Economic Development, Religious Competition, and the Rise and Fall of Muslim Science

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Abstract

Is Islam compatible with modern economic development? The poor development record of predominantly Muslim countries during the past century has led to claims that only a return to medieval Islamic institutions will produce economic growth in a manner that is compatible with Islamic culture. Using data from the thirteenth century Islamic Levant, this paper examines how one medieval Islamic institution encouraged economic growth by promoting scientific and technological innovation. The *dhimmī* institution, which guaranteed non-Muslims a relatively large degree of religious freedom, created "religious competition" for converts and societal standing. Institutionalized tolerance, coupled with Islam's initial disadvantages in number of adherents and in the sophistication of theological scholarship, gave Muslim religious and political elites incentives to encourage the study of logic. The study of logic for religious debates led, in turn, to the cultivation of the rational sciences. Results suggest that as the societies under Muslim rule became increasingly religiously homogeneous, religious competition decreased, leading to a sharp decline in non-religious intellectual enterprise. The results highlight how the positive economic effects of one medieval Islamic institution critically depended on historical circumstance.

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1 Introduction

Is Islam compatible with modern economic development? The poor development record[1] of predominantly Muslim countries during the past century has provided support to many who claim that economic reforms inspired by Western capitalism are incapable of producing growth in Islamic countries.[2] This perceived incompatibility has led, in part, to the growing popularity of Islamic economics. Islamic economics claims that the implementation of a variety of medieval Islamic institutions and practices will produce economic growth in a manner that is uniquely compatible with Islamic culture. As evidence for this development strategy, Islamic economists often recall that these medieval institutions produced rapid economic growth in the Islamic Golden Age.[3] The mechanisms through which these institutions encouraged growth are rarely discussed, and it is simply assumed that they will promote growth today as they did a millennium ago.

This paper examines one set of conditions under which medieval Islam successfully encouraged scientific and, by extension, economic development.[4] I argue that following the first wave of Muslim conquests (632-732), religious diversity created competition between religious groups for converts and social standing. This competition gave religious elites incentives to encourage the study of logic, with spillovers to other branches of the rational sciences. The result was rapid economic development, with the development of mechanized time-keeping, paper manufactures and machines

[1] See Kuran (2004) for relevant statistics.

[2] Khurshid Ahmad's frequently cited *Economic Development in an Islamic Framework* "enthusiastically calls for innovation and a full departure from the imported ideas either from the West in the form of Western capitalism or the Eastern bloc in the form of socialism. [He claims that] [n]either system can provide the Muslim nations with a model for economic development" (El-Ashker and Wilson (2006), 389).

[3] Although there is no consensus on the exact time frame for the Islamic Golden Age, Muslim economies appear to have rapidly developed between the 8th and 12th centuries.

[4] Timur Kuran has recently stressed the link between this scientific development and Islam's medieval economic development by noting that "[i]f the Islamic world was at one time economically more advanced, one reason is that it stood at the forefront of scientific and technological innovation" (Kuran (2004), pp. 125).

that worked on the same principles as the steam engine, among other advances.

Many Muslim religious authorities were wary of the "foreign" or rational sciences immediately after the conquests.[5] They viewed the rational sciences as an unnecesary addition to the Islamic or "Arab" sciences and a potential danger to the faith.[6] Despite this aversion to the rational sciences, the religious elites became interested in the study of logic as non-Muslim populations –initially the vast majority– objected to Islamic doctrines in logical terms. Muslim elites found themselves unable to counter these objections and encouraged the study of logic to refute detractors.

The study of logic, however, also imposed costs on the religious authorities. As Muslims became increasingly versed in logic and the rational sciences, a subset of the Muslim population turned to logic and philosophy –not religion– as the ultimate arbiter of truth. Once the majority of the conquered populations converted to Islam, the costs associated with allowing the study of logic dominated the benefits. When this occurred, the religious authorities withdrew their support for the study of logic and the rational sciences. The result was scientific regression and the economic stagnation of Muslim countries.

This hypothesis implies that Islamic-dominated regions with higher proportions of non-Muslims, all else equal, produced more works devoted to the rational sciences.[7] As Muslims became the majority, one would expect to see production of the rational sciences decrease among the Muslim population. I draw out these implications using a formal model of scientific production. I then test these implications using quali-

[5] The rational sciences cultivated during this period primarily consisted of medicine, philosophy, mathematics and astronomy.

[6] The Islamic sciences consisted of, among other things, the study of Islamic law (*shar'īa*). The term Islamic science is not to be confused with Muslim science, the term which we use to refer to all intellectual activity (irrespective of the religious affiliation of the author) under Muslim rule.

[7] The hypothesis of a link between the proportion of non-Muslims, conversion to Islam and scientific development is not new. Sociologist Toby Huff ((1993), pp. 47) argues that: "a likely explanation of it [the decline of Muslim science], however, is to be found in the pattern of conversion to Islam over the centuries." In addition, Timur Kuran ((2004), pp. 125) suggests that Islam's early economic flowering could have been due to "the mixing of cultures brought about by conquests, conversions, and political reorganization."

tative evidence from medieval authors, and empirical data on scientific production from a book catalog from the thirteenth century Levant. I find support for the role of religious competition in encouraging medieval Muslim scientific development.

Islamic law in the middle ages forbade conversion from Islam to other religions. This non-reversibility allows the use of the time since a given author's birth place was conquered by Muslim forces as an instrumental variable for the proportion of Christian authors in his region. The point estimates using this instrument suggest that a 10% increase (one standard deviation) in the proportion of Christian authors led to an average increase of between 4 and 8 books (one-sixth and one-third of a standard deviation respectively) written by Muslim authors. This increase was concentrated in the fields of astronomy, mathematics and philosophy; fields contributing to technological and economic development, broadly defined. The empirical findings are supported by qualitative evidence from medieval authors.

The results have implications on three levels. At a historical level, the results shed light on how medieval Islam encouraged scientific progress and economic growth. Moykr (1990) has argued that societies that effectively restrain elements resistant to change are exceptional. This paper shows how tolerance and religious diversity enabled Islam to effectively restrain its own conservative elements for hundreds of years.

The evidence suggests that religious competition prevented the dominance of "traditional" Muslim elites (i.e. those averse to change) for centuries. Consistent with the hypothesis developed in the paper, scholars have linked Muslim scientific stagnation to the rise of conservative elites who discouraged independent reasoning. These conservative elites presided over the closing of the gate of *ijtihād*, or the end of the use of independent judgment in Muslim law. Independent judgment, according to some modern scholars, was no longer necessary once Muslim scholars successfully resolved the issues for which tradition and scripture provided no explicit answer. The theory developed in this paper endogenizes the timing of this change. Competition between religions required producing answers in logical terms to refute the challenges and questions of non-Muslims. Only once the non-Muslim populations shrank to a small minority, with a concomitant decline in the number –and danger– of challenges

to the prevailing "orthodoxy's" answers, could elites successfully claim these issues had been resolved.

This explanation adds to the work of Avner Greif (1994) and Timur Kuran (2003) in furthering our understanding of Islam's commercial and economic stagnation. Greif and Kuran have drawn attention to the importance of culture and its accompanying organizational constraints in explaining Muslim economic stagnation. Although their explanations highlight some of the mechanisms that led to Muslim economic stagnation, both fail to explain why Muslim "culture" became resistant to change when it had been open to such change at an earlier date. This paper shows how the challenges associated with converting and integrating a relatively well-educated population effectively constrained conservative elements for hundreds of years.

The results also have implications at the policy level. Many Muslims today consider the scientific and economic development during the Golden Age more than history. For these individuals, the experience of the Islamic middle ages is evidence that medieval Islamic institutions can promote economic growth.

Despite widespread belief that Islamic institutions are the remedy for the economic and social ills of many Muslim countries,[8] Islamic economics has failed to produce economic growth. The results presented in this paper suggest that Islamic economics will continue to disappoint. This is a natural consequence of changing societal conditions in the past millennium, and specifically of the lack of a large, relatively well-educated non-Muslim majority in Muslim lands.

The mechanisms through which medieval institutions encouraged economic development, however, can inform the choice of reform policies today. As Islamic political parties gain popularity, it is likely that some will continue to champion the adoption of medieval institutions to encourage economic development in an "Islamic" manner. This study provides a lesson for those who look to Islam's past to inform present day policy. Muslim scientific development during the middle ages suggests that institutions that protect individual freedoms are key to promoting scientific –and thus

[8] As recently embodied in political slogans such as 'Islam is the solution.'

economic– growth. In this sense, modern liberalism –which political Islam has often derided as un-Islamic– has Muslim roots.

At the broadest level, the results suggest that polarized societies can encourage economic growth despite the negative effects caused by societal diversity. Although there is abundant evidence that the societies of medieval Islam had immense problems agreeing on a wide variety of public goods,[9] consistent with the results outlined in Easterly and Levine (1997) and others,[10] these societies were more developed economically than their more homogenous counterparts. While quantifying the negative effects of this societal polarization is impossible, the overall experience of the Islamic middle ages hints that the benefits of this diversity outweighed its costs.

The result that the coexistence of diverse societies under Islamic rule encouraged scientific development is consistent with the recent literature suggesting that societal heterogeneity can encourage creativity (e.g. Putnam (2007), pp. 140).[11] Although this literature provides suggestive correlations, the mechanisms through which diversity encourages creativity remain largely unexplained. The experience of medieval Islam suggests that societal diversity can encourage innovation by preventing the emergence of elements resistant to change.

The remainder of the paper proceeds as follows. Section 2 starts by detailing the problems Muslim religious elites faced following the conquests, explains why these elites tolerated the non-Muslim majorities and uses the incentives and disincentives faced by these elites to develop a simple model of scientific production. Section 3 presents the evidence (qualitative and quantitative) and investigates alternative explanations for the results. Section 4 uses the results to provide an additional explanation for Muslim scientific stagnation and briefly investigates why Muslim sectarian splits did not seem to have the same competition effect. Section 5 concludes.

[9] To the extent that different religious groups employed separate legal systems and lived in separate neighborhoods.

[10] For a summary of this literature see Alesina and La Ferrara (2004).

[11] Other references documenting the positive effect of diversity on a range of economic outcomes include: Caplan and Cowen (2004), Ottoviano and Peri (2006) and Rosenberg and Birdzell (1986), pp. 132.

2 Religious Competition

Toward the conclusion of the first major period of Islamic conquest (732) Muslim religious authorities faced a difficult task. Islam claimed superiority over all religions[12] and Muslims were commanded to "invite (all) to the Way of thy Lord with wisdom and beautiful preaching; and [to] argue with them in ways that are best and most gracious" (*Qur'ān* (16:125)). Yet non-Muslims responded to these invitations and their supporting arguments by claiming, like the Christian Quṣtā ibn Lūqā (820-912), that the logic of Muslim theological arguments was deficient (Edde et al. (1997), pp. 209). Some ridiculed Muslim theology by claiming that "we have not seen a learned man [...] adopt Islam for any other reason than [being afraid, pursuing prestige, escaping heavy taxes, fleeing from humiliation, or being taken prisoner]" (Ibn Kammūnā (1284), pp. 102).

Muslim religious elites[13] could not use forced conversion to silence the doubts and questions of non-Muslim detractors. Muslims were a small minority in most areas following the conquests, and their own religious law forced these elites to tolerate the presence of non-Muslims and their questions and objections.

Because the religious authorities could not use force to silence theological attacks, inter-faith debates emerged as a means of demonstrating religious superiority. Muslims (as members of a newly founded religion), unlike their non-Muslim counterparts, were not well-schooled in theological and inter-faith debates.[14] Moreover,

[12] This is seen, for example, in the prophetic saying *al-Islām ya'lū wa lā yu'lā 'alayhi* (Islam is exalted, and nothing is exalted above it).

[13] Given the great variety in religious groups across Islam during this period, it is impossible to define these elites as one precise group. Perhaps these elites are best identified with what would eventually be known as the *'ulamā'* (religious scholars). Despite the great variety in Muslim sects during the period under study, the battle between rationalism and traditionalism appears to have been present in most Muslim sects (Makdisi (1975), pp. 239). Since we are solely interested in the behavior of religious scholars towards the use of the rational sciences, we treat them as a uniform group.

[14] The inter-Christian and anti-Jewish polemics of the early seventh century meant that Christian and Jewish authors were well equipped to attack Islam's doctrines upon its arrival. See, for example, Averil Cameron (1991).

most Muslims were initially not well versed in logic, which was often the only common denominator in inter-faith debates.[15] Consequently, Muslims performed poorly in these debates.[16]

This poor performance had consequences beyond the results of arcane debates between educated elites. Although these debates were surely unintelligible to most of the population, the less educated appear to have recognized that Christians were, on average, better educated than their Muslim counterparts. For example, in the ninth century 'Abū 'Uthmān 'Amr Ibn Baḥr al-Jāḥiẓ (d. 869) stated that "the [Muslim] commoners prefer Christians [...] [because] there are philosophers and doctors and astrologers [among them], and they became by these things perceived as knowledgeable among them [the Muslim commoners]" (al-Jāḥiẓ (868), pp. 14-16). Given that many potential converts judged the merits of Islam by comparing its achievements to that of their own religion,[17] Islam's intellectual underdevelopment threatened to slow conversion and to weaken Islam itself.[18]

2.1 The *Dhimmī* Institution

Practical concerns guided the initial tolerance of non-Muslims. Non-Muslims posed a threat to Muslim religious elites after the conquests. The local non-Muslim populations greatly outnumbered the Muslim conquerors, threatening to absorb them.

[15] The emergence of logic as the lingua-franca of these religious debates appears to have been partly a product of the common use of logic in religious debates in many of the areas conquered by Muslims prior to the conquests. Thus, Islam "was unconsciously guided by its opponent in the method of attack and fell unconsciously under its influences" (Fueck (1939), pp. 107).

[16] The Abbasid Caliph al-Ma'mūn (786-833) supposedly lamented following one debate: "how I wish that I had never seen this day, nor seen the failure of the Muslims and their lack of argument on behalf of their religion!" (cited in Thomas (2003), pp. 66).

[17] See Bulliet (1994), pp. 92.

[18] The historian Muhammad ibn Ahmad al-Maqdisi (946-1000) explained that Muslim leaders following the conquest were quick to build monuments to compete with those of the non-Muslim majority. He states that 'Abd al-Malik (646-705) built the dome on the rock in Jerusalem because he "was afraid lest it [the dome of the Church of the Resurrection] assume an equally large place in the Muslims' hearts" (cited in Bosworth (1992), pp. 19).

This numerical disadvantage was compounded by the fact that non-Muslim populations were initially more learned, on average, than Muslim communities. In order to solidify their power and prevent uprisings, Muslim elites granted non-Muslims considerable autonomy and drew on their intellectual achievements by granting them bureaucratic positions.

Although the status of non-Muslims appears to have slowly worsened in the centuries after conquest, these communities were treated with "a degree of tolerance without precedent or parallel in Christian Europe" (Lewis (2003), pp. 33-34). Despite protests from some religious authorities, non-Muslims maintained their posts as highly skilled bureaucrats for centuries.

This tolerance had both religious and practical roots. The prophet Muhammad (570-632) set an early precedent for this tolerance during his Medinan years (622-632). As the Islamic community expanded, Christian and Jewish communities in the Arabian peninsula appear to have been granted generous terms, as Muhammad sought to convince these communities of his message (Bosworth (1979), pp. 13-14). These terms were recorded in the *aḥādīth* (prophetic sayings) and in *Qur'ānic* verses such as "there is no compulsion in religion" (*Qur'ān* (2:256)) and in references to Christians and Jews as *ahl al-dhimma* (the protected peoples).

Following Muhammad's death and during the first large scale conquests outside the Arabian Peninsula (632-732), the conquerors worked out pragmatic agreements with the local populations (Bosworth (1982), pp. 42). Since the conquerors were a small minority, tolerance of the conquered was in many senses the only option.[19] Muhammad's precedent gave the conquerors a convenient framework within which to administer the affairs of the local non-Muslim populations. These populations were free to retain their original creeds in exchange for the annual payment of *jizya*, or poll tax. A non-Muslim living in the lands controlled by Muslims who had paid the *jizya* was referred to as a *dhimmī* (protected person), and enjoyed legal protection.

The autonomy granted to non-Muslim populations following the conquests grad-

[19]The fact that almost all other religious groups were also granted *dhimmī* status (initially only Christian and Jews were considered *dhimmī*) argues for the pragmatic nature of these early agreements.

ually deteriorated as Muslim jurists began to systematize Muslim law (around the middle of the eighth century). These jurists worked to worsen the legal status of non-Muslims (Bosworth (1982), pp. 47). As jurists systematized the legal system, the non-Muslim's legal status descended to that of a second class "citizen" (Bosworth (1982), pp. 41).

Still, non-Muslims often held high governmental posts. Indeed, the prevalence of Jewish advisers in the Fatimid (910-1171) regime led a contemporary poet to note that "in our time, the Jews have reached the summit of their desires. They have acquired honour and fortune, and have become advisers and rulers!" (Bosworth (1979), pp. 22). There is evidence that rulers often worked to protect the status of their non-Muslim advisors and subjects.

In sum, although the treatment of the *dhimmī* varied across time, the non-Muslim populations were rarely persecuted.[20] The tolerance of non-Muslim communities was established at an early date by the prophet Muhammad, encouraged by Muslim numerical disadvantages, and institutionalized shortly following the conquests. Although religious elites did work to worsen the status of the non-Muslim populations (consistent with their incentives), the political rulers had incentives to ensure that these populations were tolerated. The resistance of many political rulers to the open oppression of the *dhimmī*, coupled with the firmly Islamic roots of the *dhimmī* institution, meant that religious leaders were effectively constrained from silencing the questions and doubts of non-Muslims by force.

2.2 Incentives and Disincentives of the "Rational Sciences": The Religious Elites

The tolerance constraints imposed by Muslim law and political reality meant that the religious elites could not engage in pogroms or forced conversions when non-Muslims refused to convert or questioned the veracity of Islamic doctrine. Non-Muslims often objected to Islamic theological claims in logical terms, which religious

[20] There were violent exceptions such as the forced conversion and expulsion of non-Muslims in north Africa and the Iberian peninsula under Almohades (1121-1269).

elites were initially poorly prepared to refute. Gutas (1998) suggests that Islam's poor performance in inter-faith debates was a factor in the start of the great translation movement[21] of the rational sciences[22] from Greek into Arabic, and thus a factor in the initial surge in Muslim scientific production.

Although many religious elites were suspicious of the "foreign" sciences (as opposed to the Islamic sciences),[23] they embraced logical methods of argument to defend their faith and to provide "proofs" to win converts.[24] The widespread use of logic in religious debates coincided with the development of '*ilm al-kalām,* a branch of Muslim theology whose "main point [...] was to attack and denounce all false religious views. It was the science of partisan dispute" (Lapidus (2002), pp. 166). Al-Fārābī (870-950) explains the difference between *kalām* and *fiqh* (the study of religious law) in that "the *faqīh* takes the opinions and the deeds of the founder of the religion as given (*musalammatan*), and makes these the basis from which he deduces things [...].The *mutakallim* [he who practices '*ilm al-kalām*] supports the things that the *faqīh* uses as a basis without deducing from them any other thing [i.e. derives them from first principles]" (Al-Fārābī (950), pp. 132). In this environment of religious competition, "the [legal-religious] schools [...] developed a method of disputation that required students to develop the ability to find 'disputed questions'" (Huff (1993), pp. 157).

The benefits of the widespread use of logic were not limited to arcane theologi-

[21]From the middle of the eighth century to the end of the tenth, scholars working in the Muslim world (primarily the Abbassid Caliphate (758-1258)) translated the vast majority of secular Greek works into Arabic. The Abbassid Caliphs supported this movement to varying degrees, as did wealthy individuals. For additional information on the translation movement, see Gutas (1998) and O'Leary (1949).

[22]We assume throughout this section, and the remainder of the paper that the widespread use of logic also led to the flourishing of the other rational sciences. Thus, we often use the terms logic and rational sciences interchangeably. The link between the two is justified by the fact that the study of logic more often than not led to the study of the rational sciences. For a characteristic medieval quote arguing that rationalistic methods led to the cultivation of other branches of the rational sciences see Goldziher (1916), pp. 195.

[23]Huff (1993), pp. 68; Sabra (1987), pp. 231; Goldziher (1916)

[24]Stroumsa (1999), pp. 25; Lapidus (2002), pp. 101

cal debates. As previously noted, potential converts often compared Islam to their original religions. As the Muslim population became increasingly well-versed in logic and the rational sciences, claims like those from Christians that "[Muslim] thinkers (*ḥukamā*) are but followers of [Christian] thinkers and that [Muslim] philosophers copied [Christian philosophers]" (al-Jāḥiẓ (868), pp. 17) lost credibility. Eventually, Muslim thinkers surpassed their non-Muslim predecessors and contemporaries.[25]

The widespread study of logic and the rational sciences also encouraged economic growth. The cultivation of these sciences helped to improve agricultural, metallurgical and textile production techniques which increased output and living standards.[26] As Muslim scientific development became increasingly advanced, the possible economic ramifications of the study of the rational sciences grew exponentially.

Perhaps the most striking link between the study of the rational sciences and the possibility for economic growth can be found in the Muslim science of *ḥiyal*, or the art of ingenious devices. Muslim thinkers, used the rational sciences (especially geometry) during the period under analysis to "construct machines which would work automatically for long periods without human intervention" (Hill (1979), pp. 233). Among these machines, the most well known are the waterwheels, windmills and tidal mills of medieval Islam which had direct economic effects.

Recent research by Hill and Hassan, however, has shown that Muslim technical advances went well beyond these labor-saving devices. Taqī al-Dīn, writing in 1551, explains that the workings of the steam turbine had long been understood by Muslim thinkers (Hassan (1976), pp. 34-35).[27] Hill has demonstrated that Muslim thinkers by the ninth century had also developed devices that "work[ed] on the same principle as the slide-valve in a double-acting steam engine" (Hill (1979), pp. 235). Medieval Muslim technology, at its most advanced, developed machines that had the potential to transform the medieval economy.

The dependence of the science of *ḥiyal*, which created these labor-saving devices,

[25] Hill (1994), pp. 26

[26] For relevant statistics and a general discussion see Issawi (1995) pp. 42-43; 60-61 and Ashtor (1976) pp. 95-100.

[27] This was well before Giovanni Branca first described a similar device in Europe in 1629.

on the rational sciences was stressed by Ibn Khaldūn (1332-1406). When explaining the decline of this science in his *Muqadimma* (1377), he notes that "some authors in this art [*ḥiyal*] devoted books to mechanical devices which contain strange works and amazing devices. Maybe this science became incomprehensible because of the difficulty of the geometric proofs" (Ibn Khaldūn (1377), II, pp. 258).

The widespread cultivation of the rational sciences had palpable economic effects during the period under study. Moreover, recent studies have highlighted the economic importance of these sciences by demonstrating that their study allowed Muslim technicians to develop machines similar to those that led to the European industrial revolution and the start of modern economic growth.

While logic could help Muslims win debates and converts and encouraged economic growth, it also imposed a cost on religious leaders. Religious diversity led some Muslims to doubt, and the doubters often turned to philosophy and logic rather than the religious authorities for answers.[28] Logic and the accompanying rational sciences threatened the societal standing of the religious elites, insofar as they presented an alternative path to truth.[29]

Muslim religious elites faced a choice between the costs and benefits of allowing the study of logic and the rational sciences. A rational representative Muslim religious figure would only support the use of logic if the benefits of its use (scientific advances, refuting non-Muslims' attacks on Islam and winning converts) exceeded the costs (doubts by Muslims themselves, and the eroding of religion's societal standing).

[28] The autobiography of Ibn al-Haytham (965-1039), one of Islam's greatest thinkers demonstrates this point. After relating that religious diversity led him to doubt his own Muslim faith, he states that: " I saw that I would not reach the truth unless it was through [...] what Aristotle laid out of the logical and natural and metaphysical (Ibn Abī Uṣaybi'a (1268), pp. 506-507)."

[29] This is seen in the fact that "Aristotle's methods of proof was [seen by the religious elites as] a serious threat to the validity of religious doctrines" (Goldziher (1916), pp. 198).

2.2.1 A Model of Scientific Production

The previous discussion suggests Islam's initial numerical and intellectual disadvantages created incentives to support the study of logic in order to gain converts. In this section I provide a simple theoretical model to investigate the implications of this hypothesis.

Consider a representative member of the Muslim religious elite in region j at time t_j, where t_j is the time since region j was conquered by Muslim forces. For ease of exposition we will suppress the subscript j. Assume this agent is infinitely lived, and faces an objective function of the form:

$$U_t = \int_0^\infty e^{-rt}[\xi(a_t, a_c, t)F(a_t) - qs_t]dt \tag{1}$$

where F(.) is a positive C^1 concave function that maps the scientific stock into "useful" output and q is the constant price of allowing scientific research. a_t is the per-capita level of scientific knowledge in the Muslim community in region j at time t and a_c is the constant per-capita level of scientific knowledge in the Christian community in region j. s_t is the amount of scientific research supported by the religious elites in region j at time t and t is the time since community j was conquered by Muslim forces. Assume for simplicity that the total population is constant.

ξ is a function that captures the value of the rational sciences to the religious elites. We assume all the necessary derivatives of ξ exist. The previous discussion suggests assuming $\xi_a < 0$ (where subscripts of ξ represent partial derivatives with respect to the subscripted variable) since the Muslim religious elites will, all else equal, became increasingly hostile to the rational sciences as the Muslim populace becomes increasing learned in these subjects. In addition, this assumption reflects the fact that a higher per-capita level of scientific knowledge in the Muslim community will attract a greater number of converts, lessening the need for the knowledge stock (since conversion to Islam is irreversible). These considerations also suggest that $\xi_{aa} < 0$. In addition, we assume that $\xi_{a_c} > 0$, since a higher knowledge stock among the competing religion increases the elites' valuation of the rational sciences (for competition purposes).

Finally, since conversion to Islam was irreversible and there were significant monetary and social incentives to convert, we assume that some portion of the population converts to Islam in each period for opportunistic reasons. These conversions are in addition to those that occurred as a result of the relative relationships between a_c and a_t. Since the competition loses some number of adherents in each period regardless of the relative knowledge stocks, it seems reasonable to assume that $\xi_t < 0$ as long as non-Muslims remained a sizeable portion of the population. This assumption is supported by evidence suggesting that the number of adherents to the competing religion was an important part of the elites' valuation of the study of logic.

The per-capita knowledge stock among Muslims a_t evolves each period according to

$$a_t = \int_{-\infty}^{t} e^{-\delta(t-v)} s_v dv \tag{2}$$

Equation (2) captures the fact that the stock of learning in the Muslim community today is a function of research done today as well as that done in previous periods. The research done in previous periods, however, is lost (because it is forgotten, destroyed...) at exponential rate δ.

The Muslim religious elite maximizes equation (1) subject to (2). The Euler condition, which must hold at the optimum, and under the stated assumptions is sufficient for optimality,[30] implies that the shadow "price" of supporting scientific research at time t is:

$$F_t^{'} = C_t = \frac{q(\delta + r) - \xi_a F}{\xi} \tag{3}$$

Equation (3) shows that the cost of supporting the sciences increases in the elites' constant "inherent" aversion to the rational sciences q, in the elites' discount factor r and in the depreciation rate of the knowledge stock δ.

If we assume that ξ_{aa_c} is positive[31] then $\frac{dC_t}{da_c} < 0$ and the cost of scientific research decreases the more knowledgeable the Christian population.

[30] This can easily be verified by showing that $e^{-rt}[\xi(a_t, a_c, t)F(a_t) - qs_t]$ is concave in a_t and $\dot{a}_t$.

[31] This seems reasonable, since we would expect the religious elites to be more tolerant of logic and the rational sciences the fiercer the competition.

The cost of scientific research increases as the Muslim knowledge stock increases. This is a product of the fact that as the population becomes increasingly educated, the religious elites face increasing questions and doubts from Muslims. In addition, a higher knowledge stock increases conversions to Islam. Thus, Muslim scientific development in one period increases the headwinds against a further increase in a later period.

Finally, if $\xi_{at} < 0$ and $\dot{a} > 0$, then the cost of scientific production increases over time. As the population converts to Islam for "opportunistic" reasons and the Muslim knowledge stock grows, investment in logic becomes more costly to the religious elites.

The long run attitude of the Muslim religious elites depends on our assumptions on ξ. If the religious elites have no valuation for the rational sciences outside that of religious competition, then ξ will approach 0 as Muslims become the overwhelming majority. Under this assumption, the religious elites will find the rational sciences more trouble than they are worth once the majority of the population converts.

In sum, the model shows that the Muslim religious elites will increasingly oppose the study of the rational sciences, as the non-Muslim population converts to Islam. Whether this opposition to the sciences becomes absolute when Islam becomes the majority religion depends on these elites' aversion to the rational sciences (the value of q and the functional form of ξ). If these elites only value the sciences for competition purposes,[32] the model predicts that Muslim religious elites will attempt to eliminate all study of these once Islam emerges as the dominant majority. The following section tests these predictions, first using qualitative, then quantitative, evidence.

3 Evidence

The model predicts that production in the rational sciences by Muslims should be inversely related to the proportion of non-Muslims in a society if the religious elites

[32] $\xi(a_t, a_c, t) = 0 \; \forall \; t > T_M$ where T_M is the date Islam becomes the dominant religion.

have sufficient societal influence. In addition, scientific production should eventually abruptly decline to 0 if the elites primarily value the rational sciences for "religious competition." This section evaluates these predictions using qualitative evidence from medieval authors and quantitative evidence on intellectual production drawn from a thirteenth century biographical dictionary.

3.1 Qualitative Evidence

An ideal hypothesis test would examine the attitudes of the religious elites towards the rational sciences before and after non-Muslims ceased to pose a threat. Although it is impossible to measure the exact date at which this occurred, it is possible to concentrate on the general period when Muslims emerged as the dominant majority in a given region.

Muslims became the majority at different times across the Islamic world. In Iraq and Iran, scholars estimate that this occurred between the eleventh and twelfth centuries. According to Lapidus, "by the eleventh century, as far as we can tell from exceedingly fragmentary evidence, Islam was no longer the faith of a dominant minority, but was the majority faith of Iraq and Iran" (Lapidus (2002), pp. 143). Bulliet ((1979), pp. 82-83) confirms this timing, estimating that the conversion process in Iraq was largely complete by the start of the twelfth century.

The Muslim historian al-Qifṭī provides detailed accounts of changing attitudes toward science in the Baghdad suburb of Karkh in his *Ta'rīkh al-Ḥukamā'* (1248). His anecdotal commentary, beginning in 1080 and concluding in 1193, reveals a distinct change in societal attitudes toward logic and the rational sciences. The timing of the change –which coincides with the emergence of Islam as a clear majority at the turn of the twelfth century– supports the model's predictions.

Qifṭī begins by relating that sometime around 1080: "Yaḥyā bin ʻIsā bin Jazla, [...] a Christian doctor in Baghdad, studied medicine under his contemporary Christians in Karkh. Desirous to study logic, but not finding any renowned Christian logician in his community, he studied under the *Muʻtazilite* Shaīkh Abū ʻAlī Ibn al-Walīd who was an expert in *ʻilm al-kalām* and logical terms. Ibn al-Walīd persisted in inviting

him to become Muslim by using clear evidence and proofs until he responded and became Muslim" (Qifṭī (1248), pp. 239).

In 1080 Yahya bin Isa bin Jazla turned to a Muslim scholar for instruction since there were no "renowned" Christian logicians. The Muslim scholar was so convincing in his use of logic that the Christian doctor himself converted to Islam under his tutelage.

By 1174, however, the atmosphere had changed. Qifṭī reported that the Muslim student ʻAlī bin ʻAlī, "learned the science of the ancients [including philosophy and logic] from a group of Christians and Jews of Karkh. After he made his knowledge public, the *fuqahā'* [religious scholars] shunned him, avoided him and questioned his belief [i.e. religious orthodoxy], after this he left Iraq" (Qifṭī (1248), pp. 161). Unlike the Christian doctor in 1080, ʻAlī bin ʻAlī had to study with Christians and Jews, and when he did, religious elites shunned him. This confirms the model's prediction that as Islam emerged as the dominant majority during the start of the twelfth century religious elites had fewer incentives to tolerate the study of logic and the rational sciences.

Muslim religious authorities did not stop at simply shunning a lone scholar once Islam emerged as the dominant religion. A further report by Qifṭī indicates that sometimes they took extreme measures to prevent the study of the rational sciences. In 1193, Qifṭī (citing al-Ḥakīm Yūsuf al-Sabtī al-Isrā'īlī) relates that al-Isrā'īlī was present "in Baghdad that day [of the burning of books] on business and [al-Isra'ili] was present at the gathering and heard the words of Ibn al-Māristāniya and saw in his hand *Kitāb al-Hay'a* by Ibn Haytham and he [Ibn al-Māristāniya] was pointing to a circle in which the author represented the universe, and he [...] ripped it up and threw it in the fire" (Qifṭī (1248), pp. 154). By 1193 religious authorities had ceased encouraging the study of rational sciences. Instead they burned books by Ibn Haytham, one of the most prominent of the earlier Muslim scientists.

Between 1080 and 1193 Qifṭī's commentary reveals a shift in the attitudes of religious elites. At the turn of the twelfth century, after Islam had emerged as the dominant faith, religious authorities withdrew their support for the study of philosophy and the natural sciences. Indeed by 1193, in Karkh at least, they had

begun to campaign actively against such studies. With Muslims as the clear majority, religious authorities no longer were threatened by other religions. As the model predicts, these elites lacked the incentive to encourage the study of logic and science. While the smaller Christian and Jewish communities continued to study logic and science, Muslims who attempted to pursue such subjects themselves were shunned or their books were burned.

The pattern of Islam emerging as the dominant religion and a decline in the study of the rational sciences was not confined to Iraq. Writing in fourteenth century North Africa, Ibn Khaldūn reflected on the reason logic was no longer a necessary topic of study. He stated that, "this science, which is called '*ilm al-kalām* [which is a logically intensive branch of Muslim theology] is not necessary in this era for the student of knowledge, since **apostasy and heresy have become extinct**, and the religious leaders of the *ahl al-sunna* have **written and recorded more than sufficient** for our needs, and the **mental proofs were needed only when they defended and supported** [their beliefs]" (Ibn Khaldūn (1377), pp. 214 emphasis added). According to Ibn Khaldūn, once "apostasy and heresy" had been eliminated and the majority of the population converted to Islam, the "religious competition" incentive for the support of the rational sciences had diminished.

As the Muslim religious elites increasingly opposed the study of the rational sciences, the individual costs associated with studying these sciences also rose. These additional costs would cause Muslims to pursue alternative occupations with higher net returns. A commentary by a fourteenth century Egyptian *muḥtasib* (market inspector) supports this prediction. He noticed the scarcity of Muslim physicians (whose profession relied on the rational sciences) across Egypt and observed that "[m]any cities have only *dhimmī* [non-Muslim] physicians." He further commented that, "Muslims continue to flock to *'ilm al-fiqh* (traditional jurisprudence) [...] is there a reason for this? The only one I see is that the profession of physician is not conducive to obtaining a judicial or government post, getting ahead of one's neighbors, or having power over one's enemies" (Ibn al-Ukhuwah (1329), pp. 254).

While the above evidence suggests an increasing opposition among religious elites to the rational sciences, this evidence does not reference the position of political

leaders. In theory, if political authorities provided support for the rational sciences, these sciences could have flourished despite the disapproval of religious elites. In some cases this did occur, as evidenced by the support for the Marāgha observatory by Mongol leaders in the thirteenth century. In general, however, the costs to political leaders of supporting such policies was large. The religious elites, or *'ulamā'*, enjoyed substantial societal support and could ultimately "force their point of view on the rulers, because they had the support of the public" (Huff (1993) pp. 183). Indeed, during this period "one could measure the extent of a statesman's influence by the number of *'ulamā'* in his camp." (Makdisi (1975), pp. 237)

In sum, though Islam's emergence as a majority religion did not mean the immediate collapse of scientific research, long-run pressures implied that scientific production would eventually decrease as a given community became dominantly Muslim. By the late Middle Ages, the *dhimmī* population no longer represented a threat in most areas. As the incentives from "religious competition" decreased, qualitative evidence suggests that scientific production among Muslims fell sharply.

3.2 Quantitative Evidence

3.2.1 Measuring Scientific Achievement

Muslim Scientific Development Until recently the general picture of the contribution of Muslim science to human technological progress was "one of stagnation rather than material progress" (Wiet (1969), pp. 371). Recent research, however, has discredited such hypotheses. As Bernard Lewis sums up existing evidence, "Muslim scientists added greatly to the material transmitted to them, through their own researches and through practical experiments and observations in fields as diverse as medicine, agriculture, geography, and warfare" (Lewis (1982), pp. 221).

These advances, primarily between the eighth and twelfth centuries, included the development of machinery similar to that used in a double-acting steam engine (Hill (1979), pp. 235), mathematical breakthroughs from algebra to trigonometry (as witnessed by the Arabic origin of the words algorithm and algebra), and a philosophical current not unlike that of the European enlightenment (Israel (2006), pp. 634). In

addition, Muslim researchers were the first to widely use the experimental method (Lewis (2003), pp. 79).

Muslim scientific accomplishments in this Golden Age dwarfed those of Europe and surpassed even the Chinese in many fields. In astronomy, the Chinese Astronomical Bureau in Peking employed Arab astronomers for centuries (Huff (1993), pp. 50). In optics (the precursor of modern Physics) Needham, the prominent historian of Chinese technology acknowledged that the Chinese "never equalled the highest level attained by the Islamic student" (cited in Huff (1993), pp. 51). In sum, there is little doubt that Muslim scientists made substantial contributions to human knowledge during our period (750-1200).

The Data The data we use to measure scientific output comes from Ibn Abī Uṣaybi'a's biographical catalogue: '*Uyūn al-Anbā' fī Ṭabaqāt al-Aṭibbā'* (sources of news on the generations of physicians). Muwaffaq al-Dīn Abu 'l-'Abbās Ahmād bin al-Qāsim bin Khalīfa bin Yūnus al-Khazradjī Ibn Abī Uṣaybi'a was a physician and bibliographer born in Damascus after 1194. He studied medicine under Ibn al-Bayṭār and al-Raḥbī and after completing his studies practiced medicine in Damascus and Cairo. In 1236 he entered the service of the prince 'Izz al-Dīn Aybak al-Mu'aẓẓamī at Sarkhad (close to the current Syrian-Jordanian border) where he died in 1270.[33]

Ibn Abī Uṣaybi'a's medical catalogue, completed in 1268, is his most important work. It is "a collection of 380 biographies which are of inestimable value for the history of Arabic science."[34]

The included authors wrote on a wide variety of subjects. The catalogue's focus on physicians is especially informative in light of the fact that "almost all the major philosophers up until the twelfth century earned their living through the practice of medicine. As a result they [physicians] were perhaps the major social group working towards the assimilation of Greek philosophy and the natural sciences into Islamic

[33]For a detailed biography, see Vernet, J. "Ibn Abī Uṣaybi'a." Encyclopaedia of Islam. http://www.brillonline.nl/subscriber/entry?entry=islam_SIM-3058

[34]Vernet, J. "Ibn Abī Uṣaybi'a." Encyclopaedia of Islam. http://www.brillonline.nl/subscriber/entry?entry=islam_SIM-3058

culture and civilization" (Huff (1993), pp. 171).

Ibn Abī Uṣaybi'a divided his book into 14 sections, by geographic region and time period: physicians at the beginning of time, physicians related to Asclepius, physicians taught by Hippocrates, physicians at the time of Galen, physicians of Alexandria, physicians who translated from Greek, Indian physicians, physicians who practiced at the beginning of Islam, Syriac physicians at the apparition of the Abbassid state, *'Ajamī* (roughly Iran and east of Iran) physicians, Iraqi physicians, *Maghribī* (western north Africa and Muslim Spain) physicians, *Masrī* (Egyptian) physicians, *Shamī* (the Levant: modern Syria, Lebanon, Israel and occupied territories) physicians.

I concentrate on data provided in the last seven sections because these focus on scientific production in lands ruled by Islam. Within a given section Ibn Abī Uṣaybi'a provides the author's date and place of birth, the titles of his writings, his religious affiliation, his death date and a biographical sketch.[35] Figure 1 presents the distribution of book production. The data have a high proportion of authors with zero books, and suggest the use of models appropriate for the analysis of count data.

I divide the books by disciplines based on their titles. I concentrate on the scientific disciplines outlined in Ibn al-Nadīm's (d. 995) *fihrist*, namely medicine, astronomy-mathematics, philosophy and religious sciences. I then look up every author in the encyclopedia of Islam[36] and create a dummy variable (ENCY) equal to 1 if that author has an encyclopedia entry. The two measures (total number of books and ENCY) are highly correlated and seem to do a good job of measuring the general quality of the writings of a given author. For example, the twelve most productive authors in the sample correspond to some of the most famous Arab scientists: Ya'qūb bin Isḥāq al-Kindī, Abū Bakr Muḥammad bin Zakariyyā' al-Rāzī (Rhazes),

[35] Although some birth dates and death dates are missing, Ibn Abī Uṣaybi'a organizes the authors in each section by the era in which they lived, from earliest to latest. This allows us to impute the birth dates (when not given) with a reasonable degree of accuracy. If either the birth date or death date is missing I add or subtract the average life span in the data set (70 *hijrī* years or approximately 68 solar years).

[36] The encyclopedia of Islam can be accessed online at http://www.brillonline.nl.

Ibn al-Haytham (Alhazen, Avennathan and Avenetan), Muwaffiq al-Dīn ʻAbd al-Laṭīf al-Baghdādī, Abū al-Ḥasan Thābit bin Qurra al-Ḥarrānī, Abū Naṣr al-Fārābī (Alfarabius and Avennasar), Ḥunayn bin Isḥāq, ʻAlī bin Riḍwān, al-Shaīkh al-Raīs Ibn Sīnā (Avicenna), Ibn Khatīb al-Rayy, Quṣtā bin Lūqā al-Baʻalbakkī, al-Walīd bin Rushd (Averroes).

Summary statistics of the variables of interest are in table 1. Column (1) shows that of the reported authors, roughly 55% were born in regions bordering that in which Ibn Abī Uṣaybiʻa lived (the Levant) and that over 25% were either Christian or Jewish.

Figure 2 details the total number of books, and the number of books written on the rational sciences (which we define to include philosophy, mathematics, astronomy, as well as books with ancient Greek authors in their title)[37] and the number of books on religious subjects written by authors born in thirteen 50 year bins. A given author is included in the bin T_k if the time between his birth and the date his birth place was conquered is less than T_k, but greater than T_{k-1}. The number of authors in each 50 year bin is given above each bar. The decline in the number of books written on the rational sciences is apparent, and is broadly consistent with our hypothesis, since the proportion of non-Muslims decreased as the time since conquest increased.

Figure 3 presents the evolution of intellectual production across time and region. Time is measured as the time elapsed since Muslims became the dominant faith. The date in which Islam emerged as the majority is taken from conversion curves calculated by Bulliet (1979). I create the variable $DateMajority_j$ equal to the date estimated by Bulliet to correspond to the emergence of Islam as the dominant religion in a given region (the period Bulliet calls "late majority"). I then construct the variable $sincemajority_{ij} = t_{ij} - DateMajority_j$ (where t_{ij} is the birth date of author i in born in region j) and divide $sincemajority_{ij}$ into 12 50 year bins. A negative value corresponds to a period before Islam emerged as the dominant majority. The number of books written on the rational sciences and on religious subjects are graphed against the variable sincemajority by region in figure 3. Bulliet provides data on the

[37] Medicine is excluded from this group since it appears to have been attacked by the religious elites as a "rational science" relatively late. This was probably due, in part, to its percieved benefits.

conversion rates for 5 regions (Iraq, Iran, N. Africa, Egypt and the Levant). The drop in the number of books written on the rational sciences after Muslims become the majority is a visually striking confirmation of one of the key predictions of the hypothesis.

Map 1 presents the geographical distribution of the birthplaces of scientists who are cited by the Encyclopedia of Islam and Ibn Abī Uṣaybi'a. For clarity I have grouped the scientists into 3 chronological bins. Those born between 100-249 *hijrī* (718-863), between 250-399 *hijrī* (864-1008), and 400-550 *hijrī* (1009-1155). The geographic distribution of scientists suggests that the most productive scientists are born closer to Islam's borders as time progresses. Many border areas were conquered relatively late by Muslim forces, and were probably (on average) less subject to efficient Muslim proselytizing (due to lax government control, for example). This "movement towards the borders" provides additional support for the hypothesis of religious competition, since these regions were most likely the last to see Islam rise as the numerically dominant religion.

3.2.2 Testing the Hypothesis: Empirical Strategy

All else equal, the model predicts that areas with a larger proportion of non-Muslims should produce more scientific works since the religious elites had a stronger incentive to tolerate the use of logic and science to win converts and societal standing. Ideally, we would regress the outcome variable of interest on the proportion of non-Muslims in a given author's place of birth at his date of birth. This last quantity, however, is not available.

The fact that conversion to Islam was non-reversible, however, suggests that the proportion of non-Muslims in a given region should be non-decreasing in the time since that region was conquered by Muslim forces. We estimate this time since conquest by constructing the variable $sinceconquest_{ij} = t_{ij} - dateconquered_{ij}$ where t_{ij} is the birth date of author i in region j and $dateconquered_{ij}$ is the date Muslim forces conquered the birth place of author i in region j. As the variable $sinceconquest_{ij}$ increases, we would expect the proportion of non-Muslims to decrease. If this is true,

than we can test our hypothesis by examining the coefficient β in the regression[38]

$$BOOKS_{ij} = \alpha + \gamma_j + \beta sinceconquest_{ij} + \theta' X + \varepsilon_{ij} \quad (4)$$

where $BOOKS_{ij}$ is the number of books written by author i, born in region j, γ_j are regional fixed effects, and X is a vector of controls including religion dummies and an indicator variable Caliph equal to one if the author received support from the political authority of the day. We include as independent variables the total number of books (Total), books written on philosophy (Phil), books that cite ancient Greek authors (such as Aristotle) in their titles (Greek), books on astronomy or mathematics (AstMath), books on medicine, books on religion, and the dummy variable ENCY that is equal to 1 if the author appears in the encyclopedia of Islam.

The results of equation (4) are presented in table 2. The error term is assumed homoskedastic as suggested in Cameron and Trivedi (1986). The results show a downward trend in the number of books, especially among the rational sciences. To test whether this trend differed between Muslim and non-Muslim scientists, we experimented by including an interaction term between $sinceconquest_{ij}$ and the Muslim indicator variable. Although the data do not allow us to distinguish statistically between the trends for the two groups, we report this interaction term for books written on philosophy in column (3) (the signs are similar for Greek and AstMath). The negative sign on this interaction term is consistent with the hypothesis, since we would expect Muslim authors to experience greater pressures to decrease their production of books on philosophy than other non-Muslims.

Although results using the time since a given region was conquered as a proxy for the proportion of non-Muslims support the hypothesis, the rest of this section investigates the robustness of this result to other measures of the proportion of non-Muslims. Ibn Abī Uṣaybi'a's catalog provides us with an alternative measure for the proportion of non-Muslims. As explained above, the catalog provides the

[38]The results using a negative binomial specification produced very similar qualitative results. Results using econometric models appropriate for count data are presented in the following subsection.

religious affiliation of each author. We calculate the proportion of all scientists who are Christian[39] across all regions in 50 year time intervals, where time is measured as the time between a given author's birth and the date his place of birth was conquered (sinceconquest), i.e. we calculate

$$Chr_{T_k} = \frac{\sum_{\{i,j|t\in(T_{k-1},T_k]\}} Chri_{ij}}{N_{T_k}} \tag{5}$$

This quantity is detailed in figure 4, where we omit the two bins estimated with less than 5 authors. Although the measure (5) gives a plausible estimate of the proportion of Christian authors in each 50 year time interval, the mapping between the proportion of Christian authors and the proportion of non-Muslims is imperfect. Despite this caveat, the strong downward trend in figure 4 is encouraging, suggesting that the decline does broadly correspond with the decrease in non-Muslim populations due to conversion. Equipped with the variable Chr_{T_k} we run the regression:

$$BOOKS_{T_k} = \alpha + \beta Chr_{T_k} + \varepsilon_{T_k} \tag{6}$$

where $BOOKS_{T_k}$ is the total number of books written in the 50 year bin T_k divided by the number of authors in that bin. Although there are only 11 observations at this level of aggregation, the results presented in the first column of table 3 show a positive correlation between the two variables.

Although aggregating the data into 50 year bins allows us to estimate the proportion of Christian authors reasonably accurately, this broad level of aggregation limits the analysis. We can also use the data to calculate the proportion of Christian authors at the region-time level. Disaggregating the variable Chr_{T_k}, however, requires estimating many bins with only a handful of observations. We only use bins that have at least 3 observations and calculate:

$$Chr_{JT_k} = \frac{\sum_{\{i|j=J,t\in(T_{k-1},T_k]\}} Chri_{ij}}{N_{JT_k}} \tag{7}$$

[39] We focus on Christians, since Christians were initially the vast majority in most regions covered by the data.

Discarding the bins estimated with less than 3 authors leaves 39 region-time bins. We then regress:

$$BOOKS_{jT_k} = \alpha + \gamma_j + \beta_1 Chr_{jT_k} + Caliph_{jT_k} + \varepsilon_{jT_k} \tag{8}$$

where γ_j are regional fixed effects and $Caliph_{jT_k}$ is the proportion of authors who received support from the political ruler in region j during the 50 year period T_k. The results are presented in columns (2) through (6) of table 3. Column (2) details the results with the average number of books written on philosophy as the dependent variable, column (3) has the average books written on the "rational sciences" as the dependent variable. The correlation between the proportion of Christian authors and the dependent variables of interest now becomes significant at conventional levels. In addition, the results show a strong correlation between political support and the cultivation of the rational sciences.

Given that the variable Chr_{jT_k} is measured with error, we instrument for this quantity with the variable T_k (which is the time since conquest, measured in 50-year intervals). While the first stage relationship between Chr_{jT_k} and the instruments is statistically significant, the first-stage suggests that the instruments are weak.[40] With this caveat in mind, we present the results in column (5).

In light of the weak instruments problem, we replace Chr_{jT_k} in (8) with Chr_{T_k} and instrument with T_k. The first stage relationship is much stronger,[41] and we present these results in columns (5) and (6). The qualitative implications of the results remain similar across specifications, with the typical inflation in the point estimates (due, perhaps, to measurement error in our estimate of the proportion of the non-Muslim population).

As a final robustness check, we use data on conversion rates in the medieval period as calculated in Bulliet (1979). We create a dummy variable Majority equal to one if a given author was born after the date at the end of the period Bulliet dubbs "late majority." We then run (8) replacing the variable Chr_{jT_k} with $Majority_{jT_k}$,

[40] The first stage F-stat is 4.41.

[41] The first stage F-stat is 43.43.

the proportion of authors born in the 50 year bin T_k in region j who were born after Islam become the "majority" (this quantity is zero or one for the vast majority of observations). The results, again, are consistent with a drop in the production of the rational sciences as Islam emerged as the majority.

Finally, we return to the individual level. We begin by using OLS (models more appropriate for count data will be considered in the following sub-section).

At the individual level, we have no ready measure of the proportion of Christians (aside from the variable sinceconquest mentioned above). Given the measurement error problems involved using the more disaggregated variable Chr_{jT_k} (which is measured with less than 10 observations for the vast majority of authors), we begin by running the individual level regression

$$BOOKS_{ij} = \alpha + \gamma_j + \beta Chr_{T_k} + \theta' X + \varepsilon_{ij} \tag{9}$$

These results are presented in table 4. Columns (1)-(3) detail results for the independent variables for the total number of books, books on philosophy and those written on the rational sciences. The results instrumenting for Chr_{T_k} with the variable $sinceconquest_{ij}$ are presented in columns (4)-(6) and the results replacing Chr_{T_k} with the variable $Majority_{ij}$ which is equal to one if the author was born after Islam emerged as a majority in region j are reported in columns (7) and (8). The results show that the number of books written on the rational sciences sharply decreased after Islam emerged as the dominant majority, in support of the hypothesis that the religious authorities only valued these sciences for purposes of religious competition.

Exponential Mean There may be problems using OLS at the individual level, given that the data are non-negative and exhibit overdispersion. We therefore use a negative binomial specification with the conditional mean specified as:

$$E(BOOKS_{ij}|X) = \exp(\alpha + \gamma_j + \beta Chr_{T_k} + \theta' x) \tag{10}$$

where the variables are as previously defined. The results of (10) are presented in column (1) of table 5 where we also include an interaction term between Chr_{T_k}

and the indicator variable Muslim. Column (2) replaces the variable Chr_{T_k} with the dummy variable $Majority_{ij}$. The qualitative implications of these results are consistent with those obtained using OLS.

In the case of a nonlinear mean, correcting for measurement error becomes more complicated. We begin by using a two step estimation procedure as suggested in Mullahy (1997) and Carroll, Ruppert and Stefanski (1995). We project the variable Chr_{T_k} onto the instruments,[42] estimate (10) by maximum likelihood with $\widehat{Chr}_{ij}$ in place of Chr_{T_k} and appropriately correct the standard errors. Although this empirical strategy is only consistent under fairly stringent assumptions (classical measurement error, or alternatively that the linear reduced form for Chr_{T_k} is correctly specified) these results are robust. We denote estimates obtained in this manner by adding the superscript IV to the end of the independent variable. These results are detailed in columns (3), (4) and (5) for the total number of books, number of books written on philosophy and number of books written on the rational sciences.

As a final robustness check, we instrument directly by assuming an orthogonality condition and estimating the parameters by GMM. We begin by assuming the error term to be additive in the exponent and thus multiplicative. Mullahy (1997) shows this specification can be consistently estimated by redefining the residual to be $T(y, x, b) - 1$ where $T = \exp(-x'\beta)y$. This residual defines the moment condition $E[Z'[T - 1]]$, where Z are the instruments, and can be solved by NLIV or GMM. Columns (6) and (8) report the estimates obtained in this manner for the total number of books, and books written on the rational sciences. GMM standard errors are reported, and are much smaller if we assume the errors to be of a standard parametric form (e.g. NB2). The qualitative implication of the results instrumenting in this matter do not change.

Finally, we consider the implications of the assumption of an additively separable error as suggested in Amemiya (1985). Treating the error in this manner defines the moment condition $E[Z'[y - \exp(x'\beta)]]$. We report the coefficients obtained in this manner for the number of books written on the rational sciences in column (7).

[42] The first stage F-stat is 262.44.

Although the magnitude of the point estimates differ from those reported in (8), the qualitative implications remain.

In sum, the quantitative evidence supports the hypothesis of a positive effect of religious competition on Muslim medieval scientific production. If one believes that the variable $sinceconquest_{ij}$ is not (at least) systematically correlated with unobservables that affect scientific production, the point estimates can be interpreted as the causal effect of the proportion of Christian authors on scientific production.

Confounding Factors The empirical results confirm the predictions of the model. There are, however, several potential problems with the empirical strategy. We investigate the most serious problems one by one.

Regional Bias The results presented use data on authors from present-day Spain to Khazakstan. Although we attempt to control for time invariant regional differences by adding regional fixed effects, there is the possibility that data from more distant regions are unreliable. Limiting the sample to observations from the regions Egypt, the Levant and Iraq (Egypt, Iraq, Israel, occupied territories, Syria and Jordan), however, produces similar results. This result argues against an important regional bias in the data, since Ibn Abī Uṣaybi'a knew these regions well.

Trends: Political Fragmentation and the Crusades Given that we instrument with the time since a given author's place of birth was first conquered by Muslim forces, we are assuming that on average this is (at least) not correlated with unobservables after subtracting various fixed effects.

Although it is impossible to prove that the time since conquest is not correlated with other societal wide trends, the period covered by our sample shows no monotonic trend in civilizational "decline." The Golden Age of Muslim science in Spain occurred around 1100, that of Egypt during the Fatimid Empire (910-1171) and that of northern Syria under Sayf al-Dawla (916-967). Moreover, although there is an obvious trend towards political fragmentation during our sample, Moykr (1990),

pp. 264 argues that political fragmentation helped foment European scientific production .

The start of the Crusades (1095), is probably the biggest threat to the validity of the identifying assumption. Some scholars have argued that the Crusades polarized Muslim society (Gutas (1998) pp. 170-171) which in turn led to a decrease in scientific production. Given that this period corresponds to the emergence of Islam as the dominant majority in many regions, our results could be picking up the effects of the Crusades.

If the Crusades are important in explaining the decline in intellectual production, we would expect the regions most affected by Crusader attacks to show significant declines in intellectual production. In addition, we would expect production of books dedicated to religion to increase and those dedicated to philosophy and the rational sciences to decrease.

We start by creating a dummy variable Crusade equal to 1 if the author was born after 1095 (487 *hijrī*), the start of the first Crusade. We concentrate on the change in the conditional mean of the independent variable of interest across regions by using the specification:

$$BOOKS_{ij} = \alpha + \gamma_j + \sum_{j=1}^{5} Region_j * Crusade_{ij} + \gamma' X + \varepsilon_{ij} \tag{11}$$

Where Region is a dummy variable equal to one if the author is born in the given region (the same regions as the fixed effect γ_j), and X is a vector of controls. The results for the Levant, the region most affected by the Crusades, are mixed (see table 11). While the decline in books written on philosophy and the rational sciences is consistent with a negative effect of the Crusades on intellectual production, this decline is not unique, nor especially pronounced in the Levant.

Further inspection of table 6 shows that the regions Iraq, Persia and Egypt all exhibit a similar decline in the production of the rational sciences following the first Crusade (although these are not significant at conventional levels). Moreover, Persia shows the largest increase in books written on religious subjects. The estimated effect of the Crusades on intellectual production in north Africa is small and statistically

insignificant. Although this broad pattern is consistent with a negative effect of the Crusades, it is also consistent with our hypothesis of a decline in religious competition during this period (since the region N. Africa was conquered later than the other regions, and Muslims consequently emerged as a majority at a later date).

To further investigate the possible biases induced by the Crusades, I dropped all scientists born after the start of the first Crusade and reran the previous regressions. All the previous qualitative implications hold (with noisier standard errors).

Finally, it is worth noting that the experiences of Muslim Iberia and the Ottoman Empire cast doubts on the negative net effect of foreign military aggression on scientific production. Some of the Iberian Penninsula's most brilliant Muslim thinkers were born in a period in which the Christian kingdoms were rapidly conquering Muslim territory (the twelfth and thirteenth centuries). In the Ottoman Empire, military defeat appears to have encouraged a large scientific translation movement. In addition, while the qualitative evidence from Iraq might reflect the effects of the Crusades, it is difficult to imagine this affecting Ibn Khaldūn writing in Morocco more that 200 years later.

In sum, although it is impossible to rule out unobservable societal trends, there are no obvious unmeasured political, scientific or social trends over the period.

Outliers Figure 1 shows that the vast majority of authors wrote less than 10 books. This raises the possibility that the results are driven by outliers. Although the results presented do hinge on including the most productive authors, inference without these authors often leads to similar qualitiative conclusions (depending on the cutoff point). Furthermore, given the nature of the data, it is not clear what the results without the most productive scientists represent. Just as it would be hard to imagine the Renaissance without Galileo or Da Vinci, the Muslim "Golden Age" without Ibn Sīnā or Ibn Haytham is incomplete. Indeed, there are plausible arguments for giving the most productive scientists more weight than the rest of the observations.

4 Conversion to Islam, a Decline in Religious Debates and the Stagnation of Muslim Science

Muslim religious elites significantly changed their attitudes towards the study of logic and the rational sciences during the centuries covered by our analysis. Initial support, or at least tolerance, for the study of logic and the rational sciences shifted around the twelfth century to intolerance and sometimes repression. The theory of religious competition explains why Islam's most conservative elements tolerated the use of logic for centuries despite the potential threat it posed. This theory also provides an explanation for their increasingly intolerant attitude toward these subjects.

Other scholars have pointed to a change in attitudes among religious elites to various forms of learning. Bernard Lewis argues that religious authorities became less tolerant of *ijtihād* (the exercise of independent judgment in legal matters) and encouraged instead a reliance on tradition. He links this shift in attitudes toward *ijtihād* to the stagnation of Muslim science. According to Lewis, once Muslim scholars had resolved all the issues that were not answered by scripture or tradition, independent judgment ceased to be necessary. Instead, jurists could rely solely on precedent (Lewis (1982), pp. 230).

The theory of religious competition developed in this paper expands upon these earlier ideas in two ways. First, it explains the timing of this change. Second, it more fully explains why Muslim religious authorities could begin to claim they "had all the answers." Religious authorities could not make such a claim earlier because of religious competition. While large and relatively well-educated non-Muslim populations remained, religious elites had to respond to their questions and doubts.[43] If they failed to do this, they risked losing potential converts to other religions who developed more convincing arguments. Once the majority of the population converted

[43]Bulliet explains that "Islamic society originally formed itself at the edge through an iterative process of question and answer. New Muslims sought to discover what it meant to be a Muslim, and Muslims from families of longer standing in the *umma* sought to refine the understandings they had inherited from parents and teachers, and to answer the questions of others" (Bulliet (1994), pp. 180).

to Islam, however, the authorities had little incentive to support logical debates, or entertain "new" interpretations.[44] At this point the study of logic became more dangerous than beneficial.

While Muslim religious authorities would perhaps have liked to repress logic from the start, large and relatively well-educated non-Muslim populations under their control prevented this repression. As the non-Muslim population decreased, however, so did the tolerance constraints (towards the rational sciences) on Muslim religious elites.

Muslim religious authorities were not unique among world religious leaders in their latent desire to repress logic and encourage religious orthodoxy. However, the rapid conquest of large territories with relatively well-educated populations, coupled with the *dhimmī* institution combined in a unique way to constrain these elites to tolerate the study of logic and the rational sciences. Their tolerance led, in turn, to prolific scientific development. When their unique tolerance constraints diminished and elites could engage in repression of the sciences, scientific development stagnated. The fact that "no social institutions were founded that could protect and support freethinking" (Huff (1993), pp. 360), meant that the fate of the rational sciences never left the hands of the religious elites. Once the majority converted to Islam by the close of the eleventh century "traditionalism prevailed over its adversaries [among which were rationalism] in the institutional domain, especially among educational institutions" (Makdisi (1975), 237).[45]

[44] This point is stressed by the experience of the *Mu'tazilite* movement. Indeed, the use of logic and rationalism "could be overlooked [...] so long as the *Mu'tazilites* perceived their main task as the struggle against dualism [a competing non-Muslim creed] and propaganda on behalf of Islam, and so long as they left the orthodox undisturbed. That changed, however, when [...] the dualistic peril was overcome." (Fueck (1939), pp. 107)

[45] Although the effects of the Ottoman conquests of Anatolia and the Balkans on religious competition and scientific research are beyond the scope of this paper, there is suggestive evidence that both rose following the Ottoman conquests (Gutas (1998), pp. 173-174).

4.1 A Decline in Religious Debate? Inter-Islamic Religious Discussion.

The analysis so far has treated Muslim religious elites as homogenous. While this assumption seems justified for modeling the costs and benefits of the use of logical methods (see footnote [13]) to combat the non-Muslim threat, our assumption also implies that religious competition ended when the entire population converted to Islam. Sectarian splits within Islam, however, continued long after the majority of the population converted. Thus, explaining why inter-Islamic debate did not create the same religious competition based on logic is crucial to using the theory of religious competition to help explain Muslim scientific stagnation.

For this explanation, we turn to the model developed early in the paper. In this model, a given religious elite will support the use of logic if the benefits of its use (refuting the competitor) overcomes the costs (threats to religion's societal standing). The benefits of encouraging the use of logic will only dominate its costs if the competitor is a large enough threat; if the rival sect has a significant numerical following.

There is evidence that by the time the conversion process to Islam was largely complete, Sunni Islam was the numerically dominant Islamic sect in most regions. In addition, Sunni Islam itself moved, from the twelfth century on, toward theological uniformity (Bulliet (1994), pp. 153). For religious competition to encourage scientific production, the sects would have to become numerous enough to threaten the dominant religious authorities, and these authorities would have to be constrained to tolerate the presence of dissenters. Only then would religious authorities encourage the study of logic to refute the tolerated and threatening sectarians.

Most often, however, Muslim sectarians did not emerge as numerical threats to the dominant authorities. Even when they did, the tolerance constraints of the *dhimmī* institution did not apply.[46] Unlike the *dhimmī*, Muslim sectarians could be branded heretics and legally and forcibly repressed. Rather than risking theological

[46] Muslim law only guaranteed protection to non-Muslims. Muslims who committed apostasy could be legally killed.

debates that were necessary when force was not an option, authorities could persecute Muslim sectarians under religious law. Indeed, it appears that minority Muslim sects were tolerated as long as they did not threaten the authorities' power. If they grew too influential, however, they were repressed (Lewis (1953), pp. 61).

In the framework of the model, then, the religious authorities of the dominant Muslim sect in a given area did not support the use of logic to refute other Muslim sects because it was not optimal to do so. These elites did not face the same tolerance constraints vis-à-vis Muslim sectarians as they did with the non-Muslim populations. Thus, any increase in the minority sectarian population could be dealt with by force, imposing a smaller cost on the religious authorities. If the minority religious sects knew the majority would respond by using repression, the costs of gaining followers would outweigh the benefits, and both the minority and majority sects had incentives to "disengage."

This prediction is supported by the evolution of Muslim theology. Indeed, jurists came to the conclusion that "the vital barrier lies, not between Sunni and sectarian, but between sectarian and unbeliever" (Lewis (1953), pp. 58). Under this "implicit contract" Muslim sectarians were tolerated in so far as they did not attempt to increase their numbers, and threaten the power of the dominant sect.

In sum, although there were sectarian splits within Islam from its inception, these splits did not, in general, produce the same "religious competition" as the divide between Muslims and non-Muslims did.[47] This seems to have been due to the emergence of a numerically dominant Muslim sect in most regions towards the end of the conversion process to Islam and the fact that sectarians did not enjoy the same legal protection as non-Muslims. Under these conditions, the use of logical methods and debates to combat sectarians was more of a cost to the dominant religious elites than it was worth.

[47]The rise of Shi'ism as a mass religion in the Seljuk period did seem to lead to a surge in philosophical production. During this period, there was a "torrent of philosophical discussion, argumentation, and counter-argumentation –and a corresponding literary output– among Sunni and Shi'ite Muslims in the central Islamic lands" (Gutas (1998), pp. 172).

5 Conclusion

This paper has argued that tolerance, diversity and religious competition were central to the development of Muslim science in the Middle Ages. It shows that the decline of the proportion of non-Muslims then led the religious authorities to discourage the study of the rational sciences.

More generally, the analysis suggests that institutions that enforce tolerance can channel between-group interactions in heterogenous societies towards productive ends. Although differences in religious beliefs have sometimes led to tragedy, medieval Islam used these differences to produce one of history's most scientifically advanced civilizations. Competition between faiths ensured that no single societal orthodoxy could emerge and created an atmosphere conducive to "freethinking."

Despite centuries of tacit support for the study of the rational sciences, Muslim religious authorities could not "credibly commit" to encouraging scientific research in their communities. As the societies under Islam became more monolithic religiously, authorities had fewer incentives to support science. No longer subject to the pressures of competition, religious leaders withdrew their support for the study of the sciences. This decline in support contributed to the stagnation of Muslim science.

Although the application of this theory to Renaissance and Enlightenment Europe remains a topic for future research, there is suggestive evidence that religious competition was central in encouraging religious authorities to allow thinkers to address a wide range of topics otherwise considered taboo. A prominent scholar of the Enlightenment has argued that "theological debate [...] lay at the heart of the Early Enlightenment" (Israel (2006), pp. 65). If this is the case and religious competition was instrumental in Europe's eventual scientific development, then future research must explain how Europe was able to avoid the fate of Muslim science.

Is Islam compatible with modern economic development? The results presented in this paper cast doubts on claims that Islamic societies are inherently hostile to "Western" economic reforms. The experience of scientific production during the Muslim Golden Age, suggest that Islamic societies are more similar to their non-Islamic counterparts than many Islamic economists today would admit.

Evidence from one of Islam's greatest eras shows how diversity of beliefs, and Islam's unique tolerance of this diversity, constrained Islam's most conservative elements for centuries. Contrary to those who use the scientific and economic advances of medieval Islam as justification for a "return" to Islamic "orthodoxy," detailed analysis of one medieval Islamic institution suggests the central role of tolerance and personal freedoms in the economic successes of medieval Islam. In absence of a return to these *Qur'ānic* principles, Muslim science will likely remain the victim of its own success.

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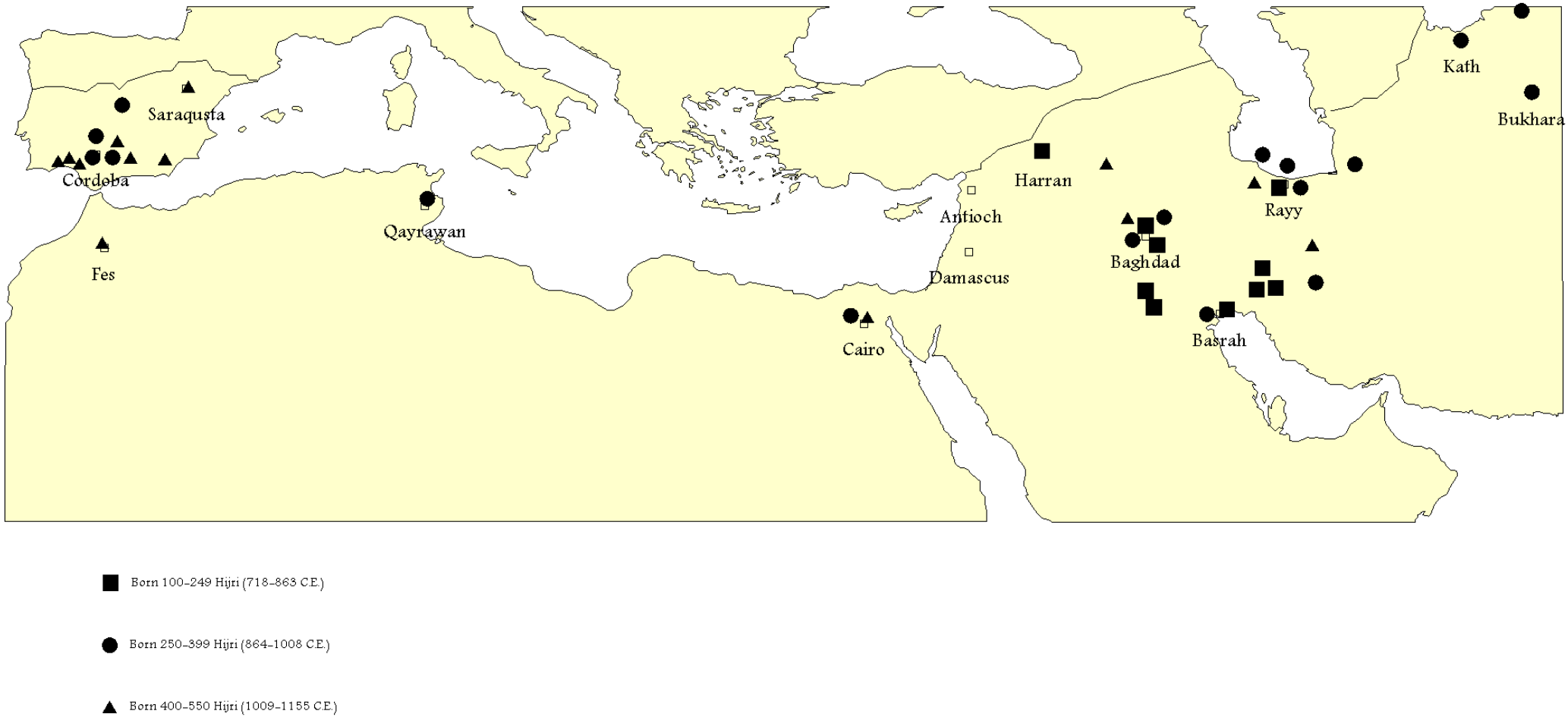
Map 1. Distribution of Scientists Cited in the Encyclopedia of Islam by Birth Place



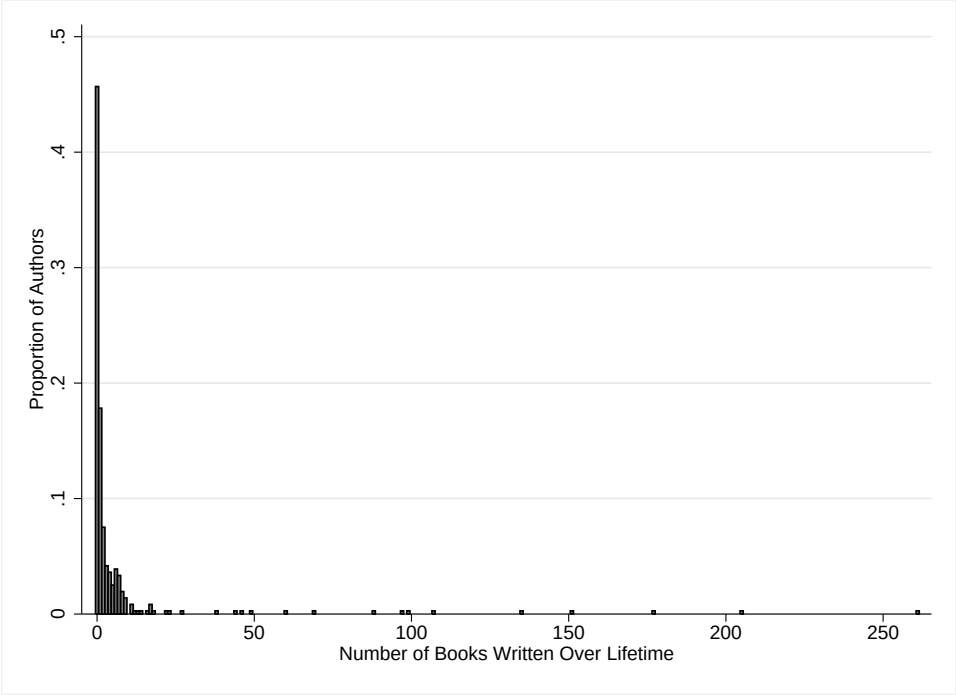


Figure 1: **Distribution of Book Production**
Number of books written over author's lifetime

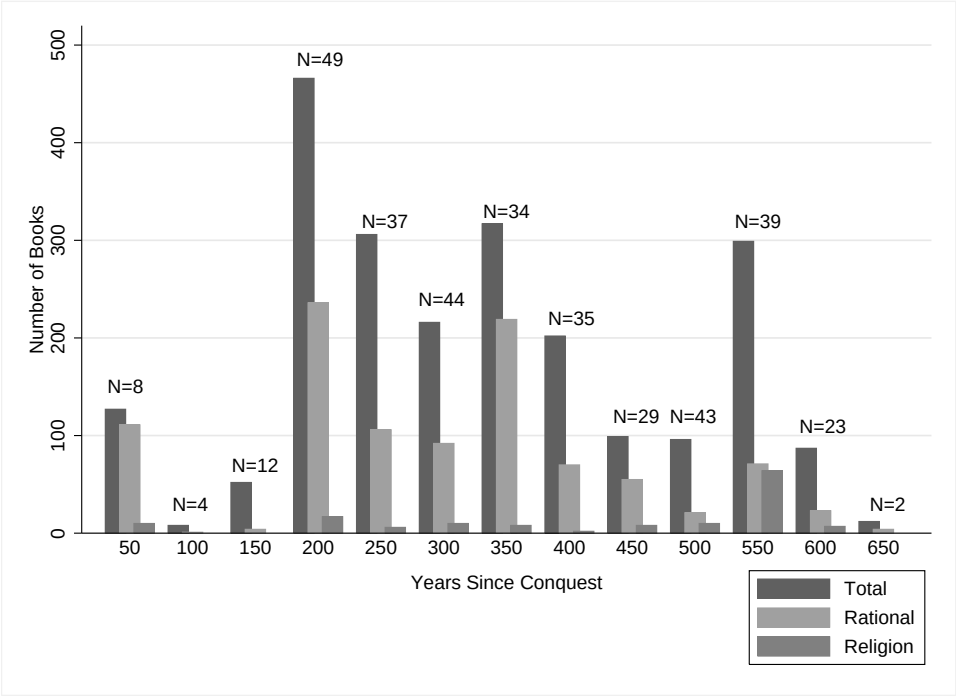


Figure 2: **Intellectual Production by Years Since Conquest**
Total number of books written in 50 year bins

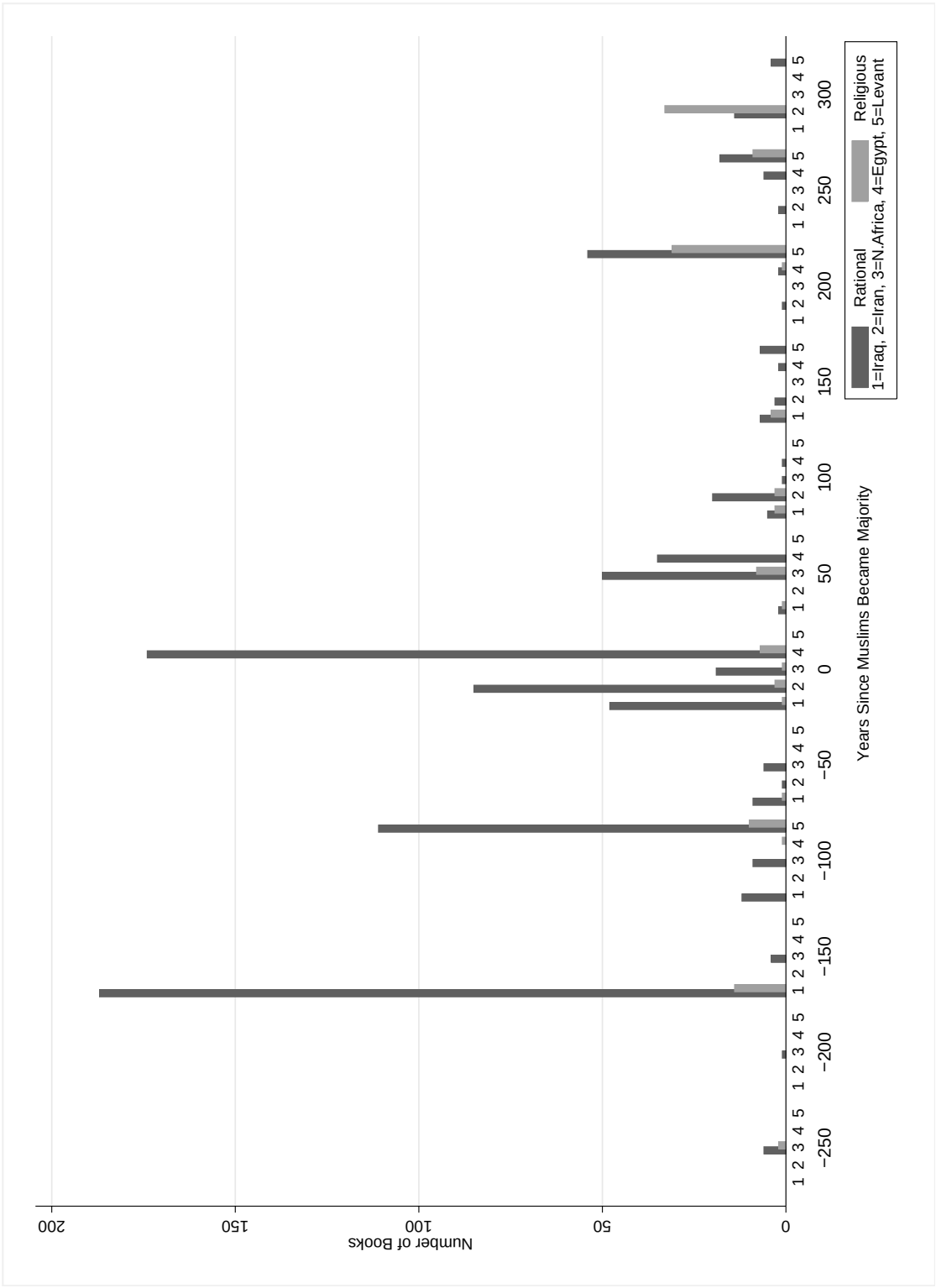


Figure 3: **Intellectual Production by Years Since Majority**
Number of books written in 50 year bins across regions

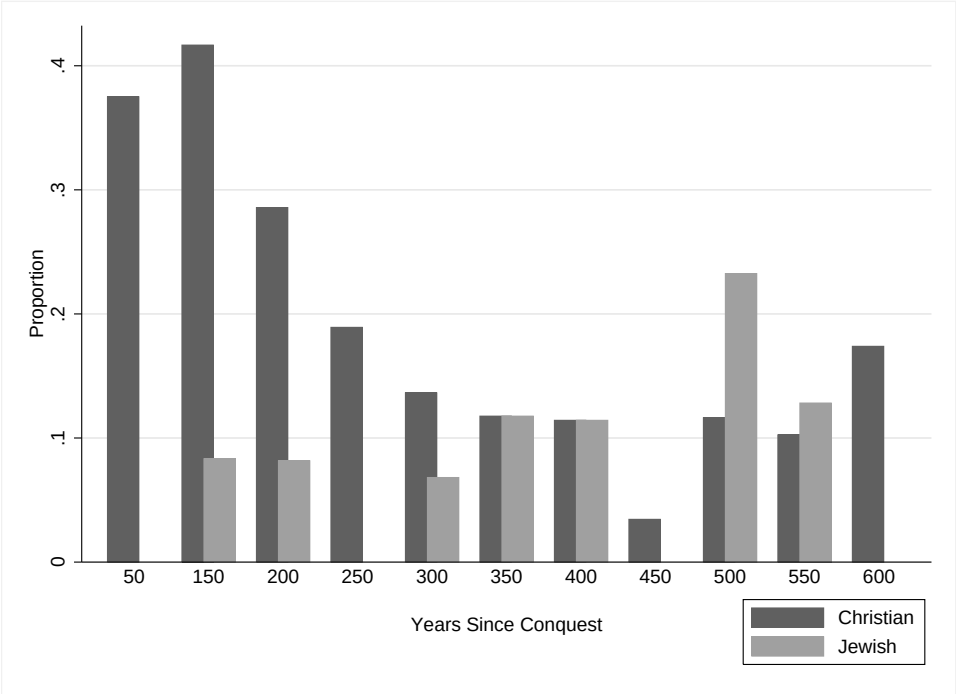


Figure 4: **Proportion of non-Muslim Authors**
Proportion of authors in 50 year bins if N>5

Table 1: **Summary Statistics**

Variable	*Description*	*Mean* (1)	*St.dev.* (2)	*Min* (3)	*Max* (4)
"Region"					
Iraq	Iraq	0.23	0.42	0	1
N.Africa	Spain or N. Africa	0.25	0.43	0	1
Persia	Iran and East	0.07	0.25	0	1
Egypt	Egypt	0.16	0.37	0	1
Levant	Levant	0.17	0.37	0	1
Early	First Islamic Century	0.03	0.16	0	1
Syriac	Syriac	0.11	0.31	0	1
Religion					
JEW	Jewish	0.09	0.29	0	1
CHRIS	Christian	0.17	0.37	0	1
Productivity					
Total	Total Books	6.6	25.24	0	261
Medicine	Medicine	2.70	9.23	0	109
Greek	Greek Author in Title	0.92	4.54	0	41
Religion	Religious Topic	0.40	2.39	0	33
Refute	Refutes Another Religion	0.06	0.40	0	4
Phil	Philosophy	1.20	6.73	0	74
AstMath	Astronomy or Mathematics	0.70	6.47	0	91
ENCY	Cited in Encyclopedia of Islam	0.15	0.36	0	1
Period (*Hijrī*)					
Birth	Date of Birth	382.99	142.84	20	630
DateConquered	Date Place of Birth Conquered	41.34	34.25	6	225
Since	Birth - DateConquered	341.66	144.39	7	614
Majority	Born After Islam is Majority	0.52	0.50	0	1
Support					
Caliph	Employed by Political Authority	0.47	0.50	0	1

Notes: N=359

Table 2: **The Evolution of Intellectual Production by Discipline**
Total number of books written by discipline since conquest by Muslim forces

	Total	*Phil*	*Phil*	*Greek*	*AstMath*	*Medicine*	*Religion*	*ENCY*
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Since	-2.95	-1.28	-0.64	-0.56	-0.68	0.26	0.06	-0.002
	(1.32)	(0.35)	(0.52)	(0.24)	(0.34)	(0.48)	(0.13)	(0.019)
$Since * Mus$			-0.82					
			(2.06)					
Iraq	9.88	3.10	2.96	1.61	2.11	-1.67	0.08	0.09
	(5.21)	(1.38)	(1.38)	(0.95)	(1.36)	(1.90)	(0.45)	(0.07)
Persia	21.46	6.41	6.46	1.56	2.15	6.62	1.71	0.22
	(6.56)	(1.73)	(1.73)	(1.20)	(1.71)	(2.39)	(0.50)	(0.09)
N.Africa	2.98	1.88	1.80	0.81	0.77	-2.21	-0.085	0.06
	(4.96)	(1.31)	(1.31)	(0.91)	(1.29)	(1.81)	(0.63)	(0.07)
Egypt	9.59	3.72	3.63	2.14	3.21	-2.96	-0.09	-0.05
	(5.94)	(1.57)	(1.57)	(1.08)	(1.55)	(2.16)	(0.47)	(0.08)
Levant	13.33	6.04	6.01	2.25	2.41	-1.33	0.48	-0.04
	(6.76)	(1.79)	(1.79)	(1.23)	(1.76)	(2.46)	(0.57)	(0.10)
Chri	4.90	-0.05	0.34	1.30	-0.15	1.91	0.09	-0.04
	(5.60)	(1.48)	(1.52)	(1.02)	(1.46	(2.04)	(0.65)	(0.08)
Mus	4.58	1.31	3.66	0.68	1.07	0.66	0.35	-0.06
	(4.74)	(1.26)	(2.35)	(0.87)	(1.24)	(1.73)	(0.45)	(0.07)
Caliph	5.16	0.96	0.95	0.61	0.18	1.63	0.29	0.11
	(2.67)	(0.71)	(0.71)	(0.49)	(0.70)	(0.97)	(0.25)	(0.04)

Notes: Total is the total number of books written by a given author.
Phil is the number of books written on philosophy.
Greek is the number of books written citing an ancient Greek author in the title.
AstMath is the number of books written on astronomy or mathematics.
Since is the time elapsed between the author's birth date and the date his birthplace was conquered by Muslim forces.

Table 3: **Impact of the Proportion of Christians on Intellectual Production**
The dependent variable is the average number of books in the indicated disciplines and region-time bins

	$Total_{T_k}$	$Phil_{jT_k}$	Rat_{jT_k}	$Phil^{IV}_{jT_k}$	$Phil^{IV}_{jT_k}$	$Rat^{IV}_{jT_k}$	$Phil_{jT_k}$	Rat_{jT_k}
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Chr_{T_k}	15.14				50.02	82.47		
	(9.46)				(21.69)	(35.02)		
Chr_{jT_k}		7.59	14.33	11.62				
		(3.61)	(8.81)	(9.21)				
$Majority_{jT_k}$							-6.63	-11.92
							(3.34)	(5.33)
$Iraq$		2.36	7.24	2.49	11.31	21.87	-1.49	0.28
		(2.24)	(5.47)	(2.30)	(6.80)	(10.98)	(5.31)	(8.47)
$Persia$		6.63	10.61	7.20	10.28	16.39	-0.95	-2.81
		(2.36)	(5.75)	(2.69)	(5.77)	(9.31)	(5.27)	(8.41)
$N.Africa$		2.29	4.51	3.21	9.54	15.93	-4.72	-8.31
		(2.44)	(5.94)	(3.14)	(6.89)	(11.13)	(5.78)	(9.23)
$Egypt$		0.14	2.01	0.23	6.90	13.33	-2.89	-3.25
		(2.24)	(5.47)	(2.29)	(6.24)	(10.07)	(5.06)	(8.08)
$Levant$		1.73	2.88	2.14	16.19	25.32	6.20	8.48
		(2.48)	(6.04)	(2.66)	(6.03)	(9.74)	(5.03)	(8.02)
$Caliph_{jT_k}$		5.89	14.22	5.95	7.31	12.49		
		(2.40)	(5.85)	(2.45)	(5.07)	(8.18)		
N	11	39	39	39	53	53	53	53

Notes: Subscript T_k indicates that the variable has been averaged over the 50 year interval T_k (see text for details).
Subscript jT_k indicates that the variable has been averaged over the 50 year interval T_k for each region j.
Superscript ^{IV} indicates estimates using T_k as an instrumental variable for the variable Chr_{T_k}.
Majority is an indicator variable equal to 1 if the author was born after Islam emerged as the dominant majority.
Rat is the sum of books on philosophy, astronomy, mathematics and book citing ancient Greek authors.

Table 4: **Impact of the Proportion of Christians on Intellectual Production**
Regressions at the author level, linear mean

	$Total$	$Phil$	Rat	$Phil^{IV}$	$Phil^{IV}$	Rat^{IV}	$Phil$	Rat
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Chr	38.91	14.17	27.35	31.66	21.20	62.29		
	(20.39)	(5.44)	(12.35)	(8.45)	(12.13)	(19.12)		
$Chr_{T_k} * Mus$					13.67			
					(12.07)			
$Majority$							-2.53	-5.50
							(0.96)	(2.16)
Mus	4.18	1.18	2.90	1.12	-0.93	2.77	1.41	3.30
	(4.86)	(1.30)	(2.94)	(1.32)	(2.24)	(2.98)	(1.43)	(3.21)
Chr	4.55	-0.13	1.10	-0.73	-0.10	-0.11	-0.13	0.68
	(5.79)	(1.54)	(3.50)	(1.58)	(1.67)	(3.58)	(1.74)	(3.91)
$Iraq$	11.00	3.16	6.82	6.25	5.99	13.00	-2.08	-2.47
	(5.90)	(1.57)	(3.57)	(1.96)	(1.96)	(4.43)	(1.31)	(2.94)
$Persia$	22.73	6.56	10.26	8.89	8.88	14.91	2.42	3.28
	(7.00)	(1.87)	(4.24)	(2.08)	(2.08)	(4.70)	(1.74)	(3.90)
$N.Africa$	4.56	2.20	4.00	4.88	4.77	9.36	-3.43	-6.26
	(5.64)	(1.50)	(3.41)	(1.81)	(1.81)	(4.11)	(1.41)	(3.16)
$Egypt$	8.85	2.92	7.46	5.95	5.68	13.51	-1.80	-0.76
	(6.16)	(1.64)	(3.73)	(2.00)	(2.00)	(4.53)	(1.36)	(3.05)
$Levant$	9.54	3.95	6.56	7.02	6.75	12.70		
	(6.18)	(1.65)	(3.74)	(2.01)	(2.02)	(4.56)		
$Caliph$	5.32	1.01	1.82	0.92	0.87	1.64	1.07	1.80
	(2.72)	(0.73)	(1.65)	(0.74)	(0.74)	(1.67)	(0.82)	(1.84)
N	353	353	353	353	353	353	311	311

Notes: Superscript ^{IV} indicates estimates using sinceconquest as an instrumental variable for the variable Chr_{T_k}.
The variable Majority is only defined for Iraq, Persia, N. Africa, Egypt and the Levant.

Table 5: **Impact of the Proportion of Christians on Intellectual Production**
Regressions at the author level, exponential mean

	$Total$	Rat	$Total^{IV}$	$Phil^{IV}$	Rat^{IV}	$Total^{IV}_{MULT}$	Rat^{IV}_{ADD}	Rat^{IV}_{MULT}
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	
Chr_{T_k}	6.81		14.06	11.25	11.43	11.93	11.44	20.99
	(2.70)		(4.14)	(4.03)	(3.83)	(5.15)	(4.57)	(7.89)
$Chr_{T_k} * Mus$	-4.98		-7.82			-8.02	2.14	-13.97
	(3.29)		(4.35)			(5.06)	(3.33)	(7.50)
$Majority$		-1.17						
		(0.62)						
Mus	1.58	1.42	1.37	0.82	1.29	2.77	0.51	2.33
	(0.60)	(0.55)	(0.73)	(0.53)	(0.48)	(0.88)	(1.43)	(1.20)
Chr	0.95	0.82						
	(0.46)	(0.73)						
$Iraq$	1.16	-0.42	1.98	2.78	2.49	1.34	3.44	2.54
	(0.55)	(0.72)	(0.73)	(1.14)	(1.13)	(0.62)	(1.44)	(0.94)
$Persia$	2.29	0.80	2.91	4.01	3.15	2.56	2.94	3.55
	(0.61)	(0.59)	(0.75)	(1.04)	(1.08)	(0.56)	(1.09)	(0.82)
$N.Africa$	0.38	-1.25	0.90	2.12	1.71	0.48	1.73	2.17
	(0.50)	(1.06)	(0.61)	(0.95)	(0.99)	(0.70)	(1.15)	(1.11)
$Egypt$	1.41	-0.03	1.98	2.74	2.79	1.51	3.72	3.11
	(0.72)	(0.71)	(0.82)	(1.19)	(1.25)	(0.84)	(1.55)	(1.17)
$Levant$	1.37		6.56	3.03	6.75	1.49	3.20	2.34
	(0.59)		(0.69)	(0.96)	(1.02)	(0.64)	(1.11)	(0.92)
$Caliph$	0.39	0.28						
	(0.31)	(0.73)						
N	353	311	353	353	353	353	353	353

Notes: Heteroskedastic-robust standard errors are in parentheses.
Subscript $_{MULT}$ indicates the results were obtained by GMM with moment condition $E[Z'[T-1]] = 0$.
Subscript $_{ADD}$ indicates the results were obtained by GMM with moment condition $E[Z'[y - exp(x'\beta)]] = 0$.

Table 6: **Impact of the Crusades on Scientific Production** Regressions at the author level, linear mean

	Total	*Phil*	*Rat*	*Religion*
	(1)	(2)	(3)	(4)
Iraq	5.43	0.74	2.39	0.23
	(4.78)	(1.27)	(2.88)	(0.44)
$Iraq * Crusade$	-7.16	-1.04	-3.52	0.17
	(8.47)	(2.25)	(5.10)	(0.78)
Persia	18.94	5.47	7.86	0.61
	(7.01)	(1.86)	(4.21)	(0.65)
$Persia * Crusade$	-8.00	-4.18	-6.76	4.94
	(11.99)	(3.18)	(7.21)	(1.11)
$N.Africa$	-1.11	-0.17	-0.60	-0.01
	(4.89)	(1.30)	(2.94)	(0.45)
$N.Africa * Crusade$	0.17	0.71	1.45	0.34
	(6.45)	(1.71)	(3.88)	(0.59)
Egypt	6.95	1.24	6.09	0.21
	(5.88)	(1.56)	(3.54)	(0.54)
$Egypt * Crusade$	-8.13	-1.50	-7.18	0.03
	(7.23)	(1.92)	(4.35)	(0.67)
Levant	5.90	5.69	7.93	0.78
	(4.27)	(2.17)	(4.94)	(0.76)
$Levant * Crusade$	-2.09	-5.20	-7.67	0.15
	(8.27)	(2.19)	(4.97)	(0.76)

Notes: Crusade is a dummy variable equal to one if the author is born after 487 *hijrī* 1094/1095 C.E., the start of the first Crusade.