Religion and the Rise and Fall of Islamic Science

Eric Chaney*

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Abstract

Why did the "Golden Age" of Islamic science end? To explore this question, I gather data on scientific production from Harvard's library collection and a catalog of books from seventeenth century Istanbul. I document that the proportion of books dedicated to scientific topics declined in the medieval period, noting that the empirical patterns weigh against explanations attributing the decline to external shocks such as the Crusades, Mongol invasions, or colonialism. Instead, the results link the decline to institutional changes starting in the eleventh century that altered the relative payoffs to producing scientific knowledge. I discuss the role religious leaders played in generating these developments, concluding that the available evidence is consistent with the hypothesis that an increase in the political power of these elites caused the observed decline in scientific output.

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Muslim-majority regions produce a disproportionately small share of world scientific output.[1] During the medieval period, however, Islamic societies witnessed a spectacular flowering of scientific and technological production. Scholars and commentators often point to this "Golden Age" as evidence that there is no inherent incompatibility between Islam and science. But the reasons behind the low levels of scientific production in these regions today remain poorly understood. Scholars have argued for generations that the current underproduction of science in the Islamic world traces its roots to the medieval decline of scientific production and the concomitant rise of an obscurantist social equilibrium that has persisted to the present. Some have argued that external shocks such as the Crusades or the Mongol invasions brought about these changes, while others have pointed to institutional changes which began in the eleventh century. In more recent years, scholars have challenged these interpretations, claiming instead that Islamic science did not decline in the medieval period and pointing to colonialism as the culprit (e.g. Saliba, 2007).

In this paper, I use two novel data sets covering over a millennium to explore whether scientific production in the Islamic world declined, to pinpoint when it declined, and to evaluate the validity of popular explanations for its decline. I provide the first, to my knowledge, systematic empirical evidence for a decline of scientific output in the medieval Islamic world. The empirical analysis shows a sustained drop in the production of books on scientific topics that becomes statistically significant in the twelfth century CE and persists through the end of the sample in 1800. Additional results weigh against claims that this decrease is driven by systematic changes in the sampling regime over time.

These empirical patterns also cast doubt on the hypothesis that the Crusades or Mongol invasions precipitated the decline since the decline does not radiate outward from areas hardest hit by these shocks. In addition, the data demonstrate that the decline occurred centuries before Columbus, undermining claims that the decline in science resulted from colonialism.

The main alternative hypothesis for the decline is what I refer to as the Sunni Revival hypothesis (or Revival hypothesis for short) (Makdisi, 1973; Gibb, 1982). The classical version of this hypothesis claims that the Revival (which is believed to have begun in the eleventh century) led to the decline of scientific production by shifting the payoff structure in favor of the production of religious knowledge at the expense of scientific knowledge (Baumol, 1990; Murphy et al., 1991). In particular, the Revival is thought to have marked the emergence of a religious bureaucracy that replaced the former secretarial class. These events coincided with the spread of madrasas (educational centers where Islamic law was taught) which are hypothesized to have emerged to train the new class of religious administrators (Gibb, 1982, pp. 22, 24). While a subset of historians favor this hypothesis (e.g. Sabra, 1987, p. 233), to my knowledge this paper provides the first empirical evidence in its support. In particular, I show that the decline in scientific activity coincides with a surge in the proportion of authors who affiliated with madrasas. In addition, I provide evidence that the decline coincides with a drop in the proportion of authors employed as secretaries.

[1] See, for example, Dallal (2010, pp. 158-159) who discusses "the dismal state of scientific and technological production in the Muslim world" and notes that "the average output [of scientific publications] of the Arab world per million inhabitants is roughly 2 percent of the output of an industrialized country."

Although data limitations preclude a formal empirical investigation of the reasons behind the Revival, I hypothesize that it reflected the culmination of the centuries-long transformation of pre-Islamic societies. In particular, historians have argued that this period witnessed the final disintegration of the pre-Islamic bureaucratic state (e.g. Hodgson, 1974, pp. 64-65) and its replacement with a new political equilibrium in which civil society was dominated by religious leaders (Blaydes and Chaney, 2013; Chaney, 2012, 2013). I provide qualitative evidence that these newly empowered elites worked to restrict the production of scientific knowledge because they believed that unrestrained scientific research led to deism and atheism. This evidence suggests the relevance of a conceptual framework in which religious leaders derive rents from their control over popular beliefs (Chaney, 2013), and thus work to restrict access to alternative world views unless otherwise constrained (Acemoglu and Robinson, 2000).

To the extent that this interpretation of the results is correct, the paper adds to the growing literature arguing that "religion matters" in understanding differences in human capital formation rates (e.g. Mokyr, 2002; Botticini and Eckstein, 2005; Becker and Woessmann, 2009; Benabou et al., 2013) and thus differences in economic outcomes across societies (e.g. Barro and McCleary, 2003). While complementing such studies, the results in this paper also suggest the importance of better understanding the impact of actions taken by religious leaders in the political and institutional spheres. Consistent with Cantoni and Yuchtman (2013), I argue that where religious elites are more powerful they will favor an institutional and educational framework that discourages human capital accumulation that could detract from their control over the population (see Acemoglu and Autor, 2012, for a related discussion). This view predicts a negative correlation between the political power of religious leaders and scientific production that is consistent with the results presented in this paper. It also suggests that better understanding these political constraints may help clarify why some religions historically encouraged human capital formation to a greater extent than others.

The paper also contributes to the economics of innovation literature. Mokyr (1994) formulated "Cardwell's law" which posits that every society in isolation will only be creative for short periods. In this framework, technological progress encounters resistance from pressure groups that stand to lose from innovation and thus innovation will come to an end in the absence of political competition. While the idea that rent-seeking pressure groups can stifle technological progress and economic growth is well-established (Krusell and Rios-Rull, 1996; Acemoglu and Robinson, 2000), this paper is novel in that it provides evidence that religious groups should be considered as rent-seeking interests that can reduce innovation if unconstrained.

Finally, the paper speaks to the sizeable literature investigating the economic rise of the Western World. This literature often highlights the role of the technological and scientific dynamism in the West as a key driver of the divergence both within the West and between the West and the rest of the world (e.g. Mokyr, 2005; A'Hearn et al., 2009; Buringh and van Zanden, 2009). It is often forgotten, however, that the Islamic world outstripped the West technologically and scientifically for much of the Middle Ages. The results in this paper suggest that future research investigating how the political equilibrium in the West placed constraints on religious leaders may provide insights into the greater scientific and technological development of the West in the run-up to the Industrial Revolution.

The remainder of the paper proceeds as follows: the first section provides an historical overview and presents the data and basic trends, the second section discusses the empirical relevance of the most prominent hypotheses for the decline of scientific production in the Islamic world, a third section provides a discussion and a fourth section concludes.

1 Measuring the Evolution of Scientific Output in the Islamic World

Scholars broadly agree that during the medieval period Islamic societies led the world in both technology and science (e.g. Huff, 2003). While the factors that led to this surge in scientific output remain a topic of debate, its timing is reasonably well known. From the rise of Islam in the seventh century until the start of the Abbasid Caliphate in 750 CE, the nascent Islamic world produced relatively little scientific output.[2] Abbasid Caliphs over the following century sponsored a translation movement aimed at rendering every available scientific text into Arabic (Gutas, 1998). This translation movement coincided with and served as a catalyst for the explosion of scientific output that occurred in the Islamic world over the following centuries. Islamic scientists during this period made important advances in fields as varied as astronomy, mathematics, medicine and optics (Kennedy, 1970, p. 337). Indeed, many scientific advances in the medieval Islamic world were eventually translated into Latin and are believed to have played a central role in the scientific development of Western Europe during the medieval and early modern periods (e.g. Lindberg, 1978).

Scientists during this period generally received support from rulers and wealthy individuals such as merchants.[3] Scientific output benefitted from the emergence of a host of competing courts across the Muslim world following the disintegration of the Abbasid Empire in the 9th and 10th centuries. Indeed, one scholar has noted that support for science during this period resembled "the situation during the sixteenth century, the Age of Enlightenment, when the state, personified by reigning monarchs, founded academies of science and competed for scholars to staff them"(Kennedy, 1970, p. 329). Both rulers and other wealthy individuals patronized scientists for both prestige (David, 2008) and for the "practical benefits promised by the practitioners of medicine and astronomy and astrology and applied mathematics" (Sabra, 1996, p. 662). This medieval surge in scientific production also resembled the European Enlightenment in that it was accompanied by the emergence of a deist/atheist fringe that argued for the primacy of reason -not revelation- in determining truth and in ordering society (Israel, 2002).

[2]In the century following the death of the Prophet Muhammad in 632 CE, Arab-Islamic armies conquered a vast territory reaching from modern-day France to Pakistan. The immediate successors to Muhammad (known as the Rashidun Caliphs) were overthrown by the Umayyad Dynasty in 661 which was replaced, in turn, by the Abbasid Dynasty in 750. Contrary to what is implied in many studies, this dynasty was relatively short-lived, at least in its ability to directly control territory. Generally speaking, after 945 the Abbasid Caliphs no longer enjoyed temporal power and primarily provided their blessing upon the true holders of power across the Islamic world. In 1258, this state of affairs came to an end when the last Abbasid Caliph was killed by the Mongols.

[3]The term scientist is, admittedly, anachronistic. Throughout, I use this term in place of others such as natural philosopher for expositional ease.

From at least the start of the translation movement, the study of what were known as the foreign or rational sciences divided Muslims. Some fully embraced rational methods while others opposed the use of reason and championed the supremacy of revelation. For generations, scholarship has focused primarily on the second group, often implying that Muslims who excelled in the study of the sciences did so in spite of Islam's presumed doctrinal aversion to the use of reason. This "classical narrative" claims that Muslim religious orthodoxy eventually gained the upper hand in this battle and when it did, persecuted Muslims who engaged in rational inquiry and scientific production. Once empowered, these religious leaders supposedly discouraged scientific production (e.g. Saliba, 2007, p. 2).

Recent scholarship has challenged the most simplistic versions of this hypothesis. Studies such as Saliba (2007) provide overwhelming evidence that important advances continued to be produced in the Islamic world long after the supposed medieval decline of scientific production. While some scientific advances continued to emerge, this does not refute the claim that there was a systematic decline in scientific production. In recent years an intellectual stalemate has arisen between those who argue for a decline and their detractors.[4] Much of this stalemate seems to be the product of a lack of systematic empirical evidence regarding the evolution of intellectual production in the Islamic world historically.

In this paper, I gather systematic data on intellectual production in the pre-modern Islamic world. Ideally, I would be able to randomly sample from all books written in the Islamic world throughout its history. I could then examine the extent to which there was a decline in the proportion of books written on scientific topics over time. While such an experiment is not possible, in this paper I construct a data set containing every book written by an author with an Islamic-sounding name that has a book held by Harvard libraries.[5]

It seems reasonable to assume that Harvard's library collection provides an approximation to the population of surviving books considered important in the West today. First, it holds the most volumes of all universities in the United States.[6] Second, Harvard's historical and present-day strengths in history, the humanities and regional studies make it likely that the world's most prominent thinkers will be represented in the database.[7] For the remainder of this section, I assume that these data represent a random sample of all books written in each time period and ignore potential selection issues for expositional ease. Selection issues will be given detailed treatment in the following section.

To construct the baseline data set, I start from Harvard's library collection. The data I accessed in November, 2014 contains information on 13,283,463 books. For each book, I keep only information on the book's author and the subject matter (MARC 21 codes 100 and 650 respectively).[8] I then generate subject dummies at the book level. This is perhaps best illustrated by example. The original subject

[4]For an introduction to this debate, see Huff (2003) and Saliba (2007).

[5]For the most part, this was straightforward. For example, Hunayn ibn Ishaq is classified as having an Islamic-sounding name even though he was Christian because his name "sounds" Arab. In the paper's replication files, I provide documentation of all the authors I selected from Harvard's database.

[6]See, for example, http://www.ala.org/tools/libfactsheets/alalibraryfactsheet22.

[7]The collection policy of Harvard libraries is explained here http://hcl.harvard.edu/collections/. In particular, this policy states that "[t]he collections aspire to comprehensive coverage of the record of scholarship, from all countries and in all relevant fields."

[8]MARC (Machine-Readable Cataloging) formats are standards for the representation and communication of bibliographic and related information in machine-readable form (see http://www.loc.gov/marc/ for additional information).

entry (with the accompanying MARC 21 codes) for the book with ISBN 9780387960135 (Completion of the conics by Alhazen (965-1039)) is "\0$aMathematics, Greek.; \0$aMathematics, Arab.; \0$aConic sections$xEarly works to 1800". This book is classified as being a book on mathematics because it contains the string sequence "Mathematics" in the subject entry. I code a book as being on a scientific topic if it contains at least one of the strings (uppercase or lowercase) "Alchemy", "Algebra", "Astronomy", "Chemistry", "Engineering", "Geometry", "Logic", "Mathematics", "Medicine", "Optics", "Physics", "Refraction", "Science" or "Trigonometry".[9] I then sum up for each author the total number of books held by Harvard and the total number of books on scientific topics.[10]

For many authors, the author entry comes with dates of birth, death or an approximate date when they lived. For these authors, I drop all who have a date after 1850. For those that don't have a date, I run their names through the website http://viaf.org and search the first three hits for dates. Thus, the philosopher Farabi who isn't assigned a date in Harvard's system is assigned the birth date 870 and the death date 950 CE based on information gathered from this website.

I then go through these data by hand and select all authors with an Islamic-sounding name. To assign dates to books, for each author I set the death year equal to the birth year plus 69 (the mean lifespan in the sample) if the death date is missing. I also set the death date equal to the date in which the author was active if both the birth and death dates are missing but this information is available. I then drop all authors with death dates greater than or equal to 1800 and all books without an identified subject. When this is done, I have information on 21,265 books written by 3,784 authors who died on the interval [250,1799].[11]

In figure 1, I present the scatter plot of the natural logarithm of books by author against death year for the 378 authors who died after 700 with at least one book on a scientific topic. The authors at the top of the graph read as a list of the giants of scientific thought in the Islamic world historically, suggesting that the MARC subject field is doing a reasonable job identifying scientific works.

In figure 2, I examine how the proportion of books written on scientific topics evolves over time. Throughout, I normalize the number of books on scientific topics by the number of books for which Harvard identifies a subject.[12] This figure presents the 100-year rear moving average of the proportion of books written on scientific topics in each year from 700 CE through the end of the sample. The four vertical lines denote: 813, the year of the Caliph al-Mamun's rise to the Caliphate; 1099, the Crusader

[9] The subject fields are generally determined by Harvard catalogers although some records contain fields assigned by outside entities, including sources like the Library of Congress, vendors, or partner libraries (email correspondence with Laura Morse on 12/2/2015).

[10] At times, authors have different MARC strings denoting their names. Thus, I assign each author a number and sum the relevant entries for authors with different MARC strings. In the rare cases where there is conflicting information in an author entry (i.e. author birth/death date) I use the information in one of the entries. These choices are documented in the paper's replication files.

[11] For authors assigned to centuries, I set the death date equal to the midpoint of the century. Thus, authors who were active in the sixteenth century are assigned the death year 1550.

[12] Throughout the paper, I limit analysis to observations with defined values of the dependent variable when relevant. Thus, regressions using the proportion of books written on scientific topics as the dependent variable are estimated on the sample of books with defined subjects. Similarly, regressions investigating the proportion of books written by secretaries are limited to those authors for whom I was able to identify a profession. In general, however, these results are qualitatively similar to those obtained when running the regressions on the entire sample.

sack of Jerusalem; 1219 CE, the start of the Mongol invasion of Iran; and 1492, the date most frequently used to denote the start of the European colonialism. I mark these dates because they are believed by many scholars to be turning points in the scientific production of the Islamic world.

Scholars believe that al-Mamun's rise to the Caliphate provided an impetus to the translation of scientific texts into Arabic. Figure 2 seems consistent with this claim, as the proportion of works written on scientific topics jumps around 813. The proportion of works written on scientific topics exhibits an upward trend until a few decades after the Crusader sack of Jerusalem in 1099 when this proportion abruptly drops off. In the century prior to the start of the Mongol invasion of Iran in 1219, roughly 7 percent of books were written on scientific topics which is half the proportion at the height of the Golden Age. This result provides some preliminary evidence against the importance of the Mongol invasions for the decline, as it precedes the invasions by roughly a century. Finally, there is little evidence of a sustained decline in the proportion of works written on scientific topics in the years following Columbus' voyage to the Americas. This result casts doubt on recent research stressing the role of European colonialism in bringing about the decline of scientific production in the medieval Islamic world.

To investigate the timing of this decline more formally, I limit the sample to authors who died on the interval [900,1799) and run a regression of the form:

$$\%Science_{th} = \gamma + \sum_{h \geq 1100} \beta_h D_h + \epsilon_{th} \tag{1}$$

where the variable $\%Science_{th}$ is the proportion of books written by authors who died in year t and in hundred year bin h on scientific topics and the D_h are century dummies. In table 1, I provide estimates of the β_h and the constant γ. Throughout unless otherwise stated, I provide results weighted by the number of books in each year as the point estimates in such a specification are equivalent to that obtained when running the regressions at the book level (i.e. the $\hat{\beta}_h$ are the proportion of all books held by Harvard written by authors on scientific topics who died in a hundred year bin relative to the omitted baseline).[13] In addition, throughout I present Newey-West standard errors allowing for the error structure to be heteroskedastic and autocorrelated up to seven lags. The results show that during the Golden Age (the omitted baseline of [900,1100)) twelve percent of books are on scientific topics. This drops to seven percent in 1100 and by 1700 has fallen to two percent. While these results provide evidence for a decline in scientific activity in the medieval period, they also provide empirical confirmation that science continued to be produced in the Islamic world long after the medieval period.

In column 2 of Table 1, I include the proportion of books written on religious topics. A book is classified as being on religion if it contains the string "Qur'an", "Muhammad", "Fatwa", "Sufi", "Hadith", "God", "Prayer" or "Law".[14] These results show that works on religion follow an almost opposite trend to those on scientific topics, increasing from thirty percent of intellectual output during

[13]While in my view such a specification is the most natural in this context, I show in the appendix that the results are robust to alternative weightings.

[14]I include the string "Law" given the religious nature of the legal system in the Islamic world historically.

the Golden Age to over forty percent in subsequent centuries.

While these results provide prima facie evidence for a decline in scientific production in the medieval Islamic world, there are a variety of hypotheses that are consistent with the results. In the following section I both explore the extent to which time-varying selection can explain the results as well as investigate the empirical relevance of the most influential hypotheses for the decline.

2 Why Does Scientific Output Decline? Potential Explanations

2.1 Time-Varying Selection

Can time-varying selection explain the results? Up until now I have maintained the assumption that Harvard's library collection provides a random sample of all works produced by authors who died in year t. Of course, one potential concern is that the results are simply representative of changes in the sampling scheme of Harvard libraries.

To fix ideas, consider the regression run at the book level (omitting those books written by authors who died before 900 CE):

$$s_i = \gamma + \sum_{h \geq 1100} \beta_h D_h + \epsilon_i \tag{2}$$

where i indexes books, and h denotes hundred year bins. In addition, define the dummy variable I_i equal to one if Harvard holds a book in its collection and zero otherwise. I henceforth assume that scientific books are measured without error for expositional ease.[15] Furthermore, and without loss of generality, assume that $E[s_i|t < 1100, I_i = 1] = \alpha E[s_i|t < 1100]$ and $E[s_i|h, I_i = 1] = \delta E[s_i|h]$ where I place no restrictions on α or δ aside from those necessary to keep $E[s_i|g, I_i = 1]$ on the unit interval. Then using standard arguments it is straightforward to show that

$$\text{plim}(\hat{\beta}_h) = \delta \beta_h + (\delta - \alpha) E[s_i|t < 1100] \tag{3}$$

Equation 3 shows that the only way one can get a spurious decline in scientific production is if $\delta < \alpha$, or if Harvard undersamples scientific works produced by authors after the Golden Age relative to the sampling regime in the Golden Age.

While there is little reason to believe that Harvard's library collections are consciously constructed to overweight scientific production during the Golden Age, it is possible that the library's collection is reflective of a spurious scholarly consensus. In other words, if scholars have assumed that there was a decline in scientific production after 1100 CE and have ignored studying scientific works after that date, then Harvard would contain a smaller proportion of scientific works after 1100 CE. In this case,

[15] This assumption is easily relaxed, and if the probabilities of not identifying a book on science and spuriously attributing a book to a scientific topic do not change over time in the observed sample the analysis is identical. As there is little reason to expect bias coming from measurement error to lead to spurious conclusions in this context, I henceforth abstract from this issue although I provide a more detailed discussion in the appendix.

however, any measured decline would be a reflection of this consensus and not an actual decline in scientific activity.[16]

I address this concern in two waves. First, in the spirit of Altonji et al. (2005), I examine how large time varying selection would have to be to completely explain away the results under the null that the true effect is zero. Plugging in the relevant point estimates yields (here I use the mode of the $\hat{\beta}_h$) $\delta = \frac{1}{3}\alpha$. To better understand the implications of this relationship in the sample, suppose that $\delta = 1$. Then results in table 1 imply that the change in the sampling regime would have to be roughly 8% of the Golden Age sample size (or Harvard including 358 too many books on scientific topics during this period) to completely explain away the results. One might expect such a sizeable change in the sampling regime to leave a trace in other observables around the observed decline in scientific output.[17]

In columns 3-7 of table 1, I show that there is little evidence of a systematic change in observables during the medieval period. In column 3, I show that the total number of books per year remains roughly stable at approximately 25 until the start of the 17th century when it significantly declines. In column 4, I show that the average number of books per author shows a similar pattern. Column 5 shows that the number of authors remains roughly constant around four per year throughout the sample, and column 6 shows that the proportion of authors for which I was unable to identify a place of birth or similar (see below for a description of the construction of these data) does not increase in a statistically significant manner until the fifteenth century. Finally, in column 7, I show that the proportion of all books that do not have a subject in the Harvard data base remains approximately constant at thirty percent until the seventeenth century.[18]

While these results cast some doubt on claims that the results are driven by time-varying selection, an alternative sample of intellectual production in the Islamic world from the seventeenth century has survived which enables a second investigation of the extent to which the results are spurious. This source is a biographical dictionary written by an Ottoman scholar named Hajji Khalifa (henceforth I will refer to this source as Khalifa) in the 17th century. This scholar was born in Istanbul in 1609 CE to a family with a military background.[19] From a young age, two large inheritances enabled him to pursue learning. He spent much of his life and these financial resources compiling the *Kashf al-Zunun* which is one of the most important sources of information on the intellectual history of the Islamic world. This work has been described as a "vast bibliographical dictionary" containing information on approximately 14,500 books written over a period spanning more than one thousand years (Chelebi,

[16]It should be noted, however, that there is no consensus on timing even among those who argue for a medieval decline of scientific production. Thus, while some argue that the decline begins around 1100 (e.g. Starr, 2013, p. 524), others stress that such a decline did not occur until the thirteenth century (e.g. Huff, 2003, p. 47).

[17]For example, if Harvard were carrying many copies of the same scientific work for Golden Age scientists this would appear in a greater number of books per author during the Golden Age.

[18]Whereas regressions whose output are in columns 1-6 are estimated on the sample of books with an identified subject, regression 7 is estimated on the entire sample. The regressions in columns 1,2 and 6 are weighted by the total number books with an identified subject in each year. The regressions in column 3 and 5 are not weighted, whereas that in column 4 is weighted by the total number of authors who died in each year. Regression 7 is weighted by the total number of books written by authors who died in that year. When weighted, these weighting are designed so that the regression output is equivalent to that obtained by running the regressions at the book or author level.

[19]See Abdulhak (1939) for an overview of Khalifa's life.

1656 [1957], p. 11).

While there is no guarantee that Khalifa provides a random sample of authors in each period, this source is arguably the best historical source available and has been trusted by generations of scholars. The available evidence suggests that Khalifa did his best to provide a comprehensive overview of both secular and religious intellectual production from the emergence of Islam until his day.[20] In compiling his source, Khalifa notes that he used previously-written biographical dictionaries which he supplemented with "thousands of volumes in the libraries I personally examined, and the books which for twenty years the book-sellers had been bringing to me in a steady stream" (Chelebi, 1656 [1957], pp. 143).

To an approximation, Khalifa can be seen as both updating and aggregating centuries of production of similar dictionaries. These dictionaries have been called "the greatest untapped source of information on the medieval Middle East"(Bulliet, 1970, p. 195) and served as a "who's who", enabling scholars to know the most important and trustworthy sources of knowledge in a given time period and locale. In the appendix I provide a further discussion of this data source and summary statistics.

From an empirical standpoint, this source is valuable because it is not subject to the same Western biases some blame for claims of a medieval decline of scientific production in the Islamic world. Given that this source seems most reliable for authors born prior to 1500, I henceforth limit the analysis to authors who died before this date using both the Khalifa and the Harvard datasets for expositional ease.

Unfortunately, Khalifa only reliably provides information on the title of the book, its author and a date (usually the author's death) and information on whether the book was derivative (i.e. a commentary on a previous work rather than an original work).[21] This metric is relevant given that many scholars have suggested that the decline of scientific production coincided with an increase in such derivative works (e.g. Bosworth et al., 2000, p. 136). While I discuss the link between the rise of derivative works and the decline of scientific production in greater detail in the discussion section, for the purposes of the empirical analysis I simply note that one line of scholarship links the decline of scientific production with the increase in derivative works.

In column 1 of Table 2, I show that the proportion of works that are denoted derivative by Khalifa jumps at the start of the 12th century. Thus, while during the Golden Age thirteen percent of works are recorded as commentaries, this has jumped to over forty percent by the fifteenth century. In columns 2-6, I investigate how other observables change in this data set over time to examine the extent to which there is evidence of time-varying selection. Columns 2 and 3 show that the number of books and books per author do not significantly change in the twelfth century. In column 4, I document that there is an increase in the number of authors in the sample over time, which suggests that Khalifa's results should be treated with some caution, although columns 5 and 6 show that there is no clear pattern in

[20]For example, Khalifa includes books written by the "atheist" Ibn al-Rawandi (e.g. Khalifa, 1657 [1835], p. 488).

[21]I also attempted to construct the subject of the book by title and information given by Khalifa. Given the significant measurement error inherent in such an exercise in addition to evidence that Khalifa was systematically underciting authors who wrote on scientific topics (as shown below), it is perhaps not surprising that results using these data are largely statistically insignificant although the point estimates of β_h in equation 1 are generally negative after 1100.

the proportion of authors without a profession or place of birth identified.[22]

When taken in unison, the results cast doubt on the possibility that time-varying selection in the Harvard library collections can explain the results. First, there is no sign of systematic changes in measurable observables in the Harvard data set around the start of the decline in scientific output. Second, an alternative data source from seventeenth century Istanbul provides evidence for an increase in the proportion of derivative works that coincides with the decline in scientific production in the Harvard data set. Although there is no guarantee that Khalifa's data are not subject to biases caused by time-varying selection it is unlikely that both the Harvard and Khalifa datasets are subject to the same time-varying biases. When taken in unison, then, I conclude that the results weigh against the hypothesis that the decline in scientific production is an artifact of time-varying selection.

2.2 Regional Variation: Crusades and Mongol Invasions

Up until now, I have treated the Islamic world as one, abstracting from potential regional variation and the fact that the borders of the Islamic world were changing over time. In this section, I explore the extent to which there is regional variation in the data. To do this, I georeferenced the birthplace of every author in the Harvard data set. I first looked up the author in both Google and the Encyclopedia of Islam, located his birthplace and then obtained the latitude and longitude of the place of birth.[23] Of the 3457 authors who died on the interval [900,1799), I was able to locate the birthplaces of 1759 authors.[24]

A map showing the location of birth for all geo-referenced authors in the Harvard data set is presented in figure 3. In this figure, larger circles denote more books written by authors born in that locale. In general, the patterns confirm much of the conventional wisdom regarding the location of intellectual activity in the pre-industrial Islamic world. Islamic Iberia, Egypt, the fertile Crescent and the areas corresponding to the pre-Islamic Iranian Empires all emerge as important centers of intellectual production.

In the geo-referenced analysis, I create three geographic regions. The first is what I call the "West" which includes modern day Algeria, Italy, Libya, Mali, Mauritania, Morocco, Portugal, Spain, Tunisia and Western Sahara. The second is what I call the "Levant" which is broadly speaking the area most likely to have been affected by the Crusades. This includes the Arabian Peninsula, Egypt, Ethiopia, Israel (with the West Bank and Gaza), Jordan, Syria and Somalia. The third and final region is what I refer to as "Iran" which was the area most likely to have been affected by the Mongol invasions and includes modern day Afghanistan, Azerbaijan, Georgia, Iran, Iraq, Kazakhstan, Kyrgyzstan, Russia,

[22]The regressions in columns 1,5 and 6 are weighted by the total number books written by authors that died in each year. The regressions in columns 2 and 4 are not weighted whereas that in column 3 is weighted by the total number of authors. Again, when weighted the weightings are designed so that the regression output is equivalent to that run at the book or author level.

[23]These latitudes and longitudes were drawn primarily from the website www.latlong.net or Kennedy and Kennedy (2011).

[24]For some authors, the birthplace was unknown but the place of death or where the author worked was available. When this was the case, I used these alternative locations.

Tajikistan, Turkmenistan and Uzbekistan. I omit the remainder of observations in an attempt to maintain the geographic boundaries roughly constant as most of the omitted areas were incorporated into the Islamic world significantly later than these "core" regions.[25]

To examine the extent to which the timing of the decline varies by geographic region, I run the generalized differences-in-differences specification:

$$\%Science_{rth} = \gamma_r D_r + \sum_{h \geq 1100} \beta_h D_h + \sum_{r \neq Iran} \sum_{h \geq 1100} \beta_{rh} D_r D_h + \epsilon_{rth} \tag{4}$$

where the variable $\%Science_{rth}$ is the proportion of books on scientific topics written by authors born in region r who died in year t and in hundred year bin h, the D_h are century dummies and the D_r are region dummies. In regression 4, the β_h measure the evolution of scientific production with respect to the omitted period [900,1100) CE for Iran whereas the β_{rh} compare the relevant change in scientific production in region r with the change over the same period in the omitted region of Iran. The γ_r provide the proportion of works written on scientific topics during the Golden Age in each of the regions. As above, throughout Newey-West standard errors allowing for 7 lags are presented and the regressions are weighted by the number of observations in each year.

In column 1 of table 3, I begin by presenting the results from equation 1, restricting the sample to the union of the Iran, Levant and Western regions. The results are almost identical to those in table 1, providing reassuring evidence that whether or not I was able to geo-reference an author can be treated as random for the purposes of this paper. In column 2, I provide estimates of the β_h whereas columns 3 and 4 provide the β_{rh}. The γ_r are presented in the row labeled "Constant." These results show that the decline in scientific activity starting in the twelfth century is strongest in Iran and the point estimates suggest that this decline does not reach the West until the fourteenth century, although only the difference in the twelfth century is statistically significant at conventional levels. As I explain in the discussion section below, this empirical result is consistent with the timing of the spread of madrasas from east to west. Note, however, that the large standard errors on the interaction terms often make it difficult to pinpoint differences by region.

In columns 5-8 of table 3, I present identical analysis using the proportion of works written on religious topics as the dependent variable. Again, the point estimates suggest that in the twelfth century an increase in the proportion of works dedicated to religious topics begins first in Iran, although these regressions suffer from even more severe power limitations than the previous ones, making it difficult to say much about the geographic distribution of the rise in the production of religious works.

While these regressions provide little evidence of significant geographic differentiation in the decline of scientific production, these data can also be used to examine the geographic distribution of authors over time. Although a relative decline in one region does not necessarily denote absolute decline, as a relative decline could denote the rise of another region, presumably long-lasting effects from major shocks such as the Mongol invasions or the Crusades would show up in the data to the extent they

[25] In the appendix, I show that the weight of these regions during the Golden Age was minimal.

existed. In figure 4, I plot the moving averages for the three region dummies over time.[26] The dominance of Iran prior to the collapse of the Abbasid Caliphate's temporal power in 945 is clear as is its collapse roughly around the start of the Mongol invasions in 1219.

There are relatively few thinkers from the Levant until the roughly the thirteenth century and the rise of the Levant seems to begin with the Mongol invasions. This result casts doubt on the importance of the Crusades in explaining the decline as the Levant -the area most likely to be affected by the Crusades- was generating a minimal proportion of the Islamic world's intellectual output prior to the start of the Crusades. Finally, there is a rise and fall of the Western Islamic world that seems to roughly correspond to the historical flowering of scientific production in Islamic Iberia and its subsequent conquest by Christian forces.

In columns 1-3 of table 4, I investigate these patterns in a more formal pattern by running equation 1 three times, limiting the sample to books written by authors who I identified as being from the union of Iran, West and Levant areas with the proportion of authors born in each region each year as the dependent variable. The relative decline of Iran in the thirteenth century and the rise of the Levant region after the fourteenth century is confirmed by this more formal analysis although the rise and fall of the Western Islamic world is not statistically significant.

In columns 4-6 of table 4, I perform the same exercise using Khalifa's data. The results are qualitatively almost identical to those obtained using the Harvard data, with the exception of the relative decline of the Western Islamic world in the fifteenth century which may be driven by the fact that works written in this region had not reached Istanbul by the time Khalifa was compiling his work in the seventeenth century. As above, the fact that results obtained using both Harvard and Khalifa's collection mirror each other increases confidence that the relative decline of Iran coinciding with start of the Mongol invasions is real.[27]

Are these results consistent with the importance of the Crusades and Mongol invasions for the decline of scientific production in the medieval Islamic world? Although there is little evidence that the Crusades had long-run effects, the results suggest that the Mongol invasions of the thirteenth century led to the long-lasting relative decline of the Iranian regions. However, the invasions come too late to explain the start of the decline of scientific production in Iran which began in the twelfth century. Moreover, the decline spreads to areas that were not directly affected by the Mongol invasions. In this sense, I conclude that this evidence is not consistent with the claim that the Mongol invasions are the fundamental cause of the decline in scientific production documented above, although they do not rule out the possibility that these invasions contributed to and perhaps solidified pre-existing trends in the Iranian regions.

[26] For each year y I regress the proportion of books written by authors born in a region who died in year y on a constant for observations in the interval [y-100,y) and weight each year by the number of books written by authors that died in that year. Thus, each coefficient represents the proportion of all books written by authors from a given region who died on the interval [y-100,y).

[27] Furthermore, these results roughly coincide with those obtained by Bulliet (1979, pp. 7-9) from an additional historical source, increasing still further confidence in the validity of the results.

2.3 Sunni Revival

The results in the previous section provide evidence that scientific production declined in the medieval Islamic world and that this decline became statistically significant in the 12th century. In addition, the results cast doubt on the claim that the Crusades, Mongol invasions or European colonialism caused this decline. Among the most popular explanations for the decline in scientific production in the medieval era, only the empirical relevance of the "Sunni Revival" hypothesis remains to be examined. In this section I investigate the extent to which the available data are consistent with the empirical implications of this hypothesis.

Madrasas are thought to have represented one of the major institutional innovations of the Revival. For example, Chamberlain (1994, p. 69) notes that "[s]cholars have generally believed that the appearance of madrasas in the high medieval Middle East transformed higher education" and Gilbert (1980, p. 106) claims that "the institutionalization of Muslim scholarship [e.g. madrasas], and the professionalization of [religious leaders...] mark a significant change in Islamic social structure and Muslim community life."

In column 1 of table 5, I provide evidence consistent with a twelfth century increase in the proportion of authors affiliated with madrasas. To proxy for the extent to which a scholar was involved with a madrasa, I first look up every individual in the Harvard sample in the Encyclopedia of Islam.[28] Using a web grabber, I then download the entire Encyclopedia of Islam entry for each scholar and construct an indicator variable equal to one if the word "madrasa" (upper or lower case) is mentioned in an author's entry. Results in column 1 are obtained from estimating equation 1, with the proportion of books written by authors with the word madrasa in their biography as the dependent variable. These results show that while during the Golden Age 4 percent of books were produced by authors whose biographies contained the word madrasa, this proportion had jumped to over 40% by the 14th century.

If the institutional changes that accompanied the Revival marked a "significant change in Islamic social structure and Muslim community life" (Gilbert, 1980, p. 106) that caused the observed decline in scientific production, one might expect to be able to find a break in the trend of scientific production that roughly corresponds to the start of the Revival. To examine the extent to which this is the case, I include all observations on the interval [250,1799) and begin by allowing for only one break in the specification:

$$\%Science_t = \gamma + \beta_1 D_t(\tau) + \beta_2 t + \beta_3 t D_t(\tau) + \epsilon_t \tag{5}$$

where $\%Science_t$ is defined as above and $D_t(\tau)$ is a dummy variable equal to one if $t > \tau$. Equation 5 allows for one break in which there is both a mean and a slope change. I use 15% trimming and find that the F-statistic testing the null-hypothesis that both β_1 and β_3 are zero is maximized in the year 1016 when weighting observations by number of books. In this year, the F-statistic is 5.77 which is well above the 10% cutoff of 5 and just shy of the 5% cutoff of 5.86. When I do not weight by number of books, I find that the F-statistic is maximized in the year 1074 although the relevant test statistic is

[28]The online version of the Encyclopedia of Islam can be found here: $http://referenceworks.brillonline.com$.

not significant at conventional levels.

In addition to allowing for only one break, I use the framework developed in Bai and Perron (1998, 2003) to allow for multiple breaks.[29] In particular, I allow for a maximum of 5 breaks (6 regimes) in the regression:

$$\%Science_t = \gamma_j + \delta_j t + u_t \qquad t = T_j - 1 + 1, ..., T_j \tag{6}$$

where j=1,...,6 and I use 15% trimming. The sequential procedure finds one break in 1137 with the 95% confidence interval ranging from 1094 to 1175.[30] While this wide confidence interval highlights that the point estimates should be treated with some caution, it is heartening that the point estimates from all three trend-break specifications fall in the eleventh and twelfth centuries as this period broadly corresponds to that in which the institutional changes that accompanied the Revival began to take root.

The Revival hypothesis also implies that individuals working on scientific topics switched to being primarily religious scholars as opposed to physicians or philosophers during the Golden Age (Sabra, 1987). Sabra (1987, pp. 241-242) suggests that by limiting the extent to which those interested in science worked on these subjects, the incorporation of science into the religious institutions that emerged during the Revival played an important role in generating the decline of scientific output in the medieval period.

In columns 2 and 3 of Table 5, I provide some evidence in support of this view. In these regressions, I limit the sample to individuals who wrote at least one book on a scientific topic and then estimate equation 1 on this reduced sample for the proportion of scientific and religious works produced in each year. These results show that those writing on scientific topics were dedicating a larger proportion of their works to religious topics and less to scientific ones after 1100.

Some studies imply that after the Golden Age, the scientific production that did occur did not widely circulate. In columns 4 and 5 of table 5 I investigate this hypothesis with the Khalifa data by creating an index of "undercitation" ($UnCit_i$) which is the number of books Khalifa lists for an author minus the number of books Harvard holds for an author.[31] I then examine the extent to which Khalifa is underciting scientists by estimating the regression:

$$UnCit_i = \gamma_h D_h + \sum_h \beta_h D_h * Scientist_i + \epsilon_i \tag{7}$$

Column 4 presents the γ_h which are the mean of the dependent variable UnCit by hundred year bins

[29] As their algorithm does not allow for weights, I only present the unweighted results here.

[30] From a technical standpoint, I apply AR(1) pre-whitening prior to estimating the long run covariance matrix, allow the moment matrices of the regressors to be different across segments but restrict the variance of the residuals to be constant across segments. In addition, the UDmax test statistic is 10.19 which is significant at the 10% level. See Bai and Perron (2003) for details.

[31] I use the Harvard data set as the baseline and match the Khalifa data by author name. In other words, the sample size is determined by the Harvard data set. In addition, I assign the value zero to the Khalifa data for Harvard authors that I could not match.

for non-scientists.[32] This column shows that Khalifa has fewer books written by non-scientists than Harvard does. In column 5, I present the β_h, or the differences in the mean of UnCit between scientists and non-scientists by century.[33] In the row labeled p-value I provide the p-value for the null hypothesis that the β_h are jointly equal to zero. These results show that Khalifa systematically included fewer books for scientists for the majority of the period covered by the data. I conclude that these regressions provide some evidence that in seventeenth century Istanbul at least, it was differentially more difficult to access the works of authors who worked on scientific topics.[34]

Finally, in column 6 of table 5 I examine how the proportion of books written by authors that Khalifa identifies as belonging to the bureaucracy (i.e. those identified as a secretary or *katib*) changes over time. I do this because the Revival is believed to have coincided with the final disintegration of this bureaucracy and its replacement with religious elites.[35] The results are consistent with this hypothesis, and show that after the Golden Age there are fewer books written by authors identified as secretaries.

3 Discussion

Although the results are consistent with the Revival hypothesis, questions regarding the Revival's timing, causes and the mechanisms through which it led to the observed decline in scientific activity remain to be explored. In this section, I investigate these issues by focusing on two of the most prominent explanations for the Revival. Where possible, I assess the extent to which the data are consistent with the empirical implications of these explanations.

3.1 Political Instability and the Rise of Mystical Islam

One view attributes the Revival to an increase in religiosity driven by a decrease in political stability during the eleventh century (e.g. Hodgson, 1974, p. 202).[36] This surge in religiosity is believe to have manifested itself, at least in part, through an increase in the practice of mystical Islam (Sufism). In columns 7 and 8 of table 5, I examine the empirical relevance of this hypothesis. In column 7, I provide output from equation 1 with mean ruler duration -which I argue is a proxy for political stability- as the dependent variable.[37] In column 8, I provide evidence that the proportion of books containing

[32]This regression is not weighted.

[33]I defined scientists as authors who have at least one work on a scientific topic in a Harvard library. In addition, in this regression I cluster standard errors by the author's year of death.

[34]An alternative explanation is that Khalifa's personal preferences led him to systematically undercite scientists. The fact that Khalifa seems to be attempting to provide a comprehensive overview of intellectual production as well as the fact that he includes a significant number of books on scientific topics weighs against this hypothesis.

[35]For example, the article on *katib* in the second Encyclopedia of Islam notes that with the Revival the function of the *katib* "merge[d] with that of the [religious leaders]" and that during this period religious elites "came to fulfill functions previously reserved for the [secretaries]." See the following section for an additional discussion.

[36]Traditionally, some scholars claimed that the religious thinker al-Ghazali (1058-1111) single-handedly dealt a death-blow to scientific inquiry through his writings. However, given that Ghazali was writing during the start of the Revival, many have noted that these societal changes are likely the fundamental cause of the decline of scientific activity (for a discussion of these issues see, for example, Montgomery Watt's entry on al-Ghazali in the second Encyclopedia of Islam).

[37]These data are drawn from Blaydes and Chaney (2013), see that article for a discussion of the relationship between political stability and ruler durations. In addition, these regressions are weighted by the number of rulers that began

the string "Sufi" in the subject jumps in the twelfth century. This result is consistent with studies arguing that a rise in mysticism accompanied the decline of scientific production in the Islamic world (e.g. Dallal, 2010, p. 154).

While these results provide evidence for a decrease in political stability during the medieval period, this decline does not become significant until the 13th century. Given that it post-dates the surge in Sufi works by a century, I conclude that these results cast some doubt on hypotheses attributing the Revival to an instability-driven surge in mysticism. In addition, I provide evidence below that the rise of mysticism may have been a product of the empowerment of religious leaders during the Revival.

3.2 Surge in the Political Power of Religious Leaders

The Revival has been defined as a "religious revival in which the forces of Traditionalism fought against the forces of Rationalism of all shades" (Makdisi, 1973, p. 157). The split between Traditionalism and Rationalism goes back to the first centuries of Islam. Whereas traditionalism stressed the importance of the use of revealed sources such as scripture and the sayings and deeds of the prophet Muhammad and his close associates and followers, rationalism argued for the importance of the use of reason in defining Islamic law.

During the first centuries following the Arab conquests, religious leaders worked to define Islamic law. This law was primarily traditionalist and developed largely independently of the state. As Islamic law gained influence, representatives of the state bureaucracy urged the Caliphs to incorporate this budding state-within-a-state into state structures (e.g. Hallaq, 2005, p. 184).[38] Many authors have argued that the Abbasid inquisition -which required all religious leaders to adopt rationalist interpretations of Islam-was an attempt to achieve this goal (e.g. Nawas, 1994). In the following century the Abbasid Caliphate rapidly disintegrated, losing all direct power when Baghdad was militarily occupied by a Shi'a military regime known as the Buyids in 945 CE. While this successor dynasty continued to support the use of reason and patronize the sciences, by the start of the eleventh century there was evidence of a "growing swell of support for Sunni traditionism" in Baghdad (Kraemer, 1986, p. 63).[39]

This growing support for Tradionalist veins of Islam is thought to have found its first institutional expression following the collapse of Shi'a dynasties across the Islamic world in the eleventh and twelfth centuries. Existing scholarship has primarily focused on the rise of madrasas, although this process included other institutional innovations and has been characterized as marking the professionalization of Muslim religious leaders (e.g. Gilbert, 1980). This professionalization is believed to have marked the final disintegration of pre-Islamic bureaucratic structures and their replacement with a religious bureaucracy in which religious leaders performed many of the functions traditionally carried out by state bureaucracies (e.g. Gibb, 1982, p. 22). The timing of these changes is linked to the surge in

their rule at the start of a given year.

[38]One line of scholarship has viewed the emergence of Islamic law as part of an attempt by religious leaders to place greater constraints on the sovereign (e.g. Hodgson, 1974, p. 119).

[39]The trends followed in Baghdad seem to have been eventually followed in other areas of the Islamic world. Thus, after the fall of the Caliphate most areas were dominated by Shi'a dynasties which were replaced, in turn, by Sunni regimes that adopted Revival institutions.

popular support for Muslim religious leaders who were henceforth "sought after by government officials and men of wealth and influence as one of the surest instruments for the control of the masses"(Makdisi, 1961, p. 53).[40]

The institutional changes of the Revival limited the study of scientific topics and encouraged the production of religious and mystical works.[41] For example, madrasas did not focus on teaching scientific topics and with their advent institutions in which scientific topic were studied "began to fade away, becoming extinct by the sixth/twelfth century" (Makdisi, 1981, p. 10). In addition, scholars who wished to be appointed to these newly endowed posts had to specialize in the production of religious knowledge (Makdisi, 1981, p. 285). It is generally believed that this shift of state and private patronage to religious leaders came at the expense of science.[42]

Why did religious leaders seek to limit the study of scientific topics? The available evidence stresses that these leaders believed that the unrestrained study of scientific topics weakened their societal influence. Thus, al-Ghazali (1058-1111), one of Islam's most renowned religious scholars, noted that "he who studies mathematics is amazed by its precision and proofs. He then takes a more positive view of philosophy and reckons that all of the rational sciences are as clear and trustworthy as mathematics [...] and he says: if religion were true, then philosophers would have proved its veracity with their precise methods [...] we have seen many deviate from [Islam] in this manner" (al-Ghazali, 1971, pp. 21-22).[43] The solution such leaders proposed to this "problem" was to limit scientific enquiry to areas that would not engender such doubts. Analysis in Sabra (1987, pp. 240-241) suggests that these leaders were largely successful as after the Revival "an instrumentalist and religiously oriented view of all secular and permitted knowledge" emerged where scientific research was constrained to "very narrow, and essentially unprogressive areas" (Sabra, 1987, pp. 240-241).

I hypothesize that one reason that science thrived during the Golden Age was because Muslim religious leaders faced significant constraints on their power. The available evidence suggests that during the Golden Age religious diversity played a central role in limiting the political power of any given group. In other words, religious authority was too fractionalized for any given leader to exert enough power to force political leaders to implement their preferred policies.[44] This hypothesis implies that the surge in the political power of religious leaders was a product of the achievement of religious conformity as local populations converted to Islam and as Sunni Islam emerged as the dominant sect.

[40]Even today, scholars have argued that religious leaders can "rent out" their networks in this manner (e.g. Murphy and Shleifer, 2004)

[41]For the link between the traditionalist religious leaders empowered by the Revival and mysticism, see Makdisi (1973, p. 161).

[42]Qualitative evidence from a market inspector in fourteenth century Egypt supports this claim. This market inspector attributes the small number of Muslim physicians in his day to the fact that "by medicine there is no access to judgeships [which required expertise in Islamic law]" (Ibn al-Ukhuwwa, 1329 [1938], p. 57).

[43]Consistent with this view, Stroumsa (1999) provides examples of the deist/atheist figures that emerged during the Golden Age. Also, see Glaeser and Sacerdote (2008) for evidence of a negative relationship between religious beliefs and human capital formation.

[44]There is some qualitative evidence consistent with this view. For example, around 903 CE, Ibn al-Faqih al-Hamadani noted that "In Baghdad opponents of the Shi'ites live together with the Shi'ites, opponents of the Mu'tazilites together with the Mu'tazilites, and opponents of the Harigites together with the Harigites; each group holds the other one in check and prevents it from setting itself up as leader" (cited in Gutas, 1998, p. 190).

Historians such as Hodgson (1974, p. 192) provide support for this view noting that "with the advent of substantial unity of allegiance in a population turned predominantly Muslim, the tendency [...] to enforce conformity in opinions became strong." Thus, in addition to a decline in scientific production, the Revival witnessed a "fervent opposition to innovations" (Berkey, 2003, p. 202) and an increase in the proportion of intellectual works that were derivative and thus safe from accusations of innovation.

A complementary hypothesis stresses the effect that the conversion of local populations to Islam had on the preferred policies of religious leaders. Chaney (2011) provides evidence that religious leaders during the Golden Age often favored rational methods despite their potentially subversive effects in order to better compete in the market for converts that had emerged in the eighth century.[45] This hypothesis implies that once Islam emerged as the dominant religion not only did religious leaders become more politically powerful but their preferred policies changed.

The available evidence supports the claim that the Revival roughly corresponds with the emergence of an Islamic majority in Iran and Iraq (e.g. Lapidus, 2014, p. 224). Interestingly, the spread of the Revival institutional complex from east to west also appears to line up with the later emergence of Islamic majorities in these western regions (Bulliet, 1979).[46] Such patterns suggest that the institutions of the Revival were the consequence of societal changes related to the conversion of local populations and were not a reflection of Turkic institutions (Gibb, 1982, p. 26).[47]

To the extent that this narrative is correct, it suggests that the political empowerment of Muslim religious leaders is a proximate cause of the decline of scientific production in the Islamic world. One line of scholarship relates this empowerment to the militarization of Islamic societies following the introduction of slave armies centuries earlier (e.g. Hodgson, 1974, p. 135).[48] The introduction of these slave armies is thought to have eventually led to the destruction of pre-Islamic secular elites. Thus, once religious diversity diminished due to conversion to Islam, Islamic religious leaders emerged as the primary domestic political interest (e.g. Lapidus, 2014, p. 224).

Of course, given the natural data constraints involved in such a study it is impossible to completely rule out all possible alternative explanations for the Revival. It remains, however, that to my knowledge such alternatives have not found favor among historians. Consequently, I conclude that the historical narrative developed in this section fits both the available facts and existing scholarship most closely.

[45] During the Golden Age, debates based on logical methods often emerged between representatives of different religions (e.g. al-Andalusi, 1095 [1997], p. 96). While the extent to which performance in these debates affected conversions to Islam remains a topic of ongoing research, Gutas (1998, p. 63) hypothesizes that the translation movement was motivated, at least in part, by the desire to aid Muslims in the growing number of such inter-faith disputations.

[46] For information regarding the spread of madrasas from east to west see Shatzmiller (1976) or Sourdel (1976).

[47] This is because Turkish rule never reached the Western Islamic world in the medieval period.

[48] In the middle of the ninth century CE, the Abbasid Caliphs began to staff their armies with foreign-born slaves. This practice soon became widespread across the Islamic world. See Blaydes and Chaney (2013) for a detailed treatment of the emergence and spread of this practice.

4 Conclusion

In this paper I have provided evidence that scientific production declined in the medieval Islamic world. The available data suggests that this decline became statistically significant by the twelfth century.

What explains this decline in intellectual production? Based on historical evidence, I have hypothesized that during this period there were a series of institutional changes that decreased the relative payoff to producing scientific works. Among these institutional changes, the spread of madrasas across the Islamic world offered lucrative posts to individuals who excelled in producing religious knowledge. As the relative payoff of producing religious knowledge increased, thinkers across the Muslim world produced more such knowledge. Presumably, religious leaders tailored institutions to reward the production of religious knowledge because they preferred intellectual production to be more heavily weighted towards such topics and less towards scientific topics. Consistent with Mokyr (2002, p. 251), I have argued that religious leaders preferred this weighting because they believed that the unrestricted study of scientific topics reduced their societal influence.

Some evidence suggests that the fragmentation of political power in Europe may have been instrumental in generating more enduring constraints on European religious elites relative to those faced by Islamic religious leaders after the Golden Age (Ben-David, 1965; Mokyr, 1994; Landes, 1998, p. 52). While examining the extent to which this is true remains a topic for future work, recent research (Blaydes and Chaney, 2013; Chaney, 2012, 2013) suggests that a deeper understanding of these political developments may shed light on the reasons behind the abnormal rates of human capital accumulation in Europe in the run-up to the Industrial Revolution.

In closing, I note that the analysis in the paper suggests important interactions between institutions, culture and human capital that seem fruitful areas for future research. I have proposed that religious leaders, like any elite, will rent-seek unless otherwise constrained. I have implicitly suggested, however, that religious leaders are unique in that their rents rest on control over what their followers believe. While this paper stresses the importance of the actions of religious leaders in the political sphere, it is difficult to understand their actions in the absence of their quest to control beliefs. In this sense, the results suggest that better understanding the institutional framework in which religious leaders operate may help explain why certain religions historically supported human capital accumulation to a greater extent than others. Finally, the results suggest that the collections of major university libraries can be fruitfully used to investigate the historical evolution of intellectual production.

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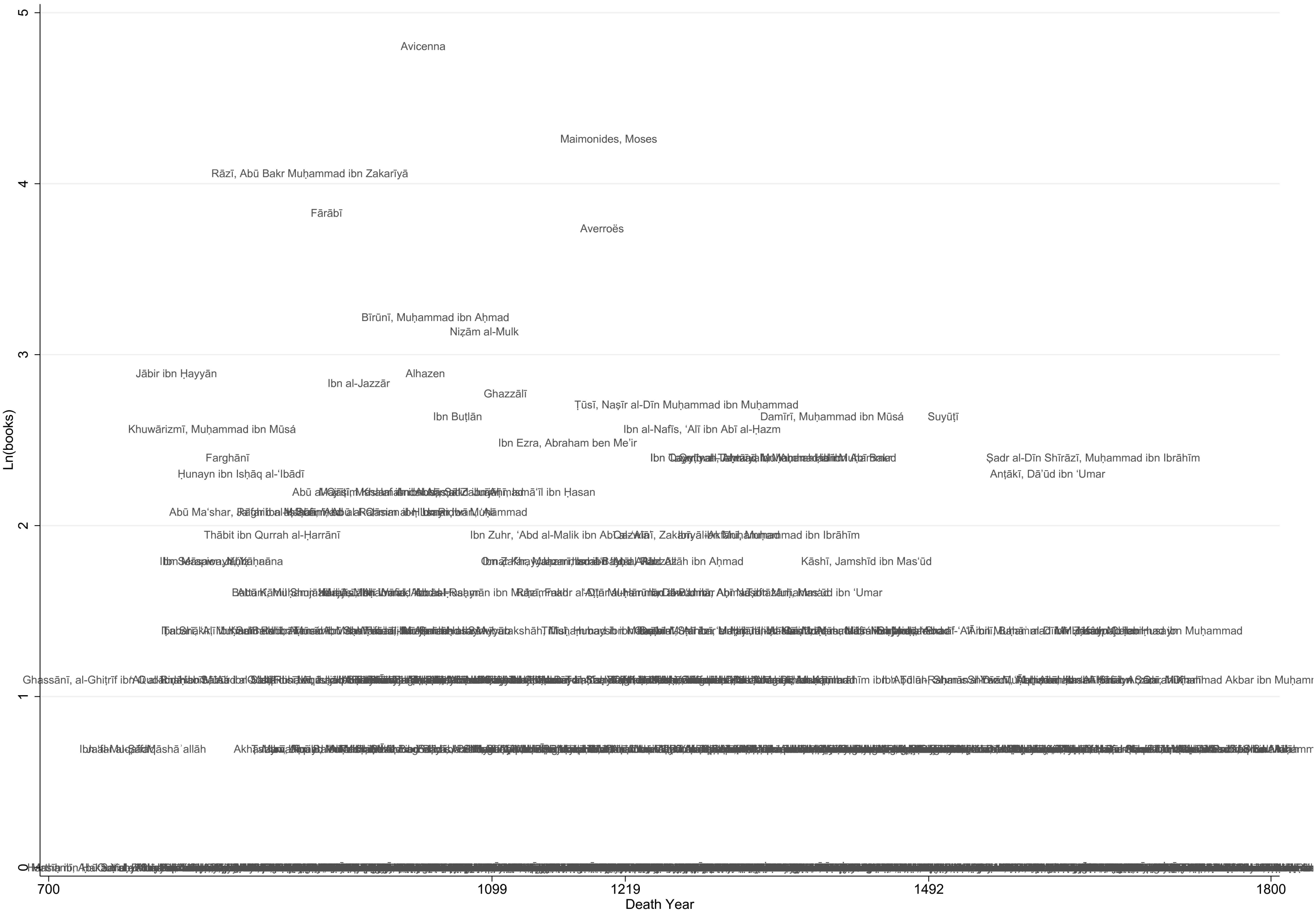

Figure 1: **Books By Author (Scientists) 700-1800 CE**

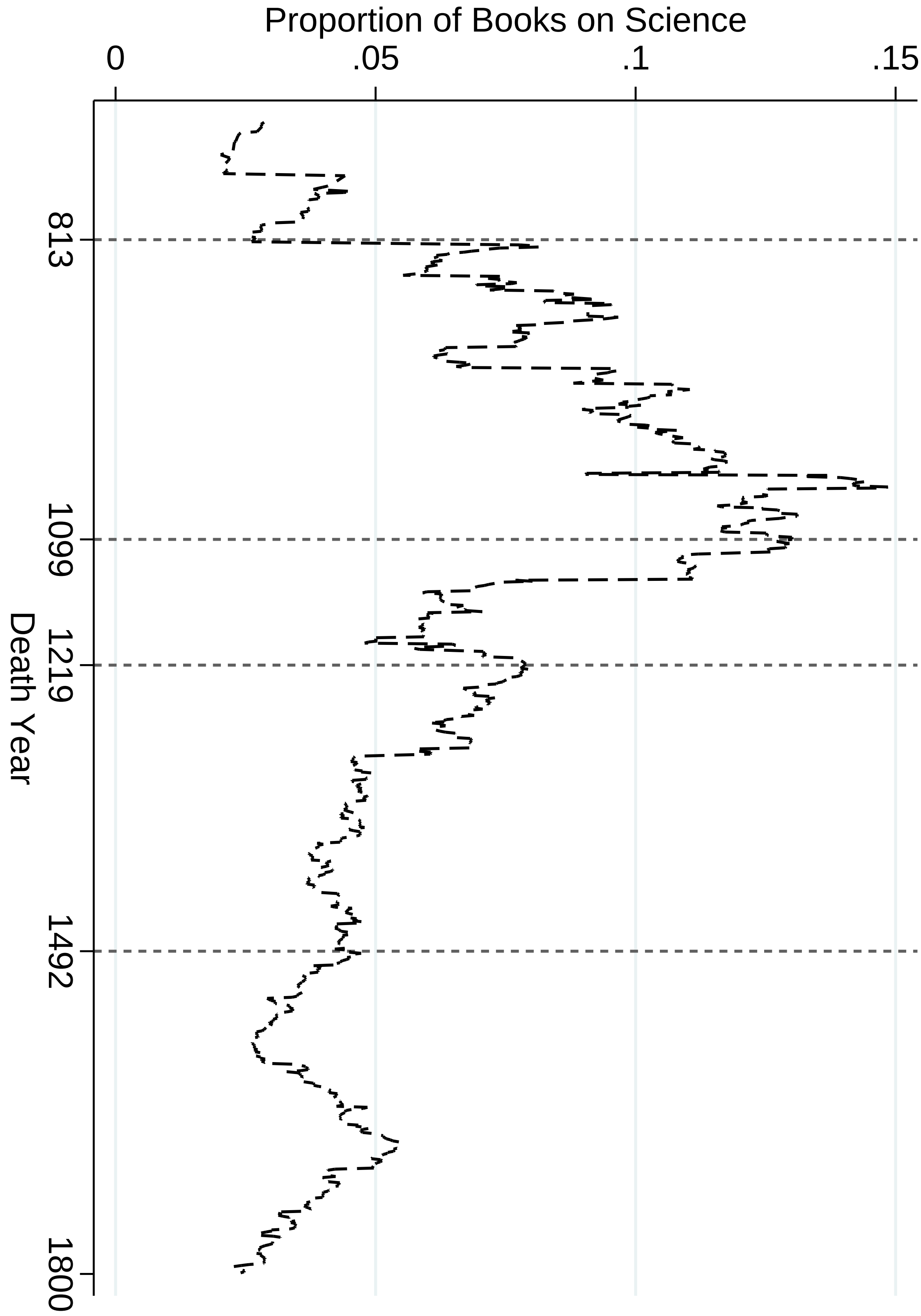

Figure 2: **The Rise and Fall of Islamic Science 700-1800**
100-year rear moving average

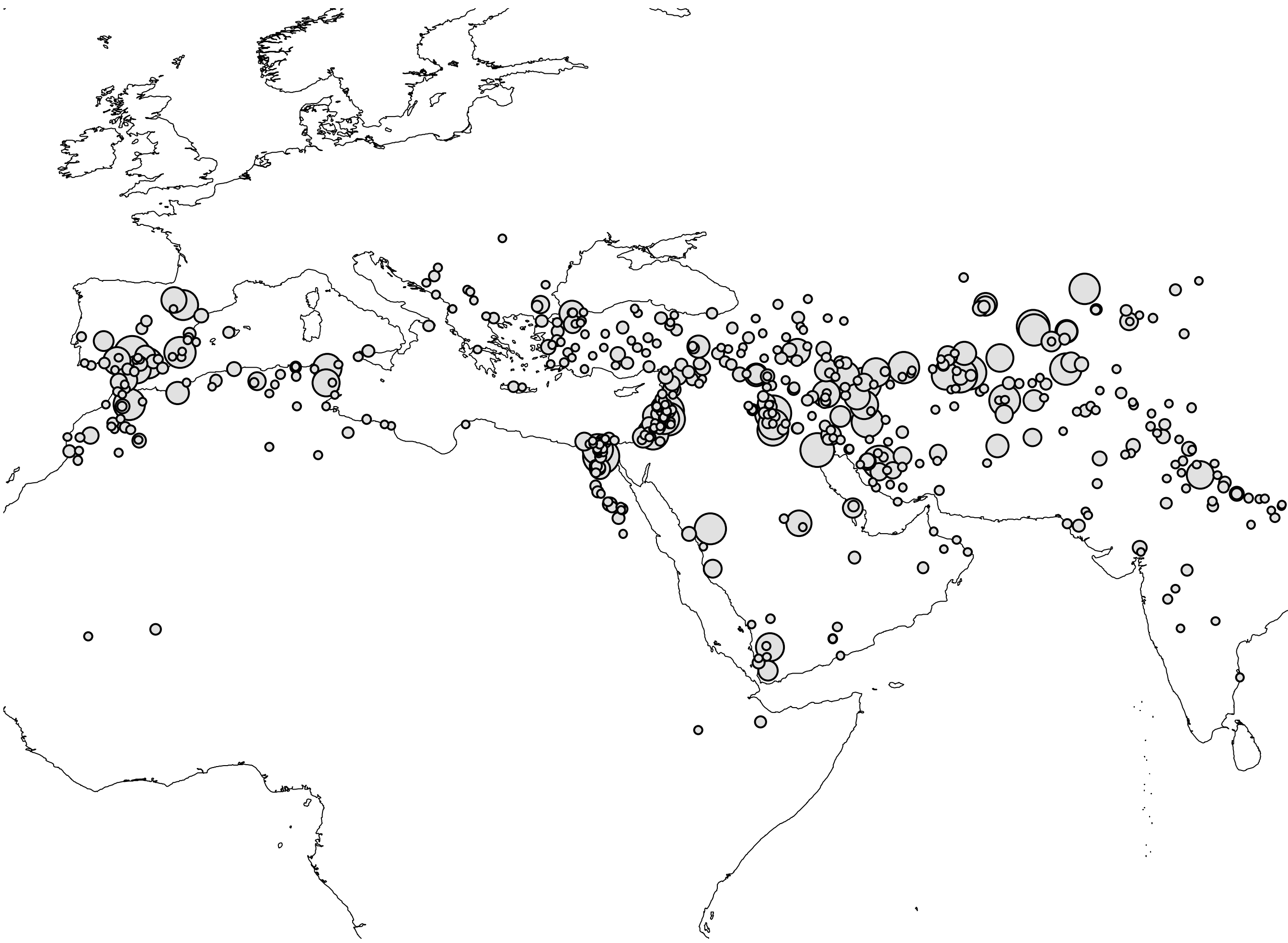

Figure 3: **Centers of Intellectual Production 700-1800**
Larger Circles Denote More Books Written by Authors Born in Location

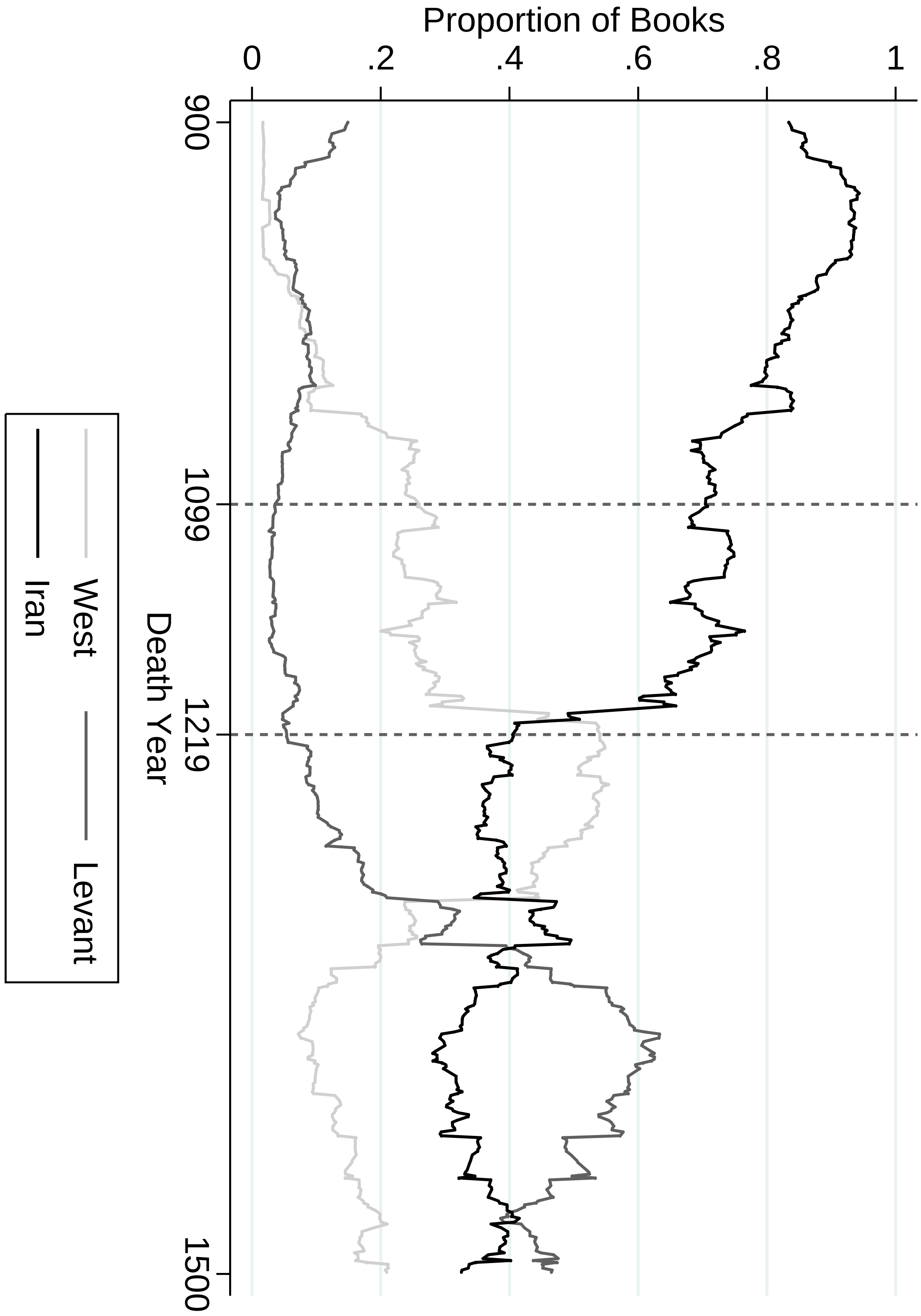

Figure 4: **Location of Books over Time 900-1500**
100-year rear moving average

Table 1: **The Decline of Scientific Production in the Islamic World: 900-1800 CE**

	Relative to Average on the Interval [900, 1100)						
	%Sci	%Rel	Books	Books2	Authors	NoPlace	NoSub
	(1)	(2)	(3)	(4)	(5)	(6)	(7)
[1100, 1200)	-0.05*	0.05	-0.78	0.15	-0.20	-0.04	0.06
	(0.03)	(0.04)	(5.29)	(1.63)	(0.57)	(0.05)	(0.07)
[1200, 1300)	-0.06**	0.12**	10.34	1.47	0.60	-0.05	0.02
	(0.03)	(0.06)	(8.89)	(2.09)	(0.56)	(0.05)	(0.04)
[1300, 1400)	-0.08***	0.13***	5.94	0.73	0.44	-0.01	-0.01
	(0.03)	(0.04)	(6.40)	(1.24)	(0.58)	(0.04)	(0.03)
[1400, 1500)	-0.07***	0.17***	-5.83	-1.69**	0.13	0.11**	0.02
	(0.03)	(0.05)	(3.94)	(0.80)	(0.67)	(0.05)	(0.03)
[1500, 1600)	-0.08***	0.12***	-6.51	-1.56	-0.12	0.10	0.05
	(0.03)	(0.04)	(5.21)	(1.42)	(0.58)	(0.08)	(0.03)
[1600, 1700)	-0.08***	0.08*	-8.92***	-2.90***	0.61	0.12**	0.11***
	(0.03)	(0.05)	(3.02)	(0.76)	(0.70)	(0.05)	(0.03)
[1700, 1800)	-0.10***	0.09**	-10.27***	-3.24***	0.67	0.18***	0.11***
	(0.03)	(0.04)	(2.95)	(0.68)	(0.57)	(0.06)	(0.03)
[900, 1100)	0.12***	0.30***	24.55***	6.42***	3.82***	0.20***	0.32***
	(0.03)	(0.03)	(2.57)	(0.58)	(0.34)	(0.03)	(0.02)
N	850	850	850	850	850	850	874

Notes: Regressions in columns 1-6 are estimated on the sample of books with an identified subject whereas the regression in column 7 is estimated on the entire sample. The regressions in columns 1,2 and 6 are weighted by the total number books with an identified subject in each year. The regressions in column 3 and 5 are not weighted, whereas that in column 4 is weighted by the total number of authors. Regression 7 is weighted by the total number of books written by authors who died in that year. Newey-West standard errors allowing for the error structure to be heteroskedastic and autocorrelated up to seven lags are presented in parentheses. ***, **and *indicate significance at the 1%, 5% and 10% levels.

Table 2: **The Rise of Derivative Works (Khalifa): 900-1500 CE**

	Relative to Average on the Interval [900, 1100)					
	%Der.	Books	Books2	Authors	NoProf	NoPlace
	(1)	(2)	(3)	(4)	(5)	(6)
[1100, 1200)	0.06***	1.58	-0.23	0.80**	0.01	-0.10**
	(0.02)	(1.39)	(0.31)	(0.32)	(0.06)	(0.05)
[1200, 1300)	0.15***	4.91***	-0.10	1.73***	0.05	-0.06
	(0.02)	(1.36)	(0.25)	(0.31)	(0.07)	(0.05)
[1300, 1400)	0.24***	8.02***	-0.09	2.75***	0.11**	-0.07
	(0.02)	(1.92)	(0.31)	(0.46)	(0.06)	(0.04)
[1400, 1500)	0.29***	6.96***	0.47	1.52***	0.11*	-0.04
	(0.02)	(1.83)	(0.35)	(0.45)	(0.06)	(0.05)
[900, 1100)	0.13***	10.19***	3.12***	3.27***	0.50***	0.30***
	(0.01)	(0.72)	(0.17)	(0.15)	(0.03)	(0.03)
N	571	571	571	571	571	571

Notes: The regressions in columns 1,5 and 6 are weighted by the total number books written by authors that died in each year. The regressions in columns 2 and 4, are not weighted whereas that in column 3 is weighted by the total number of authors. Newey-West standard errors allowing for the error structure to be heteroskedastic and autocorrelated up to seven lags are presented in parentheses. ***, **and *indicate significance at the 1%, 5% and 10% levels.

Table 3: **Crusaders and Mongols (1)**

	Relative to Average on the Interval [900, 1100)							
		%Sci				%Rel		
	%Sci	Iran	Lev.	West	%Rel	Iran	Lev.	West
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
[1100, 1200)	-0.07*	-0.11***	0.03	0.14*	0.07	0.10	-0.09	-0.03
	(0.04)	(0.04)	(0.07)	(0.08)	(0.05)	(0.06)	(0.13)	(0.12)
[1200, 1300)	-0.07**	-0.10**	0.05	0.08	0.16**	0.12*	0.14	0.09
	(0.03)	(0.04)	(0.08)	(0.07)	(0.07)	(0.07)	(0.15)	(0.13)
[1300, 1400)	-0.10***	-0.10**	0.02	0.04	0.16***	0.13*	0.00	0.07
	(0.03)	(0.04)	(0.07)	(0.07)	(0.05)	(0.07)	(0.12)	(0.13)
[1400, 1500)	-0.10***	-0.09*	0.01	0.02	0.17**	0.09	0.10	0.13
	(0.03)	(0.05)	(0.08)	(0.07)	(0.07)	(0.08)	(0.14)	(0.19)
"Constant"	0.14***	0.15***	0.11**	0.10**	0.27***	0.29***	0.31***	0.18**
	(0.03)	(0.04)	(0.05)	(0.05)	(0.04)	(0.05)	(0.08)	(0.07)
N	475	692	692	692	475	692	692	692

Notes: All regressions are limited to books whose authors were born in the union of the Iran, Levant and West regions and are weighted by the number of books written by authors who died in a given year or year/region as appropriate. Columns 1 and 5 present the output from regression (1), whereas columns 2 and 6 present the coefficients on the century dummies for the omitted region of Iran in regression (4) and columns 3,4,7 and 8 present the coefficients on the relevant interactions from that same regression. Newey-West standard errors allowing for the error structure to be heteroskedastic and autocorrelated up to seven lags are presented in parentheses. ***, **and *indicate significance at the 1%, 5% and 10% levels.

Table 4: **Crusaders and Mongols (2)**

	Relative to Average on the Interval $[900, 1100)$					
	Harvard			Khalifa		
	Iran	Lev.	West	Iran	Lev.	West
	(1)	(2)	(3)	(4)	(5)	(6)
$[1100, 1200)$	-0.16	0.01	0.14	-0.04	-0.01	0.05
	(0.13)	(0.03)	(0.12)	(0.07)	(0.05)	(0.05)
$[1200, 1300)$	-0.36***	0.13*	0.23	-0.23***	0.16***	0.07
	(0.10)	(0.08)	(0.14)	(0.07)	(0.05)	(0.06)
$[1300, 1400)$	-0.44***	0.53***	-0.09	-0.38***	0.37***	0.01
	(0.10)	(0.11)	(0.07)	(0.06)	(0.06)	(0.04)
$[1400, 1500)$	-0.44***	0.42***	0.02	-0.42***	0.53***	-0.11***
	(0.12)	(0.13)	(0.11)	(0.08)	(0.08)	(0.03)
$[900, 1100)$	0.76***	0.06***	0.18***	0.73***	0.14***	0.14***
	(0.06)	(0.01)	(0.06)	(0.04)	(0.03)	(0.03)
N	475	475	475	532	532	532

Notes: All regressions are limited to books whose authors were born in the union of the Iran, Levant and West regions and are weighted by the number of books written by authors who died in a given year. The first 3 columns are estimated using the Harvard data set whereas the last 3 are estimated using Khalifa's data. Newey-West standard errors allowing for the error structure to be heteroskedastic and autocorrelated up to seven lags are presented in parentheses. ***, **and *indicate significance at the 1%, 5% and 10% levels.

Table 5: **Rise of Madrasas, "Hybrid" Scientists and Mystical Islam**

	Mad. (1)	%Sci (2)	%Rel (3)	UnCit1 (4)	UnCit2 (5)	%Sec. (6)	Dur. (7)	%Sufi (8)
[900, 1000)				-5.50***	-7.77**			
				(0.65)	(3.19)			
[1000, 1100)				-6.35***	-13.94**			
				(0.70)	(6.74)			
[1100, 1200)	0.34*	-0.23***	0.13*	-4.32***	-35.44*	-0.06*	1.28	0.08**
	(0.19)	(0.08)	(0.08)	(0.48)	(18.50)	(0.04)	(0.86)	(0.03)
[1200, 1300)	0.14**	-0.27***	0.26**	-6.56***	-29.93*	-0.05	-2.37***	0.11*
	(0.07)	(0.05)	(0.12)	(1.31)	(16.51)	(0.03)	(0.80)	(0.06)
[1300, 1400)	0.37***	-0.30***	0.24***	-5.06***	-24.43*	-0.06**	-1.83**	0.04
	(0.13)	(0.05)	(0.07)	(0.85)	(12.97)	(0.03)	(0.90)	(0.02)
[1400, 1500)	0.32***	-0.23***	0.28*	-3.89***	-8.36	-0.08**	-2.02**	0.06*
	(0.08)	(0.05)	(0.15)	(0.68)	(5.28)	(0.03)	(0.88)	(0.04)
[900, 1100)	0.04**	0.39***	0.14**			0.09***	13.12***	0.04***
	(0.02)	(0.04)	(0.06)			(0.03)	(0.51)	(0.01)
p-value					[0.00]			
N	395	179	179	2245	2245	412	551	561

Notes: Columns 1-5 and 8 are estimated on the Harvard sample. The regression in column 1 is estimated on the sample of authors who have a biography in the Encyclopedia of Islam, whereas those in 2 and 3 are estimated on the sample of books produced by authors who have at least one book on a scientific topic in Harvard's library collection. Columns 4 and 5 present output from regressions run at the author level. Column 6 is estimated on the Khalifa sample whereas column 7 is estimated using the information on ruler durations provided in Blaydes and Chaney (2013). The regressions in columns 1-3 and 8 are weighted by books with an identified subject, that in 6 is weighted by books, those in 4 and 5 are not weighted, whereas that in 7 is weighted by the number of rulers that commenced rule in a given year. Newey-West standard errors allowing for the error structure to be heteroskedastic and autocorrelated up to seven lags are presented in parentheses except for the standard errors in columns 4 and 5 which are clustered by the author's year of death. ***, **and *indicate significance at the 1%, 5% and 10% levels.