as in Weber (1905) or any of the large literature connecting Protestantism and economic outcomes) were not likely a mediating cause between clocks and long-run development.

Table 7: Mediation Analysis: Direct and Indirect Effect of the Mechanical Clock on the Reformation

| | (1) | (2) | (3) | (4) | (5) | (6) |
|---|---|---|---|---|---|---|
| Dependent Variable: | Press by 1500 | Lutheran by 1530 | Lutheran by 1560 | Lutheran by 1600 | Calvinist by 1600 | Calvinist by 1600 |
| | | | *Direct Effect* | | | |
| Clock by 1450 | 0.42** | 0.02 | 0.21 | 0.30*** | -0.68*** | -0.11 |
| | [0.18] | [0.09] | [0.14] | [0.10] | [0.15] | [0.25] |
| Press by 1500 | | 0.29** | 0.36*** | 0.12 | 0.42* | 0.67*** |
| | | [0.12] | [0.10] | [0.07] | [0.23] | [0.09] |
| | | | *Indirect Effect* | | | |
| ACME of Clock | | 0.08** | 0.08*** | 0.08 | 0.08** | 0.09*** |
| | | [0.04] | [0.04] | [0.05] | [0.04] | [0.02] |
| Contribution of Mediated | | | | | | |
| Ratio Indirect/Direct (%) | | 24% | 17% | 23% | 9% | 35% |
| $\rho$ at ACME=0 | | 0.03 | 0.02 | 0.02 | -0.01 | 0.03 |
| Dutch/Belgium FE | NO | YES | YES | YES | YES | NO |

Notes: ***p < 0.01, **p < 0.05, *p < 0.1. The upper part of the table replicates the average marginal effects reported in Table 6. The ACME is calculated as the product of the effect of the clock on the printing press and the effect of the printing press on the adoption of religion. The contribution of the mediation effect is computed as the ratio of the the indirect effect of the clock over the direct effect of the printing press. $\rho$ is measured as correlation between the errors of the models estimated by the mediator and the final outcome of the regressions.

The fact that the coefficients on the clock were positive and significant in Table 4, along with the positive and strongly significant coefficient on the press in all three Lutheran regressions in Table 6, indicates that the effect of the clock on Lutheranism was largely *indirect*. By enabling agglomeration of elite human capital in certain places, clocks enhanced the spread of the printing press, which itself *was* important for the spread of Lutheranism. We test the degree of this indirect effect with a mediation analysis, reported in Table 7, which is divided into two parts. The upper panel reports the marginal effects of the clock and press obtained of the structural equations (7)–(9) in Table 6. These values can be interpreted as the direct effect of the technologies on religion. The lower panel shows the indirect effect of the clock on religion via press (i.e., the ACME). The ACMEs of clock are computed using the delta-method as a non-linear product of the margins of the impact of the clock on the press with the impact of the press on religion. The ratios of the indirect effect of the clock and direct effect of the press are between 9 and 35%, indicating that there is a large and significant indirect effect of the mechanical clock, with the exception of Lutheranism by 1600, for which the effect of the clock appears to be direct.[26]

## 6 Conclusion

This paper analyzes the role that the two great general purpose technologies of the late medieval period—the public mechanical clock and the movable type printing press—played in the spread of one of the most important social and religious movements of the last millennium: the Protestant Reformation. Employing a city-level data set which includes various city characteristics in Western and Central Europe from the late medieval period, we find three primary results. First, towns that were early adopters of clocks also tended to be early adopters of printing, even after controlling for unobservable covariates via instrumental variables. This finding suggests that those with the elite human capital necessary to operate and repair clocks tended to agglomerate in the same cities, thus permitting spillovers when new technologies such as the printing press were introduced. Second, the printing press was positively and significantly associated with the spread of both the Lutheran and Calvinist movements. This finding confirms the econometric tests conducted in Rubin (2014) and Dittmar and Seabold (2016) and is consistent with a large historical literature connecting printing and the Reformation. Third, while the clock was statistically unrelated to the early spread of the Lutheran movement, a mediation analysis reveals a positive and significant *indirect* effect of the mechanical clock on Lutheranism (in 1530 and 1560) and on Calvinism. This finding is obscured by regional fixed effects. The history of the Dutch Reformation suggests that clocks may have played a positive (and causal) role in the spread of Calvinism, at least in the Dutch Republic, but the Dutch Republic fixed effect does not allow us to rigorously test this possibility.

More generally, this study indicates just how much technological spillovers can affect social and religious movements in unforeseeable ways. In the context of our study, the spread of the mechanical clock had the consequence of facilitating the spread of the printing press. Both required elite human capital with similar sets of skills, and it was therefore natural that places that already housed such individuals would be more likely to adopt the printing press. In turn, the spread of printing had the unforeseeable consequence of facilitating the Reformation. The press was the cutting-edge information technology of its day, permitting anti-papal grievances to spread fast enough that the Church (and its sympathizers) had a difficult time suppressing them. But towns with presses were not randomly located. Beyond the conventional supply and demand explanations for the spread of printing, our study highlights an important supply-side factor, the

[26] The reported tests indicate that there is no correlation among the errors of the estimated regressions, implying that the basic assumption of the ACME is not violated (the so called "sequential ignorability" assumption; see Conley, Hansen, and Rossi [2012]).

spread of clocks, with deep historical roots. Clocks spread via an organic process of supply and demand. However, once in place, clocks had unforseeable spillover effects (the press) that themselves played a massively influential role in the economic, political, religious, and social life of early modern Europe.

This study presents evidence that general purpose, information and communication technology can incite religious change, at least under the economic and political conditions of late medieval Europe. It thus presents evidence complementary to the reverse argument, namely that religion can affect technological innovation and adoption. For instance, Bénabou et al. (2016) provide a theoretical argument suggesting that highly religious societies may block technological innovation, which has the effect of increasing religiosity and entrenching a "theocratic" equilibrium. Chaney (2016) and Coşgel et al. (2012) provide historical evidence from the Middle East in support of this insight. Our results suggest that this equilibrium can be self-reinforcing; where technology is permitted to spread, not only might agglomerations of labor complementary to the technology increase the rate of technological progress and adoption, but the technologies themselves may affect the spread of religious dissent in unforeseeable ways. This is turn suggests that technological adoption and massive religious/social change are highly endogenous processes which are best understood in the context of the broader technological history of the societies in question. The extent to which the endogenous processes studied here spilled over into the spread of other types of technologies (e.g., precision tools, firearms, toys, musical instruments, navigational instruments) or social/religious movements (e.g., the monastic movement, the Counter-Reformation) is an empirical question that we leave open for future study.

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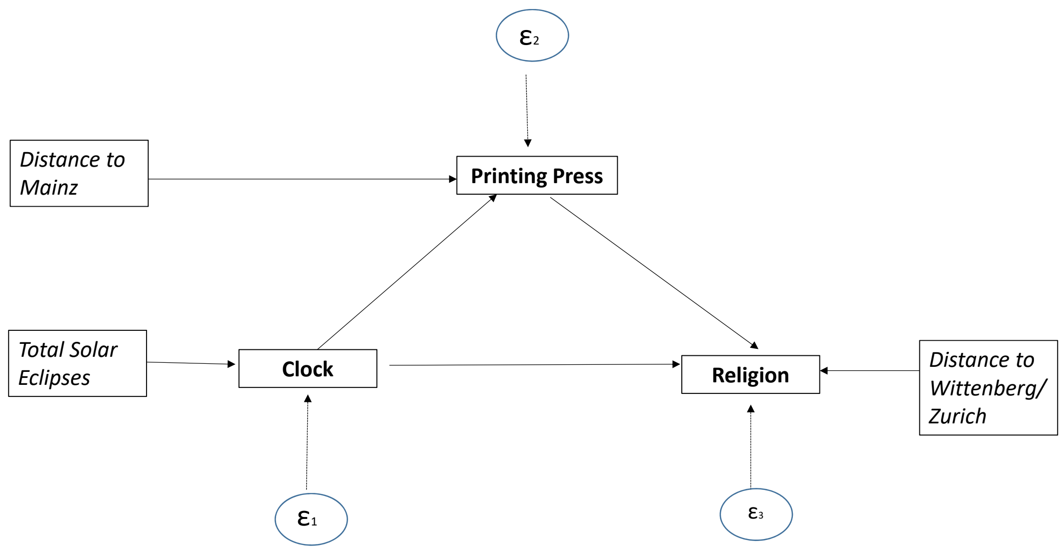
# Online Appendix

Figure A.1: Path Diagram of the Mediation Analysis




The figure displays the relationships, the dependent variables, the instruments, and the errors of the model represented by (7), (8) and (9).

Table A.1: Connecting the Spread of the Clock to the Spread of the Printing Press: 2SLS and IVProbit

| Regression Technique | 2SLS | | IV Probit | |
|---|---|---|---|---|
| | First Stage | Second Stage | First Stage | Second Stage |
| Dependent Variable: | Clock by 1450 | Press by 1500 | Clock by 1450 | Press by 1500 |
| | (1) | (2) | (3) | (4) |
| Eclipse | 0.13*** | | 0.14*** | |
| | [0.03] | | [0.03] | |
| Clock by 1450 | | 0.47*** | | 0.36*** |
| | | [0.17] | | [0.09] |
| Calories in 1450 (by 10,000) | 0.04** | 0.01 | 0.04** | 0.01 |
| | [0.02] | [0.01] | [0.02] | [0.01] |
| Independent City in 1450 | 0.08** | -0.01 | 0.08** | -0.02 |
| | [0.03] | [0.07] | [0.03] | [0.04] |
| University by 1450 | 0.38*** | 0.31*** | 0.39*** | 0.14 |
| | [0.04] | [0.07] | [0.04] | [0.09] |
| Bishop by 1450 | 0.17*** | 0.07** | 0.17*** | 0.03 |
| | [0.04] | [0.04] | [0.04] | [0.04] |
| Lay Magnate | -0.08 | -0.08 | -0.08 | -0.05 |
| | [0.06] | [0.05] | [0.06] | [0.04] |
| Hanseatic | 0.12** | 0.01 | 0.11** | 0.01 |
| | [0.05] | [0.07] | [0.05] | [0.06] |
| Water | 0.09*** | 0.10*** | 0.09*** | 0.09** |
| | [0.03] | [0.03] | [0.03] | [0.04] |
| Mean of Dep. Var. | 0.30 | 0.21 | 0.30 | 0.21 |
| Nation Fixed Effects | YES | YES | YES | YES |
| Observations | 743 | 743 | 718 | 718 |
| No. of Clusters | 18 | 18 | 18 | 18 |

Notes: ***p < 0.01, **p < 0.05, *p < 0.1. Robust standard errors clustered by country code in brackets. All regressions include a constant term (not reported). Average marginal effects reported in column (4). Nation fixed effects include Denmark, England, Finland, France, Ireland, Italy (outside of the Holy Roman Empire), Norway, Poland, Portugal, Scotland, Spain, Sweden, and Switzerland, with the Holy Roman Empire as the omitted nation.

Table A.2: Connecting the Spread of the Clock to the Spread of the Printing Press: Population as a Control

| | First Stage | Second Stage | First Stage | Second Stage |
|---|---|---|---|---|
| Dependent Variable: | Clock by 1450 | Press by 1500 | Clock by 1450 | Press by 1500 |
| | (1) | (2) | (3) | (4) |
| Eclipse | 0.13** | | 0.11** | |
| | [0.06] | | [0.04] | |
| Clock by 1450 | | 0.15*** | | 0.27 |
| | | [0.04] | | [0.29] |
| Log(Population in 1300) | 0.21*** | | | |
| | [0.02] | | | |
| Log(Population in 1400) | | 0.12*** | 0.19*** | 0.08 |
| | | [0.02] | [0.01] | [0.11] |
| Independent City in 1300 | 0.02 | | | |
| | [0.07] | | | |
| Independent City in 1450 | | -0.08* | -0.04 | -0.07 |
| | | [0.05] | [0.09] | [0.05] |
| University by 1300 | 0.03 | | | |
| | [0.08] | | | |
| University by 1450 | | 0.18*** | 0.18*** | 0.13 |
| | | [0.04] | [0.05] | [0.10] |
| Bishop by 1300 | 0.13*** | | | |
| | [0.04] | | | |
| Bishop by 1450 | | 0.10* | 0.15*** | 0.08 |
| | | [0.05] | [0.03] | [0.09] |
| Lay Magnate | 0.00 | -0.02 | -0.06 | -0.01 |
| | [0.07] | [0.03] | [0.11] | [0.03] |
| Hanseatic | -0.06 | -0.01 | -0.04 | -0.01 |
| | [0.05] | [0.07] | [0.07] | [0.07] |
| Water | 0.02 | 0.08* | 0.06 | 0.06 |
| | [0.06] | [0.04] | [0.05] | [0.05] |
| Log(Distance to Mainz) | | -0.13*** | | -0.11** |
| | | [0.03] | | [0.05] |
| Mean of Dep. Var. | 0.30 | 0.21 | 0.30 | 0.21 |
| Nation Fixed Effects | YES | YES | YES | YES |
| Observations | 530 | 530 | 354 | 354 |
| No. of Clusters | 17 | 17 | 17 | 17 |

Notes: ***p < 0.01, **p < 0.05, *p < 0.1. Robust standard errors clustered by country code in brackets. Regressions calculated using the Stata cmp command from Roodman (2015), with first stage as OLS and second stage as probit. Average marginal effects reported in columns (2) and (4). All regressions include a constant term (not reported). Distance to Mainz is in miles. Nation fixed effects include Denmark, England, Finland, France, Ireland, Italy (outside of the Holy Roman Empire), Norway, Poland, Portugal, Scotland, Spain, Sweden, and Switzerland, with the Holy Roman Empire as the omitted nation.

Table A.3: Connecting the Spread of the Clock to the Spread of the Reformation: 2SLS

| | First Stage | Second Stage | | | | |
|---|---|---|---|---|---|---|
| Dependent Variable: | Clock by 1450 | Lutheran by 1530 | Lutheran by 1560 | Lutheran by 1600 | Calvinist by 1600 | Calvinist by 1600 |
| | (1) | (2) | (3) | (4) | (5) | (6) |
| Eclipse | 0.10*** | | | | | |
| | [0.03] | | | | | |
| Clocks by 1450 | | 0.26** | 0.33* | 0.41* | -0.13 | 0.55 |
| | | [0.12] | [0.20] | [0.23] | [0.12] | [0.63] |
| Calories in 1450 | 0.03** | -0.03** | -0.03** | -0.03*** | 0.00 | -0.03 |
| (by 10,000) | [0.01] | [0.01] | [0.01] | [0.01] | [0.00] | [0.03] |
| Independent City | 0.10* | 0.11*** | 0.28*** | 0.34*** | 0.06** | -0.01 |
| in 1450 | [0.06] | [0.03] | [0.05] | [0.06] | [0.03] | [0.06] |
| University by 1450 | 0.37*** | -0.09** | -0.08 | -0.16 | 0.07 | -0.19 |
| | [0.04] | [0.04] | [0.07] | [0.10] | [0.05] | [0.25] |
| Bishop by 1450 | 0.17*** | -0.04** | -0.10** | -0.10* | 0.03 | -0.07 |
| | [0.03] | [0.02] | [0.04] | [0.05] | [0.03] | [0.10] |
| Lay Magnate | -0.09* | -0.06 | 0.12 | 0.13 | 0.01 | 0.07 |
| in 1450 | [0.05] | [0.05] | [0.07] | [0.09] | [0.04] | [0.08] |
| Hanseatic | 0.14** | -0.01 | -0.00 | 0.02 | 0.00 | -0.11 |
| | [0.06] | [0.06] | [0.07] | [0.06] | [0.03] | [0.10] |
| Water | 0.09** | -0.02 | -0.03 | -0.04 | 0.01 | 0.02 |
| | [0.04] | [0.02] | [0.02] | [0.03] | [0.01] | [0.02] |
| Market Potential | 0.01*** | -0.01** | -0.01*** | -0.01*** | 0.00 | 0.00 |
| in 1500 | [0.00] | [0.00] | [0.00] | [0.00] | [0.00] | [0.01] |
| Log(Distance | -0.05 | -0.14*** | -0.31*** | -0.35*** | | |
| to Wittenberg) | [0.06] | [0.02] | [0.03] | [0.04] | | |
| Log(Distance | | | | | -0.00 | 0.13 |
| to Zürich) | | | | | [0.01] | [0.11] |
| Mean of Dep. Var. | 0.30 | 0.10 | 0.27 | 0.32 | 0.07 | 0.07 |
| Nation Fixed Effects | YES | YES | YES | YES | YES | YES |
| Dutch/Belgium FE | YES | YES | YES | YES | YES | NO |
| R-squared | 0.29 | 0.38 | 0.54 | 0.48 | 0.66 | 0.29 |
| N | 743 | 743 | 743 | 743 | 742 | 742 |

Notes: ***p < 0.01, **p < 0.05, *p < 0.1. Robust standard errors clustered by country code in brackets. All regressions include a constant term (not reported). Distance to Wittenberg and Zürich is in miles. The first stage regressions correspond to the Lutheran regressions. Nation fixed effects include Denmark, England, Finland, France, Ireland, Italy (outside of the Holy Roman Empire), Norway, Poland, Portugal, Scotland, Spain, Sweden, and Switzerland, with the Holy Roman Empire as the omitted nation. Belgium and Dutch Republic fixed effects are included in columns (1)–(5).

Table A.4: Connecting the Spread of the Clock to the Spread of the Reformation: IVProbit (Probit coefficients)

| | First Stage | Second Stage | | | | |
|---|---|---|---|---|---|---|
| Dependent Variable: | Clock by 1450 | Lutheran by 1530 | Lutheran by 1560 | Lutheran by 1600 | Calvinist by 1600 | Calvinist by 1600 |
| | (1) | (2) | (3) | (4) | (5) | (6) |
| Eclipse | 0.19*** | | | | | |
| | [0.04] | | | | | |
| Clocks by 1450 | | 0.95*** | 1.37*** | 1.56*** | -1.84*** | 1.81 |
| | | [0.26] | [0.25] | [0.20] | [0.58] | [1.49] |
| Calories in 1450 | 0.02 | -0.21** | -0.10 | -0.12** | -0.04 | -0.34 |
| (by 10,000) | [0.02] | [0.09] | [0.10] | [0.05] | [0.07] | [0.35] |
| Independent City | 0.14* | 0.36*** | 1.01*** | 1.23*** | 0.64 | 0.65 |
| in 1450 | [0.08] | [0.08] | [0.21] | [0.34] | [0.62] | [1.30] |
| University by 1450 | 0.43*** | -0.40 | -0.18* | -0.90*** | 1.13*** | -0.08 |
| | [0.07] | [0.25] | [0.10] | [0.22] | [0.20] | [1.44] |
| Bishop by 1450 | 0.26*** | -0.36** | -0.85*** | -0.89*** | 0.73*** | -0.21 |
| | [0.07] | [0.19] | [0.13] | [0.17] | [0.20] | [0.76] |
| Lay Magnate | -0.03 | -0.72*** | 0.43** | 0.55*** | 0.20 | 0.57 |
| in 1450 | [0.08] | [0.12] | [0.17] | [0.16] | [0.67] | [0.66] |
| Hanseatic | 0.15*** | -0.11 | 0.02 | 0.23 | 0.28* | -0.42 |
| | [0.04] | [0.28] | [0.36] | [0.41] | [0.15] | [0.27] |
| Water | 0.14** | -0.01 | -0.08 | -0.17 | 0.32 | 0.29 |
| | [0.06] | [0.14] | [0.10] | [0.12] | [0.22] | 0.94 |
| Market Potential | -0.00 | -0.07** | -0.03 | 0.01 | 0.02 | 0.03 |
| in 1500 | [0.01] | [0.03] | [0.02] | [0.02] | [0.05] | [0.11] |
| Log(Distance | 0.03 | -0.72*** | -0.93*** | -1.08*** | | |
| to Wittenberg) | [0.04] | [0.09] | [0.13] | [0.12] | | |
| Log(Distance | | | | | 0.12 | 0.43 |
| to Zürich) | | | | | [0.20] | [0.67] |
| Mean of Dep. Var. | 0.30 | 0.10 | 0.27 | 0.32 | 0.07 | 0.07 |
| Nation Fixed Effects | YES | YES | YES | YES | YES | YES |
| Dutch/Belgium FE | YES | YES | YES | YES | YES | NO |
| Log pseudo-likelihood | | -207.4 | -213.1 | -196.8 | -188.4 | -256.1 |
| N | 213 | 213 | 213 | 213 | 250 | 292 |

Notes: ***p < 0.01, **p < 0.05, *p < 0.1. Robust standard errors clustered by country code in brackets. Due to discontinuous region issues calculating marginal effects, probit coefficients are reported in all columns except (1). All regressions include a constant term (not reported). Distance to Wittenberg and Zürich is in miles. The first stage regressions correspond to the Lutheran regressions. Nation fixed effects include Denmark, England, Finland, France, Ireland, Italy (outside of the Holy Roman Empire), Norway, Poland, Portugal, Scotland, Spain, Sweden, and Switzerland, with the Holy Roman Empire as the omitted nation. Belgium and Dutch Republic fixed effects are included in columns (1)–(5).

Table A.5: Connecting the Spread of the Clock to the Spread of the Reformation: Population as a Control

| | First Stage | Second Stage | | | | |
|---|---|---|---|---|---|---|
| Dependent Variable: | Clock by 1450 | Lutheran by 1530 | Lutheran by 1560 | Lutheran by 1600 | Calvinist by 1600 | Calvinist by 1600 |
| | (1) | (2) | (3) | (4) | (5) | (6) |
| Eclipse | 0.07*** | | | | | |
| | [0.02] | | | | | |
| Clocks by 1450 | | 0.38*** | 0.48*** | 0.46*** | -0.72*** | 0.50*** |
| | | [0.08] | [0.07] | [0.06] | [0.03] | [0.16] |
| Log(Population in 1500) | 0.16*** | -0.08*** | -0.09*** | -0.09*** | 0.12*** | -0.07* |
| | [0.02] | [0.02] | [0.02] | [0.01] | [0.02] | [0.04] |
| Independent City in 1450 | 0.01 | 0.03 | 0.13** | 0.13** | 0.04 | 0.06 |
| | [0.06] | [0.03] | [0.05] | [0.05] | [0.08] | [0.05] |
| University by 1450 | 0.27*** | -0.09*** | -0.07* | -0.14*** | 0.24*** | -0.11 |
| | [0.04] | [0.03] | [0.04] | [0.03] | [0.05] | 0.08 |
| Bishop by 1450 | 0.15*** | -0.07*** | -0.12*** | -0.11*** | 0.14*** | -0.10*** |
| | [0.01] | [0.01] | [0.02] | [0.01] | [0.02] | [0.03] |
| Lay Magnate in 1450 | -0.09 | -0.06* | 0.07* | 0.08** | -0.04 | 0.08 |
| | [0.08] | [0.03] | [0.04] | [0.04] | [0.08] | [0.06] |
| Hanseatic | 0.03 | 0.01 | 0.02 | 0.04 | 0.01 | -0.01 |
| | [0.06] | [0.04] | [0.05] | [0.05] | [0.04] | [0.04] |
| Water | 0.06 | -0.01 | -0.01 | -0.02 | 0.03 | 0.04 |
| | [0.04] | [0.02] | [0.02] | [0.02] | [0.04] | [0.03] |
| Market Potential in 1500 | | -0.01*** | -0.00 | -0.00 | 0.00 | 0.00 |
| | | [0.00] | [0.00] | [0.00] | [0.00] | [0.01] |
| Log(Distance to Wittenberg) | | -0.06*** | -0.10*** | -0.10*** | | |
| | | [0.01] | [0.03] | [0.02] | | |
| Log(Distance to Zürich) | | | | | 0.02 | 0.06 |
| | | | | | [0.02] | [0.04] |
| Mean of Dep. Var. | 0.30 | 0.10 | 0.27 | 0.32 | 0.07 | 0.07 |
| Nation Fixed Effects | YES | YES | YES | YES | YES | YES |
| Dutch/Belgium FE | NO | YES | YES | YES | YES | NO |
| Log pseudolikelihood | | -409.2 | -413.7 | -398.0 | -365.2 | -410.3 |
| N | 710 | 710 | 710 | 710 | 710 | 710 |

Notes: ***$p < 0.01$, **$p < 0.05$, *$p < 0.1$. Robust standard errors clustered by country code in brackets. Regressions calculated using the Stata cmp command from Roodman (2015), with first stage as OLS and second stage as probit. Average marginal effects reported in all columns except (1). All regressions include a constant term (not reported). Distance to Wittenberg and Zürich is in miles. The first stage regressions correspond to the Lutheran regressions. Nation fixed effects include Denmark, England, Finland, France, Ireland, Italy (outside of the Holy Roman Empire), Norway, Poland, Portugal, Scotland, Spain, Sweden, and Switzerland, with the Holy Roman Empire as the omitted nation. Belgium and Dutch Republic fixed effects are included in columns (2)–(5).

Table A.6: Connecting the Spread of the Press to the Spread of the Reformation: 2SLS

| | First Stage | Second Stage | | | |
|---|---|---|---|---|---|
| Dependent Variable: | Press by 1500 | Lutheran by 1530 | Lutheran by 1560 | Lutheran by 1600 | Calvinist by 1600 |
| | (1) | (2) | (3) | (4) | (5) |
| Log(Distance to Mainz | -0.10*** | | | | |
| | [0.03] | | | | |
| Press by 1500 | | -0.15 | 0.10 | -0.11 | 0.73** |
| | | [0.10] | [0.29] | [0.18] | [0.37] |
| Clock by 1450 | 0.25*** | 0.06** | -0.05 | -0.01 | -0.17* |
| | [0.05] | [0.03] | [0.07] | [0.06] | [0.10] |
| Calories in 1450 (by 10,000) | 0.02*** | -0.02 | -0.02 | -0.02** | -0.01 |
| | [0.00] | [0.01] | [0.02] | [0.01] | [0.01] |
| Independent City in 1450 | -0.02 | 0.13** | 0.32*** | 0.39*** | 0.09 |
| | [0.08] | [0.05] | [0.06] | [0.06] | [0.06] |
| University by 1450 | 0.39*** | 0.06 | 0.01 | 0.04 | -0.27 |
| | [0.05] | [0.04] | [0.11] | [0.08] | [0.17] |
| Bishop by 1450 | 0.11*** | 0.02* | -0.05 | -0.02 | -0.07 |
| | [0.03] | [0.01] | [0.05] | [0.03] | [0.05] |
| Lay Magnate in 1450 | -0.08 | -0.10 | 0.10 | 0.08 | 0.09** |
| | [0.06] | [0.06] | [0.08] | [0.07] | [0.04] |
| Hanseatic | 0.05 | 0.04 | 0.05 | 0.09*** | -0.08* |
| | [0.05] | [0.04] | [0.04] | [0.03] | [0.04] |
| Water | 0.11*** | 0.02** | -0.01 | 0.01 | -0.08** |
| | [0.02] | [0.01] | [0.02] | [0.02] | [0.04] |
| Market Potential in 1500 | -0.00 | -0.00 | -0.01*** | -0.00* | 0.00** |
| | [0.00] | [0.00] | [0.00] | [0.00] | [0.00] |
| Log(Distance to Wittenberg) | -0.00 | -0.16*** | -0.32*** | -0.37*** | |
| | [0.01] | [0.01] | [0.02] | [0.02] | |
| Log(Distance to Zürich) | | | | | 0.14*** |
| | | | | | [0.05] |
| Mean of Dep. Var. | 0.21 | 0.10 | 0.27 | 0.32 | 0.07 |
| Nation Fixed Effects | YES | YES | YES | YES | YES |
| R-squared | 0.33 | 0.48 | 0.66 | 0.69 | – |
| N | 743 | 743 | 743 | 743 | 742 |

Notes: ***p < 0.01, **p < 0.05, *p < 0.1. Robust standard errors clustered by country code in brackets. All regressions include a constant term (not reported). Distance to Wittenberg and Zürich is in miles. The first stage regressions correspond to the Lutheran regressions. Nation fixed effects include Belgium, Denmark, Dutch Republic, England, Finland, France, Ireland, Italy (outside of the Holy Roman Empire), Norway, Poland, Portugal, Scotland, Spain, Sweden, and Switzerland, with the Holy Roman Empire as the omitted nation.

Table A.7: Connecting the Spread of the Press to the Spread of the Reformation: IVProbit

| | First Stage | Second Stage | | | |
|---|---|---|---|---|---|
| Dependent Variable: | Press by 1500 | Lutheran by 1530 | Lutheran by 1560 | Lutheran by 1600 | Calvinist by 1600 |
| | (1) | (2) | (3) | (4) | (5) |
| Log(Distance to Mainz | -0.07*** | | | | |
| | [0.01] | | | | |
| Press by 1500 | | 0.51*** | 0.62*** | 0.35 | 0.57*** |
| | | [0.11] | [0.14] | [0.24] | [0.09] |
| Clock by 1450 | 0.17*** | -0.06*** | -0.13*** | -0.10*** | -0.10** |
| | [0.04] | [0.01] | [0.02] | [0.02] | [0.04] |
| Calories in 1450 (by 10,000) | 0.04** | -0.06** | -0.04 | -0.04* | -0.03*** |
| | [0.02] | [0.03] | [0.03] | [0.02] | [0.01] |
| Independent City in 1450 | -0.04 | 0.09** | 0.27** | 0.41*** | 0.13*** |
| | [0.09] | [0.04] | [0.09] | [0.05] | [0.04] |
| University by 1450 | 0.62*** | -0.33*** | -0.29** | -0.28 | -0.23*** |
| | [0.03] | [0.10] | [0.12] | [0.18] | [0.07] |
| Bishop by 1450 | 0.19*** | -0.13** | -0.23*** | -0.20*** | -0.08 |
| | [0.03] | [0.06] | [0.04] | [0.05] | [0.05] |
| Lay Magnate in 1450 | -0.11* | -0.08** | 0.15*** | 0.18*** | 0.13** |
| | [0.06] | [0.03] | [0.04] | [0.03] | [0.07] |
| Hanseatic | 0.00 | 0.00 | 0.07* | 0.16*** | -0.04 |
| | [0.05] | [0.03] | [0.04] | [0.05] | [0.04] |
| Water | 0.03 | 0.00 | 0.01 | 0.01 | -0.01 |
| | [0.02] | [0.03] | [0.02] | [0.03] | [0.04] |
| Market Potential in 1500 | -0.00 | -0.02*** | -0.01* | 0.00 | 0.01** |
| | [0.00] | [0.01] | [0.01] | [0.00] | [0.00] |
| Log(Distance to Wittenberg) | 0.01 | -0.13*** | -0.20*** | -0.31*** | |
| | [0.01] | [0.02] | [0.04] | [0.04] | |
| Log(Distance to Zürich) | | | | | 0.11*** |
| | | | | | [0.03] |
| Mean of Dep. Var. | 0.21 | 0.10 | 0.27 | 0.32 | 0.07 |
| Nation Fixed Effects | YES | YES | YES | YES | YES |
| Log pseudo-likelihood | | -161.2 | -167.9 | -152.8 | -141.2 |
| N | 213 | 213 | 213 | 213 | 250 |

Notes: ***p < 0.01, **p < 0.05, *p < 0.1. Robust standard errors clustered by country code in brackets. Average marginal effects reported in all columns except (1). All regressions include a constant term (not reported). Distance to Wittenberg and Zürich is in miles. The first stage regressions correspond to the Lutheran regressions. Nation fixed effects include Belgium, Denmark, Dutch Republic, England, Finland, France, Ireland, Italy (outside of the Holy Roman Empire), Norway, Poland, Portugal, Scotland, Spain, Sweden, and Switzerland, with the Holy Roman Empire as the omitted nation.

Table A.8: Connecting the Spread of the Press to the Spread of the Reformation: Population as a Control

| | First Stage | Second Stage | | | |
|---|---|---|---|---|---|
| Dependent Variable: | Press by 1500 | Lutheran by 1530 | Lutheran by 1560 | Lutheran by 1600 | Calvinist by 1600 |
| | (1) | (2) | (3) | (4) | (5) |
| Log(Distance to Mainz | -0.12*** | | | | |
| | [0.02] | | | | |
| Press by 1500 | | 0.14** | 0.29*** | 0.07 | 0.39*** |
| | | [0.06] | [0.07] | [0.09] | [0.13] |
| Clock by 1450 | 0.18*** | 0.00 | -0.07*** | -0.03*** | -0.06 |
| | [0.05] | [0.01] | [0.02] | [0.01] | [0.06] |
| Log(Population in 1500) | 0.14*** | -0.05*** | -0.06** | -0.02* | -0.04* |
| | [0.02] | [0.02] | [0.02] | [0.01] | [0.02] |
| Independent City in 1450 | -0.09* | 0.05*** | 0.25*** | 0.21*** | 0.09* |
| | [0.05] | [0.01] | [0.04] | [0.02] | [0.05] |
| University by 1450 | 0.39*** | -0.03 | -0.00 | -0.06 | -0.03 |
| | [0.05] | [0.03] | [0.06] | [0.04] | [0.05] |
| Bishop by 1450 | 0.10** | -0.04** | -0.13*** | -0.08*** | 0.02 |
| | [0.04] | [0.02] | [0.03] | [0.01] | [0.04] |
| Lay Magnate in 1450 | -0.05 | -0.11*** | 0.08*** | 0.06*** | 0.09 |
| | [0.04] | [0.02] | [0.03] | [0.02] | [0.08] |
| Hanseatic | -0.02 | 0.03 | 0.08*** | 0.10*** | -0.02 |
| | [0.05] | [0.02] | [0.03] | [0.02] | [0.03] |
| Water | 0.10*** | -0.01 | -0.01 | 0.00 | -0.06 |
| | [0.03] | [0.02] | [0.02] | [0.01] | [0.05] |
| Market Potential in 1500 | | -0.01** | -0.01* | 0.00 | -0.00 |
| | | [0.00] | [0.01] | [0.00] | [0.01] |
| Log(Distance to Wittenberg) | | -0.08*** | -0.18*** | -0.17*** | |
| | | [0.00] | [0.02] | [0.02] | |
| Log(Distance to Zürich) | | | | | 0.03 |
| | | | | | [0.03] |
| Mean of Dep. Var. | 0.21 | 0.10 | 0.27 | 0.32 | 0.07 |
| Nation Fixed Effects | YES | YES | YES | YES | YES |
| Log pseudo-likelihood | | -297.7 | -302.7 | -288.1 | -253.2 |
| N | 710 | 710 | 710 | 710 | 710 |

Notes: ***p < 0.01, **p < 0.05, *p < 0.1. Robust standard errors clustered by country code in brackets. Regressions calculated using the Stata cmp command from Roodman (2015), with first stage as OLS and second stage as probit. Average marginal effects reported in all columns except (1). All regressions include a constant term (not reported). Distance to Wittenberg and Zürich is in miles. The first stage regressions correspond to the Lutheran regressions. Nation fixed effects include Belgium, Denmark, Dutch Republic, England, Finland, France, Ireland, Italy (outside of the Holy Roman Empire), Norway, Poland, Portugal, Scotland, Spain, Sweden, and Switzerland, with the Holy Roman Empire as the omitted nation.

Table A.9: Connecting the Spread of the Clock and Press to the Spread of the Reformation: Population in 1300-1500 as a Control

| | First Stage | Second Stage | | | Third Stage | | |
|---|---|---|---|---|---|---|---|
| Dependent Variable: | Clock by 1450 | Press by 1500 | Lutheran by 1530 | Lutheran by 1560 | Lutheran by 1600 | Calvinist by 1600 | Calvinist by 1600 |
| | (1) | (2) | (3) | (4) | (5) | (6) | (7) |
| Eclipse | 0.13** | | | | | | |
| | [0.06] | | | | | | |
| Log(Distance to Mainz | | -0.12*** | | | | | |
| | | [0.04] | | | | | |
| Clock by 1450 | | 0.21*** | -0.03 | -0.20*** | -0.09*** | -0.14*** | -0.18*** |
| | | [0.06] | [0.05] | [0.07] | [0.02] | [0.05] | [0.06] |
| Press by 1500 | | | 0.31 | 0.41** | 0.02 | 0.67*** | 0.71*** |
| | | | [0.23] | [0.19] | [0.16] | [0.07] | [0.09] |
| Log(Population) | 0.21*** | 0.15*** | -0.05 | -0.05 | -0.02 | -0.11*** | -0.11*** |
| | [0.02] | [0.02] | [0.04] | [0.03] | [0.02] | [0.02] | [0.02] |
| Independent City | 0.02 | -0.10 | 0.08*** | 0.27*** | 0.27*** | 0.04 | 0.10 |
| | [0.07] | [0.07] | [0.03] | [0.04] | [0.07] | [0.06] | [0.06] |
| University by 1450 | 0.03 | 0.22*** | -0.05 | -0.05 | -0.03 | -0.11* | -0.14*** |
| | [0.08] | [0.05] | [0.06] | [0.07] | [0.06] | [0.06] | [0.05] |
| Bishop by 1450 | 0.13*** | 0.12 | -0.06 | -0.02 | -0.01 | 0.09 | -0.01 |
| | [0.04] | [0.08] | [0.06] | [0.08] | [0.04] | [0.10] | [0.08] |
| Lay Magnate | 0.00 | -0.04 | -0.10*** | 0.15*** | 0.10** | 0.07 | 0.11** |
| | [0.07] | [0.05] | [0.02] | [0.04] | [0.04] | [0.05] | [0.05] |
| Hanseatic | -0.05 | -0.02 | -0.02 | 0.09** | 0.14*** | -0.02 | 0.05 |
| | [0.05] | [0.08] | [0.02] | [0.05] | [0.05] | [0.06] | [0.06] |
| Water | 0.02 | 0.07 | 0.02 | -0.05** | -0.02* | -0.10** | 0.09* |
| | [0.06] | [0.04] | [0.01] | [0.03] | [0.01] | [0.05] | [0.05] |
| Market Potential | | | -0.01** | -0.00 | 0.01* | 0.00 | 0.01 |
| | | | [0.00] | [0.00] | [0.00] | [0.00] | [0.01] |
| Log(Distance to Wittenberg) | | | -0.11*** | -0.21*** | -0.17*** | | |
| | | | [0.01] | [0.06] | [0.01] | | |
| Log(Distance to Zürich) | | | | | | 0.03*** | 0.16** |
| | | | | | | [0.01] | [0.07] |
| Mean of Dep. Var. | 0.30 | 0.21 | 0.10 | 0.27 | 0.32 | 0.07 | 0.07 |
| Nation Fixed Effects | YES | YES | YES | YES | YES | YES | YES |
| Dutch/Belgium FE | NO | NO | YES | YES | YES | YES | NO |
| Log pseudo-likelihood | | | -346.2 | -352.3 | -342.3 | -325.4 | -353.8 |
| N | 521 | 521 | 521 | 521 | 521 | 521 | 521 |

Notes: ***p < 0.01, **p < 0.05, *p < 0.1. Robust standard errors clustered by country code in brackets. Regressions calculated using the Stata cmp command from Roodman (2015), with first and second stages as OLS and third stage as probit. Average marginal effects reported in all columns except (1) and (2). All regressions include a constant term (not reported). Distance to Mainz, Wittenberg, and Zürich is in miles. The population, independent city, university, and bishop variables are year 1300 in the first stage and 1450 in the second and third stages. The first and second stage regressions correspond to the Lutheran regressions. In all regressions, nation fixed effects include Denmark, England, Finland, France, Ireland, Italy (outside of the Holy Roman Empire), Norway, Poland, Portugal, Scotland, Spain, Sweden, and Switzerland, with the Holy Roman Empire as the omitted nation. In regressions (3)–(6), Netherlands and Belgium fixed effects are also included.

Table A.10: Connecting the Spread of the Clock and the Printing Press to the Spread of the Reformation, no Dutch or Belgium Fixed Effects

| | (1) | (2) | (3) | (4) | (5) |
|---|---|---|---|---|---|
| | First Stage | Second Stage | | Third Stage | |
| | Clock | Press | Lutheran | Lutheran | Lutheran |
| Dependent Variable: | by 1450 | by 1500 | by 1530 | by 1560 | by 1600 |
| Eclipse | 0.13*** | | | | |
| | [0.03] | | | | |
| Log(Distance to Mainz) | | -0.10*** | | | |
| | | [0.03] | | | |
| Clock by 1450 | | 0.42** | -0.03 | 0.04 | 0.13 |
| | | [0.18] | [0.11] | [0.17] | [0.12] |
| Press by 1500 | | | 0.34*** | 0.48*** | 0.29*** |
| | | | [0.13] | [0.12] | [0.09] |
| Calories in 1450 (by 10,000) | 0.04** | 0.01 | -0.03* | -0.02 | -0.02 |
| | [0.02] | [0.01] | [0.02] | [0.02] | [0.01] |
| Independent City in 1450 | 0.08** | -0.05 | 0.07*** | 0.19*** | 0.19*** |
| | [0.03] | [0.06] | [0.03] | [0.04] | [0.03] |
| Lay Magnate in 1500 | -0.08 | -0.05 | -0.09*** | 0.08* | 0.08* |
| | [0.06] | [0.05] | [0.01] | [0.05] | [0.04] |
| University by 1450 | 0.38*** | 0.33*** | -0.14*** | -0.18** | -0.22*** |
| | [0.04] | [0.07] | [0.05] | [0.08] | [0.06] |
| Bishop by 1450 | 0.17*** | 0.09** | -0.07** | -0.17*** | -0.14*** |
| | [0.04] | [0.03] | [0.03] | [0.04] | [0.04] |
| Hanseatic | 0.12** | 0.02 | -0.03 | -0.02 | 0.01 |
| | [0.05] | [0.06] | [0.03] | [0.04] | [0.03] |
| Water | 0.09*** | 0.10*** | -0.04* | -0.07*** | -0.06** |
| | [0.03] | [0.03] | [0.02] | [0.02] | [0.02] |
| Market Potential in 1500 | | | -0.02*** | -0.02*** | -0.01*** |
| | | | [0.01] | [0.01] | [0.00] |
| Log(Distance to Wittenberg) | | | -0.10*** | -0.16*** | -0.17*** |
| | | | [0.01] | [0.02] | [0.02] |
| Mean of Dep. Var. | 0.30 | 0.21 | 0.10 | 0.27 | 0.32 |
| Nation Fixed Effects | YES | YES | YES | YES | YES |
| Dutch/Belgium FE | NO | NO | NO | NO | NO |
| Observations | 743 | 743 | 743 | 743 | 743 |
| No. of Clusters | 18 | 18 | 18 | 18 | 18 |
| Log (pseudo-)likelihood | | | -690.0 | -700.1 | -685.9 |

Notes: ***$p < 0.01$, **$p < 0.05$, *$p < 0.1$. Robust standard errors clustered by country code in brackets. Regressions calculated using the Stata cmp command from Roodman (2015), with first and second stages as OLS and third stage as probit. Since the regressions are jointly determined, the first and stage results are not always exactly the same, although they are always close. The results reported in column (1) and (2) are from the joint regression with column (3). Average marginal effects reported in columns (3) through (5). All regressions include a constant term (not reported). Distance to Mainz, Wittenberg, and Zürich are in miles. In all regressions, nation fixed effects include Denmark, England, Finland, France, Ireland, Italy (outside of the Holy Roman Empire), Norway, Poland, Portugal, Scotland, Spain, Sweden, and Switzerland, with the Holy Roman Empire as the omitted nation.

Table A.11: Connecting the Spread of the Clock and the Printing Press to the Spread of the Reformation. Instrument: Overlapping Eclipses within 50 years

| | (1) | (2) | (3) | (4) | (5) | (6) | (7) |
|---|---|---|---|---|---|---|---|
| | First Stage | Second Stage | | | Third Stage | | |
| | Clock | Press | Lutheran | Lutheran | Lutheran | Calvinist | Calvinist |
| Dependent Variable: | by 1450 | by 1500 | by 1530 | by 1560 | by 1600 | by 1600 | by 1600 |
| Eclipse | 0.09*** | | | | | | |
| | [0.02] | | | | | | |
| Log(Distance to Mainz) | | -0.10*** | | | | | |
| | | [0.03] | | | | | |
| Clock by 1450 | | 0.43 | -0.71*** | -0.20 | 0.44*** | -0.27 | 0.50*** |
| | | [0.56] | [0.04] | [0.37] | [0.08] | [0.66] | [0.08] |
| Press by 1500 | | | 0.16*** | 0.44*** | 0.09 | 0.52*** | 0.30** |
| | | | [0.06] | [0.10] | [0.06] | [0.12] | [0.15] |
| Calories in 1450 | 0.04** | 0.01 | 0.01 | -0.02 | -0.03*** | -0.02 | -0.04*** |
| | [0.02] | [0.02] | [0.02] | [0.03] | [0.01] | [0.01] | [0.01] |
| Independent City in 1450 | 0.08* | -0.05 | 0.09*** | 0.26*** | 0.11*** | 0.11* | 0.02 |
| | [0.04] | [0.08] | [0.03] | [0.06] | [0.04] | [0.07] | [0.05] |
| Lay Magnate in 1500 | -0.07 | -0.05 | -0.11** | 0.11** | 0.10** | 0.12 | 0.12** |
| | [0.06] | [0.06] | [0.05] | [0.05] | [0.04] | [0.11] | [0.050] |
| University by 1450 | 0.37*** | 0.02 | 0.19*** | -0.06 | -0.24*** | -0.03 | -0.28*** |
| | [0.04] | [0.08] | [0.04] | [0.11] | [0.04] | [0.26] | [0.06] |
| Bishop by 1450 | 0.16*** | 0.08 | 0.08** | -0.15** | -0.13*** | 0.06 | -0.10*** |
| | [0.04] | [0.09] | [0.04] | [0.06] | [0.02] | [0.13] | [0.02] |
| Hanseatic | 0.12** | 0.02 | 0.09** | 0.06 | -0.01 | -0.05 | -0.10*** |
| | [0.05] | [0.08] | [0.03] | [0.08] | [0.05] | [0.08] | [0.03] |
| Water | 0.09*** | 0.10** | 0.04* | -0.02 | -0.04*** | -0.08 | -0.04 |
| | [0.03] | [0.05] | [0.03] | [0.03] | [0.01] | [0.08] | [0.03] |
| Market Potential in 1500 | | | -0.01*** | -0.01* | -0.00 | 0.00 | 0.00 |
| | | | [0.00] | [0.01] | [0.00] | [0.01] | [0.00] |
| Log(Distance to Witt ) | | | -0.06*** | -0.19*** | -0.11*** | | |
| | | | [0.01] | [0.03] | [0.02] | | |
| Log(Distance to Zurich) | | | | | | 0.05 | 0.04* |
| | | | | | | [0.04] | [0.02] |
| Mean of Dep. Var. | 0.30 | 0.21 | 0.10 | 0.27 | 0.32 | 0.07 | 0.07 |
| Nation Fixed Effects | YES | YES | YES | YES | YES | YES | YES |
| Dutch/Belgium FE | NO | NO | YES | YES | YES | YES | NO |
| Observations | 743 | 743 | 743 | 743 | 743 | 743 | 743 |
| No. of Clusters | 18 | 18 | 18 | 18 | 18 | 18 | 18 |
| F-stat on instrument | 21.91 | 9.85 | | | | | |
| Log (pseudo-)likelihood | | | -693.7 | -701.6 | -685.6 | -653.3 | -681.6 |

Notes: ***p < 0.01, **p < 0.05, *p < 0.1. Robust standard errors clustered by country code in brackets. Regressions calculated using the Stata cmp command from Roodman (2015), with first and second stages as OLS and third stage as probit. Since the regressions are jointly determined, the first and stage results are not always exactly the same, although they are always close. The results reported in column (1) and (2) are from the joint regression with column (3). Average marginal effects reported in columns (3) through (7). All regressions include a constant term (not reported). Distance to Mainz, Wittenberg, and Zürich are in miles. In all regressions, nation fixed effects include Denmark, England, Finland, France, Ireland, Italy (outside of the Holy Roman Empire), Norway, Poland, Portugal, Scotland, Spain, Sweden, and Switzerland, with the Holy Roman Empire as the omitted nation. In regressions (3)–(6), Netherlands and Belgium fixed effects are also included.

Table A.12: Connecting the Spread of the Clock and the Printing Press to the Spread of the Reformation. Instrument: Overlapping Eclipses within 200 years

| | (1) | (2) | (3) | (4) | (5) | (6) | (7) |
|---|---|---|---|---|---|---|---|
| | First Stage | Second Stage | | | Third Stage | | |
| | Clock | Press | Lutheran | Lutheran | Lutheran | Calvinist | Calvinist |
| Dependent Variable: | by 1450 | by 1500 | by 1530 | by 1560 | by 1600 | by 1600 | by 1600 |
| Eclipse | 0.11*** | | | | | | |
| | [0.03] | | | | | | |
| Log(Distance to Mainz) | | -0.09*** | | | | | |
| | | [0.03] | | | | | |
| Clock by 1450 | | 0.72*** | 0.17 | 0.21 | 0.38*** | -0.68*** | -0.53*** |
| | | [0.30] | [0.15] | [0.22] | [0.12] | [0.07] | [0.11] |
| Press by 1500 | | | 0.25** | 0.35*** | 0.07 | 0.48*** | 0.70*** |
| | | | [0.11] | [0.12] | [0.09] | [0.18] | [0.12] |
| Calories in 1450 | 0.04** | -0.00 | -0.04** | -0.03 | -0.03*** | -0.01 | -0.05*** |
| | [0.02] | [0.02] | [0.02] | [0.02] | [0.01] | [0.01] | [0.02] |
| Independent City in 1450 | 0.08** | -0.07 | 0.05*** | 0.20*** | 0.17*** | 0.13** | 0.19*** |
| | [0.04] | [0.05] | [0.02] | [0.03] | [0.05] | [0.05] | [0.05] |
| Lay Magnate in 1500 | -0.07 | -0.07 | -0.07*** | 0.12*** | 0.10*** | 0.07 | 0.12* |
| | [0.06] | [0.05] | [0.02] | [0.04] | [0.04] | [0.10] | [0.07] |
| University by 1450 | 0.38*** | 0.21 | -0.18*** | -0.18** | -0.21*** | 0.12 | -0.04 |
| | [0.05] | [0.15] | [0.06] | [0.09] | [0.04] | [0.09] | [0.08] |
| Bishop by 1450 | 0.15*** | 0.04 | -0.08*** | -0.17*** | -0.13*** | 0.12** | 0.01 |
| | [0.04] | [0.06] | [0.03] | [0.03] | [0.02] | [0.06] | [0.06] |
| Hanseatic | 0.08* | -0.02 | -0.05 | -0.02 | 0.00 | 0.01 | 0.01 |
| | [0.05] | [0.05] | [0.04] | [0.06] | [0.05] | [0.05] | [0.06] |
| Water | 0.09*** | 0.08*** | -0.04* | -0.05** | -0.04* | -0.03 | 0.05 |
| | [0.03] | [0.03] | [0.03] | [0.02] | [0.02] | [0.07] | [0.04] |
| Market Potential in 1500 | | | -0.01*** | -0.01* | -0.00 | 0.00 | 0.01 |
| | | | [0.00] | [0.01] | [0.00] | [0.00] | [0.01] |
| Log(Distance to Witt) | | | -0.09*** | -0.16*** | -0.14*** | | |
| | | | [0.01] | [0.03] | [0.03] | | |
| Log(Distance to Zurich) | | | | | | 0.05* | 0.14** |
| | | | | | | [0.03] | [0.05] |
| Mean of Dep. Var. | 0.30 | 0.21 | 0.10 | 0.27 | 0.32 | 0.07 | 0.07 |
| Nation Fixed Effects | YES | YES | YES | YES | YES | YES | YES |
| Dutch/Belgium FE | NO | NO | YES | YES | YES | YES | NO |
| Observations | 743 | 743 | 743 | 743 | 743 | 743 | 743 |
| No. of Clusters | 18 | 18 | 18 | 18 | 18 | 18 | 18 |
| F-stat on instrument | 16.24 | 11.85 | | | | | |
| Log (pseudo-)likelihood | | | -686.2 | -692.2 | -675.7 | -645.4 | -678.3 |

Notes: ***p < 0.01, **p < 0.05, *p < 0.1. Robust standard errors clustered by country code in brackets. Regressions calculated using the Stata cmp command from Roodman (2015), with first and second stages as OLS and third stage as probit. Since the regressions are jointly determined, the first and stage results are not always exactly the same, although they are always close. The results reported in column (1) and (2) are from the joint regression with column (3). Average marginal effects reported in columns (3) through (7). All regressions include a constant term (not reported). Distance to Mainz, Wittenberg, and Zürich are in miles. In all regressions, nation fixed effects include Denmark, England, Finland, France, Ireland, Italy (outside of the Holy Roman Empire), Norway, Poland, Portugal, Scotland, Spain, Sweden, and Switzerland, with the Holy Roman Empire as the omitted nation. In regressions (3)–(6), Netherlands and Belgium fixed effects are also included.