The Diffusion of New Institutions: Evidence from Renaissance Venice's Patent System [1]

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Abstract

This paper exploits the introduction of the first regularized patent system, which appeared in the Venetian Republic in 1474, to examine the factors shaping inventors' propensity to use a new form of intellectual property right. We begin by developing a model that links patenting activity of craft guilds with provisions in their statutes. The model predicts that guild statutes that are more effective at preventing outsiders' entry and at mitigating price competition lead to less patenting. We test this prediction on a new dataset that combines detailed information on craft guilds and patents in the Venetian Republic during the Renaissance. We find a negative association between patenting activity and guild statutory norms that strongly restrict entry and price competition. We show that guilds that originated from medieval religious confraternities were more likely to regulate entry and competition, and that the effect on patenting is robust to instrumenting guild statutes with their quasi-exogenous religious origin. We also find that patenting was more widespread among guilds geographically distant from Venice, and among guilds in cities with lower political connections, which we measure by exploiting a new database of noble families and their marriages with members of the great council. Our analysis suggests that local economic and political conditions may have a substantial impact on the diffusion of new economic institutions.

Keywords: patents, competition, guilds, institutions.

JEL classification: O33, O34, K23

1 Introduction

The social, economic, legal, and political organization of a society, its 'institutions', is a primary determinant of economic growth. Acemoglu and Johnson (2005) distinguish between contracting institutions - supporting private contracts - and property rights institutions - constraining government and elite expropriation - and observe that their impact depends on the extent to which they are widely adopted and displace older institutions. Understanding the factors that explain the diffusion of new institutions is a central question in the development economics literature (Acemoglu et al., 2005; Glaeser et al., 2004; Tabellini, 2010; Ashraf and Galor, 2011).

In this paper, we aim to provide novel insights into this issue by looking at the earliest pattern of local diffusion of one of the main property rights institutions that governments use to increase innovation incentives and spur economic growth: patents which provide temporary monopoly rights over a new technology. Our analysis exploits the introduction of the first regularized patent system, which appeared during the Renaissance in the Venetian Republic, to understand how local conditions - such as market power, industry composition and the presence of elites – relate to the propensity of inventors to use the new form of intellectual property right -i.e., to adopt the new economic institution. In 1474 the Venetian Senate passed a patent act that regulated the granting of patents for novelty, ingenuity, and utility. The dominant view among patent law historians is that this act established an administrative-centered system, strikingly similar to the modern Anglo-American system (Kaufer, 1988; Merges and Duffy, 2013). Therefore, the patents awarded in the late fifteenth century in the Venetian Republic provide a unique opportunity to study the diffusion of a drastically new form of property rights. This is not common in the literature on patents, where most studies typically examine marginal changes of pre-existing property rights (Hall and Harhoff, 2012).

The innovation literature has documented a large variation in the rate of patenting across industries and in the perceived effectiveness of patents across firms (Levin et al., 1987; Cohen, Nelson, and Walsh, 2000). These findings have typically been interpreted as suggesting that the social and economic value provided by intellectual property rights is highly heterogeneous. Understanding the roots of this heterogeneity - i.e., why some inventors choose to heavily rely on patents and why others do not - is essential for the design of patent policies. If, for example, a substantial share of innovation occurs in industries in which patents do not play an important role, policies that strengthen intellectual property rights may do little to raise the overall level of innovation (Machlup and Penrose, 1950; Moser, 2012). Similarly, when only a few industries rely heavily on patent rights, changes in patent policies may dramatically affect the direction of technical change (Moser, 2005). Finally, if the effects of patent rights are highly heterogeneous across firms and industries, it is likely that a one-size-fits-all patent system, like the one currently in place, is second best (Acemoglu and Akcigit, 2012). The historical nature of our data is useful in understanding whether heterogeneity in the use of patents is persistent over time, or is a more recent phenomenon linked to modern technology trends.

We begin our analysis with a simple theoretical model that describes the patenting decision of inventors at the time of the Venetian Republic. The theoretical framework highlights few key differences between the modern patent regime and the Venetian system and explores the interaction between patent law and guilds, associations of craftsmen and merchants that played a key role in Medieval and Renaissance Europe. Venetian patents provided not only the negative rights to exclude through monopoly power, but also the positive rights to enter into craft guilds for innovators that were not guild members (Mandich, 1948). Moreover, guilds had the power to oppose and block patent applications (Berveglieri, 1995;1999; Trivellato, 2008). We show that the interplay of these two features implies that the level of patenting can vary substantially across guilds, and that this is true both for guild members and for outside inventors. More specifically, the model shows that the level of patenting in a technology area is strongly related to the ability of guild statutes to prevent entry of outsiders and to mitigate competition among members. Greater statutory restrictions allow guild members to extract high rents, and this increases their incentives to prevent patenting by other members and external innovators.

Our empirical analysis exploits a new dataset which combines information on the patents granted by the Venetian Senate with detailed digitized data on craft guilds operating in the cities of the Venetian Republic. Our sample comprises 340 guilds of the Venetian Republic whose statutes have been examined and coded by a team of Italian historians as part of a research project financed by the Italian Ministry for Education, Universities and Research.

The main findings are as follows. First, we show a strong negative association between patenting in the technology sector of a guild and the presence of statutory rules which strongly limit entry and competition. Results are robust to including controls for city and guild characteristics, and to using alternative econometric models. A variety of placebo tests show that only restrictions to entry and competition are correlated to patenting and no other provisions in guild statutes.

To address the concern of unobserved heterogeneity, we exploit as instrumental variable the religious origin of some of the guilds in our sample. A number of the guilds in Northern Italy originated from medieval religious confraternities formed a couple of centuries before the patent act. The history literature suggests that establishment of these confraternities was driven by idiosyncratic reasons related to the local success of religious movements in the 13th century (Mackenney, 1994). To confirm the quasi-exogenous nature of this variable, we show that it is orthogonal to many observable guild characteristics such as industry, location and a variety of statutory rules. At the same time, religious origin is a strong predictor for statutory provisions restricting entry and competition. This is because religious confraternities followed strict rules regulating members' admission and interaction, and such rules often inspired guild statutes (Mackenney, 1994). The instrumental variable analysis confirms the negative relationship between patenting and the strength of guilds' statutes.

Our second finding is that patenting was more frequent for guilds located in cities geographically distant from Venice. This suggests that patents were particularly beneficial for non-elite inventors with limited access to political power (Khan, 2005). To study this issue in more detail, we construct a measure of political connection exploiting a unique database of Venetian nobility and marriages between patrician families and members of the great council. We find that guilds located in cities with less political connection were more likely to patent their technologies, supporting the idea that politically connected guilds could substitute intellectual property rights with other forms of formal and informal protection.

Taken together, our findings suggest that local economic and political conditions may have a substantial impact on the diffusion of new economic institutions.

Our analysis is connected to the economic history literature on the role of craft guilds. A common view is that medieval craft guilds were technophobic (North, 1981). Recent studies provide a more nuanced view, recognizing that some guilds were much more receptive to novelties and technological advances than others (Epstein, 2004). In her analysis of the Venetian silk and glass production, Trivellato (2008) emphasizes the crucial role of intra-guild interactions and argues that experimentation took place only when statutory norms were not too restrictive. Our findings are consistent with Trivellato's thesis, and highlight a link between guild statutes and technology management.

While there is a growing theoretical literature examining the economics of guilds (inter alia see Greif et al., 1994; de la Croix et al., 2016; Greif and Tabellini, 2017), one of the difficulties in studying these institutions is the lack of comprehensive data. Our paper contributes to this line of research and introduces a novel dataset, which may also prove useful for future research.

Our paper is connected to the recent growing literature examining how micro-level and regional factors affect institutional change and growth. Dell (2012) shows that severe drought affecting some Mexican municipalities in early 20th century affected insurgency during the Mexican Revolution, in turn influencing long-run economic and political development. Dittmar and Meisenzahl (2016) document how German cities implementing public policies during the Protestant Reformation in 1500s grew to be significantly larger in the long-run. Dittmar and Seabold, (2015) show that the competitive structure of the local media market affected the diffusion of Protestant ideas.

Our research is also related to studies that investigate the effects of occupational licensing. Kleiner (2000) provides a survey of the literature. Persico (2015) develops a theory showing how internal politics of a licensing association can lead to expansion of the licensure. Our analysis illustrates how occupational licensing and self-regulation may interact with the diffusion of new economic institutions. The role of internal rules and how they influence technology adoption is also the focus of Bridgman (2015), who studies why unions may favor restrictive work regulations and how these regulations may induce resistance to technology adoption. Finally, our paper adds to the literature on the relationship between competition and innovation (Aghion et al., 2005; Cohen, 2010). Our findings suggest that market power may affect not only the level of innovation but also the propensity to rely on patent protection.

The paper is organized as follows. Section 2 provides a brief description of the origin and functioning of the Venetian patent system. Section 3 develops a model showing the link between guild statutory norms and patenting. Section 4 describes the data and discusses the econometric specification. Section 5 examines the empirical relationship between guild statutes and patenting. Section 6 confirms the results exploiting the quasi-exogenous variation in guild religious origins. Section 7 studies the relationship between guild locations and patenting. Section 8 provides a discussion of the results and their implication for policy. Concluding remarks briefly summarize our main findings.

2 Renaissance Venice and its patent system

This section provides a brief historical overview of the Venetian Republic between the fifteenth and sixteenth century, and illustrates the main features of the 1474 patent act.

2.1 The Venetian Republic in the 15th and 16th centuries

During the period of our study, the 'Serenissima' Republic of Venice was one of the largest regional economies of Renaissance Europe. Its center was the maritime city of Venice with roughly 150,000 inhabitants at the end of the 16th century, about half of the population of north-east Italy at that time (Costantini, 1987). The Venetian state included the 'Terraferma' dominion, a compact and densely populated area which included large cities such as Verona and Vicenza. Figure 1 (from Knapton, 2013) illustrates the state boundaries around the period of our study. A number of additional cities in the Greek peninsula and in South-East Europe, such as Corfu, Andros, and Cyprus were also under the control of the Venetian Republic and were instrumental ports for long-distance trade between Western Europe and the Levant (Borelli, 1980).

The Venetian Republic was based on a careful balance of power that originated as an attempt to restrain the power of a single person or governing body and led to remarkable political stability (Lane 1973). Membership in the main governing institutions was precluded to lower classes, such as artisans and shopkeepers. Moreover, following the 'Serrata' (closure) in 1297, political functions were restricted to a hereditary nobility that had the exclusive right to sit in the great council, the legislative assembly of the Republic. Because of the large size of the great council, most legislative functions were delegated to the senate, a smaller assembly (about 300 senators) elected by the great council (Borelli, 1980). Some members of the senate had the right of legislative initiative ('metter parte'), others were only entitled to vote ('metter ballotta'). Among the senators entitled both to vote and to propose new laws, there were three 'provveditori di comun' who also oversaw transport infrastructures and mercantile trade (Borelli, 1980; Zaggia, 2004; Di Stefano, 2011). The doge was the personal embodiment of the Republic, it was elected by a committee of 41 nobles chosen by the great council. In 1474 the doge was Nicolo' Marcello, and eleven doges took office between 1474 and 1550 (Rendina, 1984).

At the time of our study, the main threat to Venice's trade supremacy and the preservation of its economic power was the Ottoman Empire, which was expanding dramatically under the leadership of sultan Selim I (Borellli, 1980). Moreover, the 1492 discovery of America started shifting the center of long-distance trade away from the Mediterranean toward the Atlantic.

The economy of the capital was driven by the vast trading activity in spices, dying materials, silk, cotton, slaves, and precious metals (Pezzolo, 2013). On top of this vibrant trade, artisan production also flourished both in Venice and in Terraferma. The Arsenal was one of the largest industrial sites in Europe, and glassmaking was among the most prestigious urban occupations at the time (Trivellato, 2008). The mainland was marked by a lively wool and silk production (Demo, 2013).

Merchants and craftsmen were organized in guilds, self-governed organizations that controlled various aspects of economic activity. Guild statutes prescribed technical characteristics of products and regulated entry, apprenticeship, and competition (Belfanti, 2004). The Venetian government fostered guild membership for fiscal reasons, and about 20 percent of the population of the city of Venice belonged to a guild.[1] Guild members were excluded from government, but the Venetian constitution guaranteed them the right of judicial appeal against the government and guild officers (Lane, 1973).

2.2 The 1474 patent act

On March 19, 1474, the Venetian senate passed by a large majority a 'parte' (act) regulating the granting of patents. While there is evidence that a small number of ad-hoc privileges for new inventions and mineral extraction were granted by the Venetian government before this act (only five patents according to Mandich, 1936), the parte of 1474 is the very first law regulating the patent application and granting process, and has been recognized by numerous historians and law scholars as the legal foundation of the modern patent system (inter alia see Mandich 1948; Duffy, 2007; Golden, 2013).

The process of patenting involved different steps. Patent applications (or 'suppliche') were addressed to the doge and filed at the senate (Mandich, 1948). The provveditori di comun evaluated the proposal and collected information from interested parties, particularly from the representatives of the relevant guilds. Sometimes, the senate involved other magistrates for the necessary preliminary investigations and reports. These magistrates were selected based on the content of the invention. For example, in the case of hydraulic devices the water committee

[1] This share remained stable, with minor fluctuations, from the 16th century until 1797, the end of the Venetian state (Costantini, 1987).

(Savi sopra le acque) was involved. Patents were granted after senatorial approval (Berveglieri, 1995, Mandich, 1948, and Molà, 2000).[2]

The subject matter to be patented was required to be a "new and ingenious device" and the effect of a patent was to stop "every other person in any of our territories and towns to make any further device conforming with and similar to said one without the consent and license of the author" (Mandich, 1948). The novelty content was evaluated on the basis of the technical knowledge available in the Venetian dominion, implying that a patent could be granted to products or processes already in use elsewhere (Molà, 2014). The patentee was required to implement the invention ('messa in opera') within a specified period of time.[3]

The impact of the act on patenting was substantial. The number of patents granted by the senate grew considerably, increasing from 5 ad hoc privileges granted before 1474 (Mandich, 1936) to 43 patents approved between 1474 and 1500, 126 patents granted in 1501-1550, and 471 patents granted in 1551-1600.

There are three main features of the Venetian patent system that are central to our analysis. First, patents could be granted to all inventors regardless of their citizenship status or guild membership. Thus, patents were both 'negative' rights to exclude but also 'positive' rights to practice the invention and operate in industries controlled by guilds (Mandich, 1948; and Sichelman and O' Connor, 2012). For example, Florentine inventor Cosmo Scatini was granted a patent for high quality black silk dying, which permitted him to enroll in the dyers' guild of Venice (Belfanti, 2004).

Second, guilds were often involved in the patent granting decision process, through the evaluation of the novelty content of the application. This examination involved, most of the time, a test of the new product or process (the 'experienza') to verify, before granting the patent, whether the invention was actually working. Historians have provided anecdotal evidence of guild opposition. For instance, Trivellato (2008) describes the opposition of the Venetian silk spinners' guild to the patent application of Iseppo Giovan Perin Mattiazzo for a new hydraulic

[2] The Senate was the dominant route to obtain a patent and alternative routes do not appear to have played a significant role. Sichelman and O'Connor (2012) suggest that in some cases the Provveditori di Comun could directly award petty patents granting protection limited in duration and scope which were not a real alternative to the Senate route (on these aspects, see Molà, 2000; and Sichelman and O'Connor, 2012). Data on these minor rights are not available, thus our analysis only focuses on patents granted by the Senate.

[3] The act established a patent length of 10 years, but it was common for applicants to request longer protection. Mandich (1936) describes cases in which patent rights lasted 25 and even 70 years.

mill for spinning and throwing silk.[4] It is difficult to assess the success rate of guild opposition, because senate records only provide information on patents that were eventually granted. Molà (2000) argues that the rejection rate was significant, suggesting that there were more than a thousand applications for the several hundred patents granted by the senate during the fifteenth and sixteenth centuries.

Third, patent holders were expected to share the technology with guild members through the payment of an appropriate licensing fee. Such a licensing requirement is often mentioned in the patent records, without specifying the precise amount but requesting a "discrete sum" of money for the transfer or payment of an "adequate reward" (Berveglieri, 1995).

While a number of historians have examined the administrative details of the Venetian patent system and collected detailed information on patent records, very few studies have addressed the question of why the senate passed the patent act in 1474. Lane (1973) and May (2002) suggest that the growing economic and trading power of the Ottoman empire and Antwerp led Venetian policy makers to focus on industrial activities. Berveglieri (1995, 1999) and Belfanti (2004) emphasize the goal of attracting foreign inventors to the Venetian Republic to compensate for the lost supremacy of Venetian guilds in various industrial sectors.[5] Mandich (1936) suggests that successful experimentation with monopolies in mineral rights may have led Venetian authorities to legislate on patent rights.

3 Theoretical model

In this section we develop a simple theoretical model to describe patenting incentives in the Venetian Republic. The objective of the theoretical framework is to highlight few key differences between modern patent regimes and the Venetian system and to generate testable predictions on the interaction between the Venetian patent law and the guild system.

[4] Similarly, Berveglieri (1995) discusses cases of guilds opposing patent applications by foreign inventors (e.g. against Flemish inventor Pietro Comans and French inventor Francesco Antola). Molà (2000) reports a number of additional opposition cases, such as the 1583 spinning machine patent of Urbano Bonturelli and the 1597 silk bleaching patent of Giacomo di Bianchi and Innocente Soardo.

[5] While some scholars suggest that the aim of the Venetian patent act was to attract foreign inventors and improve the human capital of the Republic, the evidence on early patents does not seem to be entirely consistent with such a view. As we report below in the paper, Berveglieri (1995) finds that only 6,5% of inventors were foreigners – the author classifies as foreigner an inventor who was not Italian. A similar finding is in Mandich (1948): about 15% of inventors were not from the Republic of Venice, a share that reduces to less than 5% when we consider as foreigner an inventor who was not Italian. This is not to say that the relationship between immigration flows, growth, and innovative activities is not important in other historical contexts (see Akcigit et al., 2017a and Akcigit et al. 2017b for recent contributions on these issues).

3.1 Set-up

Consider an industry with three firms and two periods $t = 1, 2$. Two firms belong to a guild, while the third one is an outsider. In the absence of innovation, guild members sell a standard product to consumers. The surplus created by the standard product is π per period. We assume that the guild can appropriate a fraction $\alpha(\theta)$ of this surplus, with $\alpha'(\theta) > 0$. The appropriated surplus is shared equally among guild members. The parameter θ captures the strength of the guild's internal statute, with a larger value of θ indicating larger collusive power among the members, which allows greater profit extraction.

At $t = 1$, one of the firms develops an innovation that increases the surplus to $\pi + \Delta$ per period. Innovations are distributed with cumulative distribution $F(\Delta)$ with support $[0, \infty]$. To patent the innovation costs c and patent protection lasts for one period. The patent grants the innovator the right to extract the full surplus for the period. The patent holder negotiates licensing deals with the other guild members by making take-it-or-leave-it offers to them. At $t = 2$, once the patent has expired the technology becomes freely available to all guild members.

The outsider firm cannot enter the guild without an innovation. Entry is guaranteed if the outsider firm obtains a patent. If it innovates but does not apply for a patent, entry occurs with probability $\beta(\theta)$ with $\beta'(\theta) < 0$, which captures the idea that the stronger guild statutes are, the more difficult it is for an outsider to enter.

Before a patent is granted, each guild member can oppose the patent application by paying an opposition cost, κ. If the patent is opposed, the technology is appropriated and shared among all the guild members during both periods. If the patent of the outsider is opposed, entry to the guild is blocked as well.

We solve the game by backward induction, starting from the opposition decision. We distinguish two cases, depending on whether the innovation is developed by a guild member or by the outsider firm. For simplicity, we set $\alpha(\theta) = \theta$ and $\beta(\theta) = 1 - \theta$ (we relax this assumption in section 3.4). We also assume that $\pi > 3c$ to focus on the cases in which the cost of obtaining a patent is not too large relative to the baseline surplus.

3.2 Patenting by a guild member

We first focus on the case in which the inventor is a guild member. Suppose that the innovator applies for a patent and consider the incentives of the other guild member to oppose it. If opposition takes place, the technology is shared between the two firms for two periods. Therefore, by choosing to oppose the patent, the guild member obtains $\theta(\pi+\Delta)/2$ per period, net of the opposition cost, κ.

If the patent is not opposed, the innovation is freely shared among guild members only in the second period, once the patent has expired. In the first period, the patentee and the other guild member negotiate a licensing deal and the licensee obtains $\theta\pi/2$, i.e., the status quo profits in the absence of innovation.[6] Therefore, opposition is profitable if

$$\theta(\pi+\Delta)-\kappa > \frac{\theta\pi}{2}+\frac{\theta(\pi+\Delta)}{2}$$

which is satisfied if

$$\Delta > \widehat{\Delta}(\theta)=\frac{2}{\theta}\kappa.$$

Notice that $\frac{d\widehat{\Delta}(\theta)}{d\theta}<0$, which implies that guild members block patents of other guild members more often as the strength of the internal statute increases.

Consider now the innovator's choice of whether to apply for a patent or not. Clearly, if it anticipates that there will be opposition (i.e., $\Delta > \widehat{\Delta}(\theta)$), then patenting is not profitable. Hence, applying for a patent may be beneficial only when there is no opposition (when $\Delta \leq \widehat{\Delta}(\theta)$). In this case the profits of the patentee are equal to

$$\pi+\Delta-\frac{\theta\pi}{2}+\frac{\theta(\pi+\Delta)}{2}-c.$$

Specifically, in the first period, patent protection allows the firm to extract the full surplus $\pi+\Delta$. At the same time, the licensing negotiation with the other member implies that $\theta\pi/2$ is transferred through licensing. At $t=2$, once the patent has expired, the total surplus guild members appropriate reduces to $\theta(\pi+\Delta)$, and each of them obtains half of it. When choosing not to patent, the innovator obtains $\theta(\pi+\Delta)/2$ in each period because the technology is shared starting from $t=1$. Therefore, patenting is more profitable than not patenting only if

$$\pi+\Delta-\frac{\theta\pi}{2}+\frac{\theta(\pi+\Delta)}{2}-c > \theta(\pi+\Delta)$$

or

$$\Delta > \widetilde{\Delta}(\theta)=\frac{2}{2-\theta}\left(c-\pi(1-\theta)\right).$$

[6] The implicit assumption here is that in case of disagreement the innovation is not implemented for one period until the patent is expired, so that each firm gets $\theta\pi/2$. Results are robust to considering alternative outside options, as we discuss in section 3.4.

Notice that $\widetilde{\Delta}(\theta) > 0$ only if θ is large enough. Moreover, $\frac{d\widetilde{\Delta}(\theta)}{d\theta} > 0$, which implies that as the strength of the internal statute increases guild members patent only their more valuable innovations, i.e., the propensity to patent decreases in θ.

The above discussion implies that the likelihood of patenting goes down as the strength of the statute increases because guild members are less likely to apply for a patent and more likely to block patents of other members. Formally, patenting occurs when $\Delta \in \left[\widetilde{\Delta}(\theta), \widehat{\Delta}(\theta)\right]$ with a probability equal to

$$P(\theta) = F(\widehat{\Delta}(\theta)) - F(\widetilde{\Delta}(\theta))$$

which decreases in θ.

3.3 Patenting by an external innovator

Suppose now that the inventor is the outsider firm and consider the opposition decision. By opposing the patent, a guild member prevents entry of the outsider and shares the technology with the other guild member from $t = 1$, obtaining $\theta(\pi+\Delta)/2$ per period net of opposition cost, κ. Without opposition, a guild member receives a payoff of $\theta\pi/2$ for one period (net of paid licensing fees) and shares the technology with the other two firms (the other guild member and the external innovator) in the second period. Therefore, opposing the patent is more profitable than accommodating entry if

$$2\theta\frac{(\pi+\Delta)}{2} - \kappa > \frac{\pi}{2}\theta + \frac{\theta(\pi+\Delta)}{3}$$

or

$$\Delta > \widehat{\Delta}_E(\theta) = \frac{3}{2\theta}\left(\kappa - \frac{\pi}{6}\theta\right).$$

One can easily check that $\widehat{\Delta}_E(\theta)$ is decreasing in θ, i.e., opposition is more likely with high θ.[7]

Similar to what happens with an internal innovator, patenting is profitable for the outsider only when there is no opposition (when $\Delta \leq \widehat{\Delta}_E(\theta)$). In this case, by patenting, the external innovator obtains

$$\pi + \Delta - \theta\pi + \frac{\theta(\pi+\Delta)}{3} - c.$$

[7]For simplicity, our focus here is on pure strategy Nash equilibria between the guild members. Similar predictions are obtained: (i) in a model in which guild members cooperatively decide whether or not to oppose the outsider's patent, (ii) in a symmetric mixed-strategy Nash equilibrium in which each guild member opposes the oustider's patent with probability p.

In the first period, the innovator extracts the full surplus and strikes licensing deals with the guild members, offering $\theta\pi/2$ to each of them. In the second period, the innovation is shared among the three firms. Without a patent, the external innovator enters the guild with probability $1-\theta$ and the technology is immediately shared with the guild members. Therefore, patenting is more profitable than entering without patent if

$$\pi + \Delta - \theta\pi + \frac{\theta(\pi + \Delta)}{3} - c > (1-\theta)\frac{2\theta(\pi + \Delta)}{3}$$

which occurs if

$$\Delta > \widetilde{\Delta}_E(\theta) = \frac{3c - 3\pi + 4\pi\theta - 2\pi\theta^2}{3 - \theta + 2\theta^2}.$$

One can easily check that, when $\pi > 3c$, $\widetilde{\Delta}_E(\theta) < 0$ for each θ, which implies that, absent opposition, the external innovator always patents, no matter the strength of the guild statutes.[8] Intuitively, for low values of θ, patenting is beneficial because the innovator appropriates a large share of the profits generated by the innovation during the first period. When θ is large, patenting is useful to overcome the difficulties of being admitted to the guild.

Therefore, conditional on the outsider innovating, the likelihood of patenting is

$$P(\theta) = F(\widehat{\Delta}_E(\theta))$$

which is also decreasing in θ.

3.4 Discussion

Our simple model illustrates how the propensity to patent in a technology area is affected by the strength of the statutes of the guilds operating in the field. As the strength of the statute increases, the collusive power of a guild goes up, and the value of the monopoly rent generated by the patent decreases. Thus, strong statutes reduce the patenting incentives of guild members. Moreover, statute strength allows guild members to extract high rents from the technologies that they appropriate through patent opposition. This implies that, in the presence of strong statutes, patents by guild and non-guild members are more likely to be opposed. Together, these two effects generate the testable prediction that patenting activity is likely to be less prominent in technology fields in which guilds have strong statutes.

[8] Assumption $\pi > 3c$ implies that $\widetilde{\Delta}_E(0) = (3c - 3\pi)/3 < 0$, $\widetilde{\Delta}_E(1) = (3c - \pi)/4\widetilde{\Delta}_E(\theta) < 0$ and $\frac{d\widetilde{\Delta}_E(\theta)}{d\theta} > 0$.

The model builds on a number of assumptions that are worthy of additional discussion. First, to obtain a closed form threshold for the patenting and opposition strategies we set the impact that guild statutes have on rent sharing and entry equal to $\alpha(\theta) = \theta$ and $\beta(\theta) = 1 - \theta$. In the appendix, we show that the main predictions are robust to considering more general functions $\alpha(\theta)$ and $\beta(\theta)$. Specifically, we show that our comparative statics hold under mild assumptions on these functions and derive a sufficient condition that generalizes our main results. Second, our baseline setting assumes that the patentee has full bargaining power during the licensing negotiations and that it can appropriate the whole surplus of the innovation (while the other guild members obtain the status-quo profits $\theta\pi/2$). In the appendix, we relax this assumption and study a more general set-up in which the surplus is shared through Nash bargaining. We show that our main results are robust, as long as the bargaining power of the patentee is not too small. Finally, our model assumes that opposition cannot be avoided through side payments from the patentee to guild members. In the appendix we extend our setting and allow patentees to negotiate with incumbents to avoid opposition, and we show that also in this case patenting is less likely for larger values of θ.

A feature of the Venetian patent system highlighted in our model is the opportunity for guild members to oppose patent applications. This resembles modern administrative processes at the European and United States patent offices (Harhoff and Reitzig, 2004; Hall and Harhoff, 2004). Our simple model suggests that these opposition systems may have a variety of effects on entry and patenting behavior. On the one hand, opposition allows incumbent firms to screen out inefficient patenting by external innovators (i.e., technologies with $\Delta < c$). On the other hand, opposition allows non-innovating incumbents to protect their short- and long-term rents, which creates an incentive to block entry and oppose efficient technologies. This trade-off suggests that a well-designed opposition system needs to balance screening and rent-preservation incentives.

4 Data and methods

Our empirical analysis combines data on craft guilds active in the Venetian Republic during the Renaissance with information on the patents granted by the Venetian senate during this period.

Our main source of data on craft guilds is the dataset 'Istituzioni Corporative, Gruppi Professionali e Forme Associative del Lavoro nell'Italia Moderna e Contemporanea' (Istituzioni

Corporative, henceforth) which is the outcome of a research project financed by the Italian Ministry for Education, Universities and Research involving a variety of leading history departments across multiple Italian universities. The goal of the project was to release a dataset with detailed information on the universe of Italian guilds for the period 1400-1700.[9]

Key variables include the name of each guild, the time period of its activity, and its geographical location. The data provide a detailed description of the manufacturing operations and trading activities of each guild. The dataset also reports a variety of indicators related to the internal organization of the guild, such as the presence of restrictions to market competition or the existence of a structured apprenticeship system.

Our analysis focuses on 340 craft guilds identified in Istituzioni Corporative as active in the Venetian Republic before 1600. Costantini (1987) estimates that at the end of the 16th century Venetian guilds included about 34,000 members, which was roughly 20 percent of the population and about half of the economically active labor force. The guilds in our sample capture a large fraction of the European economic activity at that time, because Venice was the third largest city in Europe and a leading international trading center (Pezzolo, 2013).

The books by Berveglieri (1995, 1999) are our main data sources on Venetian patents, as they report information on the patent rights granted by the senate and retrieved from the state Archives of Venice. Berveglieri's work extends previous research by Mandich (1936, 1948), who classified and translated into modern Italian 109 Venetian patents for the period 1474-1550. For the same period, Berveglieri (1995) identifies 169 patents. The first panel of appendix Table A1 shows the technological breakdown of these patents: mills account for roughly half of the inventions, followed by drainage devices (11 percent), and hydraulic pumps (7 percent). Interstingly, these higher patenting rates in manufacturing and agricultural machinery are strikingly similar with those observed by Moser (2012) in her study of British and American innovations at world's fairs between 1851 and 1951.

For each guild in our sample we identify the patents involving technologies related to the guild's activity. To manually match guilds with patents we exploit the detailed description of each guild's manufacturing operations provided in Istituzioni Cooperative, and the patent

[9] The researchers start from the sample of 73 Italian cities with more than 10,000 inhabitants in 1300, and successfully retrieve information on guilds for 50 of these cities (no data were available for smaller cities in southern Italy, where the economy was predominantly based on agriculture). The final dataset comprises more than 1,000 guilds active in Italy during the period 1400-1700. Guilds for which researchers were not able to retrieve enough information are missing from the sample -these are likely to be smaller institutions of little economic importance. A comprehensive description (in Italian) of the data is provided in Moioli (2004).

technology classification provided by Berveglieri (1995).[10]

Two things need to be noted here. First, patents can be assigned to multiple guilds. For example, a patent covering a new type of sawmill is assigned to all guilds whose activities involve the use of sawmills. This approach is consistent with our model and captures a crucial feature of the Venetian patent system: a patent allowed the patentee to enter each of the guilds that could use the technology. In fact, a sawmill patent permitted the inventor to enter all the guilds that used sawmills and, at the same time, each of these guilds was entitled to oppose the patent.[11]

Second, our matching procedure does not imply a one-to-one mapping between the sector in which the guild operates and the patents assigned to the guild. This is because the description of guild activities in Istituzioni Cooperative shows that guilds belonging to the same sector (and usually sharing the same denomination) often carried out different sets of manufacturing activities. Take, for example, the 'fabbri' (blacksmiths') guilds scattered across the various cities in our sample. Some of these guilds produced armours and weapons, whereas others produced keys, locks or other metal products. To account for these differences, we impute armour and weapons patents only to the relevant subset of blacksmiths' guilds. Similarly, a fraction of the 'biavaroli' (corn traders') guilds owned mills to produce flour, but a number of them were only involved in trading activities. Also in this case we assigned cereal-mills patents only to the guilds using such technologies.[12]

The main variables used in the empirical analysis are described below.

Patents. This is the endogenous variable in the analysis. It captures the number of patents granted by the Venetian senate from 1474 to 1550 in the primary technological field of the guild. While Berveglieri (1995) reports patents for a longer period, our main analysis focuses on patenting for the period 1474-1550 to avoid the 1575-76 plague, which had a profound

[10] We drop patents related to inventions that cannot be easily imputed to a guild in our sample (e.g. perpetual motion). In Section 5.2 we discuss alternative empirical approaches that exploit all the patents in Berveglieri's sample.

[11] Moreover, Berveglieri (1995) does not provide information on the specific location and origin of the patentee, he only indicates whether the patentee was a foreigner or not. For the smaller sample of patents described in Mandich (1936, 1948) we have information on geographical scope of the patent, i.e. in some cases the patentee could only enter guilds of specific cities. We exploit this information it in a robustness exercise in section 5.3.

[12] There is also large variation in patenting acorss the 'molineri' (millers) guilds. In fact, some of these guilds specialized in textile production, others grinded grains into flour, others cutted wood, etc. In the construction of this variable we restrict each guilds to a primary technology area among those provided by Berveglieri (1995), but we confirmed that results are robust to using less restrictive mappings when guild's activities spanned multiple technology areas.

impact on the Venetian economy. Pezzolo (2013) documents the large demographic effects of the plague, with an estimated decrease in population of between 15 and 26 percent. In Section 5.2 we show that our results are robust to using patents granted up to 1600. Appendix figure A1 describes the evolution of patenting over time.

Guided by the work of historians, we construct a variable capturing the strength of guild statutes. A number of statutes in our sample include restrictions on competition, such as price fixing, minimum distance between workshops ('botteghe') or a ban on serving customers of other guild members. Granting privileges to sons and sons-in-law of members was a typical way to restrict entry of local potential competitors (Moioli, 2004). In some cases, such as the goldsmith guild of Venice, entry was completely precluded to those who were not descendents of guild members. In other statutes, entry fees or exams were required for those who were not sons of guild members. To preclude the entry of foreigners, various statutes included additional provisions targeting all foreigners, or specific ethnic groups. This leads us to generate the following variable.

Strong internal regulation. This dummy variable is equal to one if the guild has internal rules that: (i) limit competition among the members, (ii) grant entry privileges to sons of guild members, and (iii) restrict entry rights of foreigners.

It is likely that all guilds operating in the Venetian Republic adopted some formal or informal restriction to limit competition and entry. Thus, one has to interpret *Strong internal regulation* as capturing guilds for which historians have identified statutory provisions that are more severe than those of other guilds in the sample.[13]

We now introduce some of the other control variables to be used in our empirical analysis.

Distance to Venice. This variable captures the distance (in kms) between the city of the guild and Venice. We construct this measure by exploiting a variety of historical maps describing the most important transportation routes in the Venetian Republic in the period of our study. These include the 'Atlantic Map' of the state Archive of Venice and various maps in Lanaro Sartori (1985) illustrating trade routes in the Venetian Republic.

Trade Guild. This dummy equals one for guilds that are only involved in trade (including transportation and financial services) and not in manufacturing. Roughly 46 percent

[13] Unfortunately, the Istituzioni Corporative dataset describes the exact statutory provision for only a small subset of guilds. For most guilds the information is available only as a dummy (i.e., restriction to competition? Y/N; Privileges to sons? Y/N, etc. . .). This is the main reason why our empirical analysis exploits these binary variables.

of the guilds in our sample are trade guilds.

Guild Members. This information is available only for 169 guilds. On average, guilds in our sample have 164 members (with median equal to 48 and a standard deviation of 392).

Table 1 provides summary statistics. On average, there are 1.47 patents in the main technology field in which a guild operates, with a standard deviation of roughly 5 patents. About 21 percent of the guilds in our data have strong internal regulation. The second panel of appendix Table A1 illustrates the geographical distribution of the guilds across the ten cities of the Venetian Republic in our sample. Roughly 50 percent of the guilds are located in Venice. Verona, Padua, and Brescia are the cities with more guilds in the mainland (Terraferma).

4.1 Econometric specification

Building on the theoretical analysis of Section 3, our main econometric model focuses on the relationship between our measure of patenting, $Patents_{ij}$, related to guild i located in city j and the indicator for the strength of internal regulation of the guild. We typically model the conditional expectation of patenting activity as

$$E(Patents_{ij}) = \exp(\alpha \text{Strong internal regulation}_{ij} + \beta x_{ij} + \gamma_j)$$

where x_{ij} is a vector of guild-specific control variables and γ_j is a city-specific idiosyncratic effect. The log-link formulation is appropriate in our setting because of the non-negative and highly skewed nature of our count-based dependent variable.

Following a long-standing tradition in the economics of innovation literature (Hausman et al., 1984), we estimate this model via Poisson, with robust standard errors to account for over-dispersion. Consistency of the Poisson estimates is guaranteed as long as the mean of the dependent variable is correctly specified (Gourieroux et al, 1984).[14]

The coefficient α captures the relationship between statutory provisions restricting entry and competition and patenting in the technology area of the guild. When $\alpha < 0$ strong statutes are associated with lower patenting, which is the prediction of our theoretical model. A finding of $\alpha = 0$ would indicate that statutory clauses generating market power are not associated with patenting in the technology area. When $\alpha > 0$ we would conclude that patenting is more frequent in technology areas in which guilds have strong statutes.

[14]We confirm the robustness of our baseline results with alternative clustering of the standard errors at the city and the guild level.

In principle, the regression coefficient α captures the combined effect of statutory clauses on innovation investments as well as on the propensity to use patents to protect technologies. However, our reading of the history literature cautions us to interpret α as capturing the relationship between innovation and statutory clauses. This is because the novelty content of the patents was evaluated on the basis of the knowledge available in the Venetian dominion and patents could involve technologies already available elsewhere (Molà, 2014). Moreover, historians have documented substantial innovation activity occurring outside the patent system. For example, Moser (2012) shows that 89 percent of the technologies presented at the 1851 world fair in London were not patented. The extent of non-patented innovation is likely to be even larger during the first few decades of the Venetian patent system. This is supported by a variety of anecdotal evidence illustrating a considerable amount of innovations by guilds for which we observe little patenting. For example, Molà (2007) describes a vibrant innovation activity in the soap-boiler guilds which developed a variety of new products during the period of our study. Yet, there are no patents related to these technologies in our data. Similarly, Caniato (1996) and Trivellato (2008) describe substantial innovation activity for the Arsenal and Murano's glassblowers which are also guilds for which we observe very little patenting. This suggests that α speaks more to the propensity to use intellectual property rights to protect technologies (i.e., to adopt the new institution) than to the propensity to innovate and develop new technologies. We leave for future research an examination of the effect of Venetian patents on innovation investments.

5 Empirical results

5.1 Baseline specification

Table 2 provides the first set of results. The regressions show a strong negative association between the patents granted in the technology field of a guild and the strength of its internal rules. All regressions include a control for trade guilds, which indicates substantially lower patenting activity for this type of organization. In column 2 we control for the geographic distance between the city in which a guild is located and Venice. The likelihood of patenting increases with the distance from Venice, and the coefficient on internal regulation remains stable. Column 3 shows that the relationship between guild statute strength and patenting is robust to the inclusion of city fixed effects. Exponentiation of the coefficient implies that patenting is roughly 65 percent lower when guilds adopt strong internal regulation. In column

4 we show that results are similar when we control for the number of guild members, even if this restricts the analysis to a much smaller sample. The coefficient on the number of members is positive (but statistically insignificant), suggesting that patenting is more frequent in technology fields where guilds are larger.[15]

Overall, the results in Table 2 document a negative correlation between patenting and statutory provisions limiting entry and competition, which is consistent with our theoretical model.

5.2 Robustness and Extensions

We perform a variety of additional empirical tests to confirm the robustness of our main finding. First, we show that the estimates of the strength of internal regulation and of geographical distance are unaffected once we include additional controls for city characteristics. In column 1 of appendix Table A2 we show robustness to the inclusion of controls for the size of the city measured with population in 1300, 1400, and 1500 (data from Malanima, 1998). Interestingly, population controls do not appear to explain much of the variance in patenting activity, suggesting that the number of patents is not simply driven by city size. In a model with city effects, column 2 of Table A2 shows that the negative correlation between strength of the statute and patenting is robust to including a variety of additional controls for guild characteristics, such as the age of the guild (in 1600) and a dummy for the presence of an apprenticeship system.[16] The regression also includes industry effects for guilds in agriculture, construction, and textile. In column 3 of Table A2 we expand the time period considering the patenting activity up to 1600. For this longer time window the patent dataset expands substantially including now 640 patent rights. The estimates show that our findings are robust to using this alternative dependent variable. Column 4 shows that results are robust to including a dummy for guilds whose operations require the use of mills. While the magnitude of the coefficient on *Strong internal regulation* drops by about one quarter, the correlation remains negative and statistically significant, indicating that our results are not exclusively driven by patents related to mills.

[15] In unreported regressions we capture guilds with a large number of members with a dummy variable equal to one if the number of members is above the top quintile (180 members). In such specifications the dummy is positive and statistically significant at the 0.1 level, supporting the idea that patenting is more likely in fields where guilds have many members. We also examined whether there are heterogeneous effects of statutory strength between smaller and larger guilds but we do not find any supporting evidence.

[16] De la Croix et al (2016) discuss how apprenticeship was a key determinant of knowledge transfer and economic growth in Medieval cities.

There is the concern that the effect of statutory norms on patenting is not driven by specific provisions related to entry and competition, but by other statutory rules. Specifically, the reader may worry that *Strong internal regulation* simply captures statutes that are very detailed, and that some other rule in these statutes may affect patenting more than those related to entry and competition. To address this concern, we perform a number of placebo tests, constructing variables that identify statutes containing detailed regulations of guild activities not directly related to entry and competition. For example, in column 5 of Table A2 the variable *Placebo* equals one if the statute includes: (i) a list of manufacturing activities precluded to women, (ii) the name of the guild's patron saint, and (iii) a description of the hierarchical structure of the guild. The coefficient on this variable is positive, statistically insignificant, and small in magnitude. We obtain similar estimates (positive, small, and statistically insignificant) with alternative placebo tests that exploit various combinations of the above variables and other statutory clauses, such as the presence of an apprenticeship system, or of technical restrictions on the quality of the products. These findings support the idea that patenting propensity is strongly related to provisions in guild statutes restricting entry and competition, but not to other statutory rules.

One may also be concerned about changes in statutory clauses over time. Two things need to be noted here. First, Istituzioni Corporative typically relies on documents that are contemporaneous with the patent act (Moioli, 2004). Second, historians have emphasized how changes in guild statutes over time typically led to lower entry barriers and greater competition (Costantini, 1987). This implies that in constructing *Strong internal regulation* we are more likely to classify as strong, statutes that are not strong, and that measurement error will bias our estimates toward zero. While the dataset provides information on whether the statute of a guild changes over time, we do not know the exact clauses that are affected by the change, which precludes us from using the longitudinal nature of the data. Nonetheless, we exploit this information to perform robustness tests. Specifically, we identify statutes that changed during the period 1474-1550. In roughly 81 percent of the sample there was no statutory change during the time period, for about 18 percent of the guilds the statute was changed once, and for the remaining 1 percent it was changed twice. In column 6 of Table A2 we show that our baseline estimates are robust to dropping guilds that change their statutes during our sample period. The coefficient is roughly 15 percent larger than our baseline, confirming the idea that measurement error biases our estimates toward zero.[17]

Our results may be driven by differences in patenting and guild structure between Venice and other cities in the Republic. In particular, one may worry that international competition can lead some of the most prominent guilds of the city of Venice to reach the technology frontier, and this may affect their patenting strategies. To examine this issue, column 1 of Table A3 drops from the sample the guilds located in Venice. Addressing similar concerns, column 2 of Table A3 drops the guilds involved in trade. For both of these exercises the sample size drops of roughly 40 percent, but the negative relationship between statutory strength and patenting is robust, with statistically significant coefficients and stable magnitude.

Columns 3 and 4 of Table A3 examine the robustness of our findings to using two alternative approaches to measure statutory strength. Column 3 replaces the *Strong internal regulation* dummy with a *Statutory strength index* which is set equal to 2 for statutes restricting both entry and competition, equal to 1 for statutes restricting only entry or only competition and equal to 0 for the other statutes. The estimated coefficient confirms the negative association between statutory strength and patenting. Building on this approach, column 4 includes two separate dummies, one for statutes restricting both entry and competition (this is our original *Strong internal regulation* dummy) and one for statutes which only restrict one of the two dimensions. The estimates confirm that only the most restrictive statutes are associated with lower patenting.[18]

In our baseline analysis the unit of observation is a guild. This approach is consistent with our theoretical framework and allows us to fully exploit the richness of the Istituzioni Corporative dataset. As an alternative approach, in appendix Table A4 we show that our main findings are robust to conducting the analysis at the industry level. Specifically, we assign each of the guilds of our sample to one of 51 unique industrial sectors exploiting the description of the guild activities in Istituzioni Corporative. We also assign each of the 169 patents in Berveglieri (1995) to one of these sectors. These regressions confirm the negative effect of strong statutes

[17] We confirm this result in regressions: (i) that include a control for statutory changes, and (ii) consider changes over different time windows.

[18] We also run a regression that separately includes dummies for each of the three components of the strong guild variable (i.e., limits to competition, entry privileges to offspring of the guild members, and entry limits to foreign members). All coefficients are insignificant and we cannot reject that they are equal to each other. Including the strong guild indicator together with the three dummies also leads to insignificant coefficients for the three individual components, but a negative and statistically significant effect for strong guild, with a magnitude similar to the one in our baseline regression. These robustness checks confirm that it is not only one feature of the statute that drives the effect and that only guild statutes with detailed rules on all three features correlate with lower patenting.

on patenting. The larger the fraction of guilds with strong internal regulation the lower the number of patents for the industrial sector. The implied elasticity is -0.6, a magnitude which is in line with our baseline estimates of Table 2. This robustness test also confirms the positive correlation between patenting in the technology field and average distance of the guilds from Venice.[19]

In addition, the regressions in Table A4 show a negative correlation between the number of guilds active in a sector and the patenting activity in that sector. We confirmed this finding in (unreported) regressions at the guild level by including a control for the number of active guilds in the guild's technology area. The negative coefficients support the idea that the likelihood of patent opposition increases as the number of guilds that can oppose the patent gets larger. This finding also mitigates the concern that patents were more widespread in technology areas where multiple guilds were active and that patentees could coordinate competition across guilds through licensing.[20]

Finally, in unreported regressions we confirm the robustness of our main findings to estimating alternative econometric specifications, such as OLS, zero-inflated Poisson and a linear probability model for the presence of at least one patent for the guild.

5.3 Foreign inventors and alternative patent data

We turn next to two extensions that are of independent interest.

First, we examine whether the determinants of patenting differ between local and foreign inventors. We obtain information on the origin of the inventor from Berveglieri (1995) who classifies an inventor as foreign if he is not Italian and shows that only 6.5 percent of the patents in the sample were granted to foreign inventors. Exploting these data, columns 1 to 4 of Table 3 show statistically significant associations between geographical distance and strength of internal rules for patenting both of local and of foreign inventors. The magnitude of these correlations is much smaller for foreign inventors. Nonetheless, our estimates show that the characteristics

[19] Few of the patents relate to inventions which cannot be easily imputed to only one sector (e.g. inventions related to perpetual motion). These patents are assigned to the sectors in proportion to the each sector patenting propensity. Similarly, patents related to mills with multiple usages are imputed to sectors in which mills are used, proportionally to their sector-specific patents. Table A4 confirms that the results are robust to dropping these patents from the sample. Results are also similar in Poisson regressions where observations are weighted by the number of guilds active in the sector.

[20] The history literature confirms the idea that cooperative interactions across guilds were extremely rare. Markets were mostly local, guild members were strongly embedded in their city and multiple memberships to guilds of different cities were not permitted (Caracausi, 2008; Olgivie, 2014).

of the city and the guild seem to affect patenting propensity of inventors independently of their origin. It is possible to reconcile the larger magnitude of the effect for local inventors with our theoretical model. In fact, under standard assumptions on the distribution of the parameter Δ (e.g. uniform, exponential, etc.) the derivative of the probability of patenting with respect to θ has a smaller magnitude for external innovators than for guild members.[21]

Second, we examine the relationship between statutory clauses and patenting, exploiting a different source of patent data. Specifically, rather than matching guilds and patents using the data and the technology classification of Berveglieri (1995, 1999), we construct a new dependent variable that relies on the patents collected and described by Mandich (1936). Interestingly, this smaller sample also includes information on the geographical scope of patent rights. Even though the wording of the 1474 act indicates that patents were enforceable in the entire dominion, about 12 percent of the patents described in Mandich (1936) appear enforceable only in specific locations (e.g. only in Venice or other specific cities). We use this information to construct an alternative measure of patenting that imputes patents with limited geographical scope only to the guilds located in the relevant cities. Columns 5 and 6 show that our results on the geographical distance and on the strength of internal rules are robust to exploiting this alternative data source.

6 Instrumenting guild's regulation strength

Our analysis has shown a strong negative association between the strength of a guild's internal rules and patenting in the technology area in which the guild operates, which is consistent with the predictions of our theoretical framework. We have documented robustness of this finding in a variety of specifications that include city effects and control for several guild characteristics. But still, to interpret this result causally is challenging, because unobservable variables may be correlated both with *Strong internal regulation* and with patenting.

In particular, there are two alternative explanations that need to be addressed. First, guilds with strong statutes may be more likely to operate in technology areas in which secrecy can be used more effectively and there is less need for patents. Specifically, the concern is that *Strong internal regulation* is spuriously correlated with low information leakages, which would imply that our estimates do not capture the effect of statutory clauses restricting market power.

[21] From Berveglieri's classification it follows that foreign inventors are never guild members while local inventors may or may not be.

Our industry controls partially address this concern, because information leakages are likely to be similar for guilds operating within the same industry. Moreover, one would expect guilds facing high information leakages to be more likely to adopt clauses to restrict entry, which would generate a positive rather than a negative correlation between patenting and *Strong internal regulation*.[22]

Second, the 1474 patent act may have been introduced as a response to technology shocks affecting guilds without strong statutes, or as a political move to curb the power of stronger guilds. There are two reasons why we think this is unlikely. First, one would expect the Venetian government to react to technology shocks in specific industries with targeted policies rather than with a one-size-fits-all patent act affecting all the guilds in the dominion (we describe examples of such targeted policies in section 7). Second, senatorial records show that the act passed with a very large majority (116 votes in favor, 10 against, and 3 abstentions), which is inconsistent with a politically contentious act harming powerful guilds (Berveglieri, 1995).

Addressing these issues and other unobservable heterogeneity concerns more constructively requires an instrumental variable correlated with the presence of statutory norms restricting entry and competition and uncorrelated with patenting strategies. In this section, we propose an instrument that relies on the religious origin of some of the guilds in our sample.

A number of the guilds active in the Venetian Republic during the Renaissance find their origin in religious confraternities that arose from the spread of the Flagellant movement during the 13th century. A confraternity (also called 'scola' or 'fratalea') was an association of lay people driven by Christian devotion and works of charity (Gasparini, 1987). While people from all social classes could join a confraternity, most of the members were craftsmen. Confraternity members were required to follow rules and bylaws in exchange for help in times of hardship and the security of a good funeral (Monticolo, 1896; Pullan, 1971).

During the 14th and 15th centuries the Venetian government promoted the formation of craft and trade guilds as a way to collect tax revenue and to recruit soldiers, and this led members of confraternities to set up craft guilds linked to the various confraternities (Constantini, 1987; Gasparini, 1987). For example, in Venice the guild of ironmongers was connected to the confraternity of San Lorenzo, fishermen with that of San Nicolò, and goldsmiths with San

[22] At the time of our study, knowledge circulation was closely linked with circulation of people, and enforcement of trade secrets required restrictions to guild access and cooperation between members. Therefore, in our model one can interpret the larger surplus appropriation from an increase in θ as capturing both greater market power and lower information leakage.

Mattio's (Mackenney, 1994).[23]

Istituzioni Corporative shows that roughly 30 percent of the guilds in our sample originated from a religious confraternity. There is no clear pattern linking the religious origin of guilds with their geographic location or their industry. For example, the barbers' guild in Verona originated from a confraternity, but none of the barber guilds in the other cities in the sample have religious origins. Similarly, the blacksmiths' guild of Udine is linked to a confraternity, whereas those of Padua, Venice and Vicenza are not.

More than half of the guilds in Venice are linked to a confraternity, whereas in the other cities the proportion is typically below 20 percent. Nonetheless, once we control for city effects, we do not find any significant correlation between the religious origin of the guild and other observable characteristics, such as its age, the presence of an apprenticeship system, or the industry. Table A5 in the appendix illustrates this result in a series of regressions in which religious origin is the dependent variable. In all cases the correlations are close to zero and statistically insignificant. These results support the idea that the religious origin of a guild is likely to be driven by idiosyncratic reasons related to the local success of the Flagellant movement centuries before the patent act, and thus unlikely to be correlated with shocks affecting patenting strategies after 1474.

Historians also documented how religious confraternities followed a strict set of rules - which were recorded in a book called 'Mariegola'- regulating both admission of new members and day-to-day interactions among members (Monticolo, 1892; 1896; Gasparini, 1987; Black, 1989). Black (1989) describes how admission of new individuals involved serious scrutiny by the confraternity's leading officials and, in some cases, it required a vote of the whole congregation and the payment of an entrance fee. Statutes of guilds that originated from confraternities were often inspired by the Mariegolas of the related confraternities (Mackenney, 1994). Moreover, entry restrictions may have been required to limit access to the public good provided by the associated confraternity (Greif and Tabellini, 2017). This suggests that guilds with religious origin were more likely to adopt internal rules restricting entry and competition.

In Table 4 we exploit the linkages between guilds and confraternities as instrumental variable. Column 1 reports the first stage regression, which indicates a strong positive correlation between the religious origin of the guild and the strength of its internal rules. Columns 2

[23] These connections generated obligations on both sides. For example, guilds were required to make financial contributions to the confraternity, but were also allowed to use the confraternity venues as meeting places.

and 3 contrast the OLS estimates and the 2SLS estimates of similar linear regression models. Both specifications confirm the strong negative relationship between patenting and the guild's internal rules. The estimates of the IV regression are larger in magnitude but not statistically different from those in the OLS model. The larger magnitude of the coefficient is consistent with measurement error in statutory strength biasing the estimates toward zero, as discussed above.[24]

Following Galasso et al. (2013), we also instrument *Strong internal regulation* with the predicted probability of a strong statute obtained from a probit model in which the endogenous variable is regressed on the instrument and other first-stage covariates. When the endogenous regressor is a dummy, this estimator is asymptotically efficient in the class of estimators where instruments are a function of the religious origin of the guild and other covariates (Wooldrige, 2002). The 2SLS estimate with this alternative model is essentially identical in magnitude and of stronger statistical significance than the one presented in column 3 of Table 4.[25]

While the vast majority of the guilds in our sample formed in the 14th and 15th century, there is the possibility that for some of the oldest guilds in our sample confraternity and guild developed side by side. For these observations, the exogeneity of our instrument may be questionable because unobservable factors may have driven the joint formation of the confraternities and the guild. To address the concern that the oldest guilds are not biasing our estimates, in column 1 of Appendix Table A6 we show that our IV estimates are robust to including more flexible controls for age of the guild, i.e. separate dummies for each age quartile. To further capture idiosyncratic features of the oldest guilds, in column 2 we add an extra dummy for guilds above 95th percentile of the age distribution. Column 3 drops these old guilds altogether. Across the three columns we find strong, negative and statistically significant coefficients confirming the robustness of our estimates.

6.1 Religious origin and innovation incentives

Our IV strategy rests on the assumption that the religious origins of guilds are not related to anything that affects patenting a few centuries in the future, save stronger admission re-

[24]We obtain qualitatively similar results with an IV Poisson model, but our estimates are much larger in this case. We also experience convergence issues with some specifications of the IV Poisson model, which are common for this estimator, as described in Silva and Tenreyro (2011).

[25]Following Angrist and Pischke (2009), we exploit the first stage estimates to compute the proportion of the treated who are compliers which is 0.22. This indicates that our estimates are not specific to a small compliant subpopulation.

quirements to enter these guilds. One concern is that members of guilds with a religious origin may be more risk averse, i.e., less likely to implement changes in their statutes and business practices, and therefore less likely to use patents internally and more likely to oppose patents of external innovators. Using modern data on religiosity across countries and the US States, Benabou, Ticchi, and Vindigni (2015) provide support for such a negative effect of religion on innovation, documenting a negative correlation between religiosity and patenting, which suggests a lower propensity to adopt new ideas and embrace change. While we cannot rule out this possibility, there are a number of reasons why we do not expect this channel to play an important role in our setting.

First, the religious confraternities that spread throughout Northern Italy in the Middle Ages represented a novel and more modern way of practicing the Christian faith. They placed more emphasis on the individual role and less emphasis on the role of the church and the clergy (Black, 1989). Their laity, openness to women, and diversity in social composition are evidence of these modern attitudes (Gasparini, 1987). These confraternities also had an important educational role, which led to more openness in the ideas of their members, liberating many from superstition and profound ignorance (Black, 1989). They also improved literacy rates and generated more debate about religious beliefs, which provided the foundation for the subsequent Catholic reform.

Second, risk taking and individual entrepreneurship were not discouraged by confraternities. Often, confraternities provided loans to their members, on the security of pledged goods, charging minimal interest to cover administrative costs. Moreover, confraternities benefitted from the individual success of their members through donations of buildings, their decoration, and other philanthropic initiatives of patrons willing to be remembered by their successors (Black, 1989).

Third, studies examining the Mariegolas of the confraternities of Venice and the Terraferma do not report any restrictions to the adoption of new technologies, production processes or property rights. Instead, they stress the ability of confraternities to accommodate changes and adapt to innovation (Monticolo, 1892: Gasparini, 1987, Mackenney, 1994).

As additional supporting evidence, in column 3 of Table A5 we show that guilds originating from religious confraternities were as likely to change their statutes during the period of our study as those not linked to religious confraternities. This finding mitigates the concern that the religious origin of a guild is simply a proxy for the risk aversion of the guild many decades in the future.

Finally, exploiting data on 19th-century France to examine the impact of religion on knowledge diffusion Squicciarini (2017) finds a negative effect only during the second industrial revolution, not before. This confirms the idea that the link between innovation and religiosity started to matter only in more modern times.

7 Distance from Venice and patenting

Our empirical analysis has shown that patenting was more pronounced in technology fields of guilds located in cities geographically distant from Venice. A possible interpretation of this finding is that formal protection through patent documents was more beneficial to innovators operating further away from the center of political activity. In other words, innovators who were close to Venice may have had access to alternative (formal or informal) mechanisms to protect their technologies. This interpretation is supported by historical evidence that geographical proximity determined a special relation between the guilds and the Venetian government. For example, Demo (2016) and Caracausi (2016) argue that when conflicts arose between Terraferma's and Venetian guilds, often the government favored those located in Venice.

To explore in more detail this issue, we develop an additional measure capturing the political strength of each city. To construct this variable, we collect data on the noble families residing across the different cities of the Venetian Republic and their marriages with members of the great council, the legislative assembly of the Republic. After the 1297 serrata, great council membership was patrilineal hereditary and this restricted political power to families of 'nobili veneti' the high nobility of the Venetian Republic. While the vast majority of these high nobles resided in Venice, in the other cities of the dominion some families were recognized with lower nobility statuses such as 'nobili', 'conti' or 'nobili palatini'. Marriages between nobles residing in a city and members of the great council could be used strategically to increase the political influence and create stronger connection between the city and the center of political power.[26] Even if nobles could not be members of guilds, they often supported business activities in their city (Demo, 2013).

To identify high and low nobility families residing in each city of our sample we digitize

[26] Other studies in economics and sociology have examined the network of marriages in Medieval Italy. Padgett and Ansell (1993) show that the success of the Medici family in Florence was driven by strategic marriage alliances. Puga and Trefler (2014) document the use of marriage alliances in Venice to monopolize the galley trade.

the census of the patrician families residing in Veneto and nearby regions compiled in the nineteenth century by Schroeder (1830). For each noble family Schroeder reports the date in which the family obtains the nobility title and the city in which it resides. This allows us to identify the number of noble families residing in each city at the time of the patent act. On average there are about 60 noble families for each city in our sample. More than 100 noble families were located in Venice and smaller cities, such as Udine or Treviso, had less than 30 families.[27]

We combine this digitized census of patrician families with additional data to generate our measure of political power. First, exploiting the information in Raines (2004), we identify the names of the families with great council membership. Second, we obtain data on marriages involving a noble husband during the period 1400-1599. Records of these marriages are available from the 'Avogaria di Comun' of the Archivio di Stato di Venezia. Puga and Trefler (2014) digitized these records, building on the work of nineteenth century archivists. Combining these data sources, we construct the indicator variable *Politically connected families,* which equals one if we identify in the city at least one family belonging to the great council or linked through marriage to a family in the great council.[28]

In column 1 of Table 5 we show that there is a positive and statistically significant correlation between the number of noble families in a city and patenting by the guilds in the city. At the same time, the regression also shows that the number of noble families in a city explains much more of the variance in patents than does its population. Including these controls has no effect on the estimates of the effect of geographical distance and internal strength of the guild. This finding suggests that patenting is not simply driven by the sheer size of the city, but it is likely to be related to other regional characteristics. For example, the presence of noble families in a city may affect the quality of its human capital and the availability of financing, and thus spur technological activity (Demo, 2016).

In column 2 we introduce the variable *Politically connected families,* which captures the political strength of the city. We find a negative and statistically significant association between the presence of politically connected families and patenting, suggesting that formal intellectual

[27] Six observations had to be dropped from our sample because they are associated with smaller cities that were not covered by Schroeder (1830).

[28] More than half of the cities in our sample are not connected to the great council according to this measure. We use an indicator variable because of the limited variance in this variable (apart from Venice, in all the other cities the number of linked families ranges between 0 and 3).

property protection may have been a substitute for alternative forms of protection available to guilds with stronger political connections.[29]

There is the concern that the results of columns 1 and 2 are driven by Venice because most of the noble families and members of great council resided in Venice or because of other legal and judicial differences with other cities (Knapton, 2013). To address this issue, in column 3 we drop from our sample all the Venetian guilds. All our findings are robust to focusing on this smaller sample of guilds located in Terraferma.

An additional concern is that more distant cities differ in their human capital or growth potential and this may be correlated with their political power and the propensity to patent. An important determinant of growth and human capital for European cities in the 1400s was the availability of the printing press, as documented by Dittmar (2011). To take this issue into account, we collect data on the number of printed books available in each city of our sample in 1500. This information is obtained from *'Incunabula Short Title Catalogue,'* a database of the British Library that includes nearly all books printed in Europe before the year 1501. For each item, the dataset provides authors, titles, language and, more importantly for our scope, date and place of printing. In column 4 of Table 5, we introduce this control and find a positive but statistically insignificant correlation between the number of books in a city and patenting. At the same time, all other results on geographical distance and political power are robust.[30]

As a final robustness test, we examine the sensitivity of our results to our measure of geographical distance. Appendix Table A7 compares the estimates obtained with our preferred measure of distance - which is constructed using maps of transportation routes of the Venetian Republic- with two alternative distance measures. In column 2 we obtain the distance data from the "Digital Atlas of Roman and Medieval Civilizations" which provides maps of the ancient Roman road network (McCormick et al., 2013). In column 3 we use instead the modern road network (excluding highways) as an alternative source of distance. The estimates on the geographical distance measures and the other variables are robust and essentially identical across the three specifications.

Many other factors may vary across cites, and it is quite likely that omitted variables correlated with geographical and political distance are important for the propensity to patent.

[29]In this table standard errors are clustered at the city level as the main variable of interest only vary at the level of the city.

[30]We obtain similar qualitative and quantitative estimates in regressions run on the smaller sample in which observations are collapsed at the city level.

Nonetheless, the correlations reported in Table 5 suggest that the diffusion of the very first patent rights was shaped by geographic and political forces. From a theoretical perspective, the relationship between patenting and political or geographical distance from Venice is ambiguous. On the one hand, patents might have been easier to enforce for inventors located closer to the capital. On the other hand, inventors and guild members with greater political connections might have been able to obtain protection from the government through other formal or informal channels. Our empirical evidence suggests that the second effect dominated the first, and that patents were not as widespread among guilds located in the proximity of Venice and among those in cities with stronger political ties.

A variety of historical accounts can support this interpretation of our findings. First, some of the guilds located in the proximity of Venice - such as those active in the Arsenal or Murano's glassblowers - were under close scrutiny by the Venetian government, which often passed laws to complement their statutes and to provide additional regulation of the sector. Some of these guild-specific regulations involved technology adoption. Caniato (1996) describes various legislative acts related to the Arsenal guild members that protected local production (e.g. by burning ships not built in Venice) and that rewarded selected foreign shipbuilders. Davanzo Poli (1984) describes a senate decision in 1462 that contained provisions supporting the tanner and shoemaker guilds of Venice. Manno (1995) describes similar forms of protection for glassmakers, blacksmiths, and the silk guild of Venice. Second, the Giustizia Vecchia - which was the main magistracy enforcing guild statutes and solving disputes between guild members- was located in Venice (Monticolo, 1892; Shaw, 2002). Closer interaction with guilds located in the vicinity of Venice may have allowed resolution of disputes on new products and processes without the need of formal patent documents.

8 Discussion

Our empirical analysis has shown that guilds with weak statutes and located in cities geographically distant from Venice revealed immediate interest in the new form of property rights and patented with greater intensity than other guilds. These results resonate with the modern economics of innovation literature, which has documented that patenting strategies vary across fields (Levin et al., 1987), that the effectiveness of patent protection interacts with other government policies (Schankerman, 1998), and that patenting is less common when firms have high market power (Aghion et al., 2005). The similarity between the IP strategies of contemporary firms and those of the pre-industrial economy suggests that the economic forces shaping modern patenting behavior are not a unique feature of contemporary technologies.

In her analysis of the origin of modern patent rights, Khan (2005) argues that the British and French patent systems were designed to support and increase the market power of elites. Differently, she shows that the United States system was more democratic, with patents accessible to non-elite inventors. In this respect, our finding that patents were more valuable for innovators located in frontier cities without political connections suggests that the American patent system was closer to the Venetian experience than were the French and British laws.

A natural question that arises is "What would have happened to these frontier cities in the absence of the Venetian patent system?" In the ideal empirical experiment, we would compare the economic growth of a Venetian city to the economic growth of the same city had the senate not passed the patent act. While this counterfactual is not observed, we examine this issue by constructing an empirical proxy for the hypothetical growth in the absence of patent rights for two of the cities in our sample, Padua and Vicenza. These two cities had roughly similar size in 1500 (the population of Padua was 20,000, that of Vicenza was 27,000). Nonetheless, our data show that roughly 60 percent of the craft guilds of Vicenza did not have a strong statute, whereas in Padua the fraction was less than 50 percent. Our data also show that in Vicenza the proportion of guilds in sectors with high patenting propensity (those using mills and those involved in the textile industry) was larger than in Padua. In light of our findings, these features of the local economy suggest that the availability of patents had a stronger impact on the guilds of Vicenza than on those of Padua. Indeed, we do observe more patenting per guild in Vicenza (4.58 patents per guild) than in Padua (1.76 patents per guild).

We use the synthetic control method (Abadie et al., 2010) to obtain a graphical representation of the effect of the patent system in the two cities. In the synthetic control approach, the control group is constructed through a data-driven procedure that aims to reproduce the counterfactual trajectory in the absence of a patent system and not simply averaging across cities. We use two alternative samples to conduct this exercise. First, we use the dataset constructed by Malanima (1998), which reports the population of 543 Italian cities during the period 1300-1600. Second, we exploit a smaller sample of 34 cities in Northern and Central Italy for which we can complement the population data with detailed information about the local guilds and their statutes (Moioli, 2004). In both cases, we construct the synthetic control only from cities outside the Venetian Republic, i.e., cities not affected by the Venetian patent act.

Appendix figure A2 illustrates the findings obtained from the first sample, in which the synthetic control is constructed by minimizing the difference in population growth before the patent act. The exercise shows that the difference in population growth after 1474 between Vicenza and its synthetic counterpart is much sharper than the corresponding difference between Padua and its synthetic counterpart. We also perform the analysis on the smaller sample of cities for which we can construct the control group by minimizing differences in city population, number of guilds, average guild statutory strength, and industry composition. Despite the small sample and the sparsity of the data, also in these (unreported) graphs we observe an increase in Vicenza's population after 1474 relative to the control group. Such an increase is not observed for Padua where, if anything, the population appears below that of the synthetic control group after the patent act.

These figures are only illustrative and should not be over-interpreted. Nonetheless, the estimates suggest that the availability of patents may have had some impact on the economic growth of frontier cities.

9 Conclusions

In this paper we study the diffusion of patent rights in the Venetian Republic following the 1474 senate act, which instituted the very first regularized patent system. There are two key empirical findings in the paper. First, we find a strong negative association between the number of patents granted in the technology sector of a guild and the presence of statutory provisions limiting entry and competition. Second, we find that patenting was more frequent for guilds located in cities geographically distant from Venice and in cities with lower political connection.

Overall, our findings indicate that the diffusion of new economic institutions may be strongly affected by features of the local economic and political environment. This has potential implications for the design of patent policies, because it suggests that policy outcomes may vary substantially across locations and industries, even within a region. Our estimates are also in line with the more recent innovation literature, which has documented substantial variation in the rate of patenting across industries and in the perceived effectiveness of patents across firms (Levin et al., 1987; Schankerman, 1998; Cohen, Nelson, and Walsh, 2000). Our data show that even in the very first patent system, the private economic value provided by intellectual property rights appears highly heterogeneous. Finally, our analysis underscores the importance of considering the potential substitution between new institutions and existing alternatives.

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Appendix: Extensions of the theoretical model

Generalized impact of guild statutes

In this Appendix we extend our baseline model generalizing the impact that guild statutes have on rent sharing, $\alpha(\theta)$, and entry, $\beta(\theta)$. We assume that the ability to appropriate rents increases with θ, $\alpha'(\theta) > 0$ while the probability of entry decreases, $\beta'(\theta) < 0$. Finally, we assume that $\alpha(0) = \beta(1) = 0$ and $\alpha(1) = \beta(0) = 1$.

We analyze first the case in which a guild member is the innovator. As in Section 3, we solve the model by backward induction considering first the opposition decision. Opposition is profitable if

$$\frac{2\alpha(\theta)(\pi + \Delta)}{2} - \kappa > \frac{\alpha(\theta)\pi}{2} + \frac{\alpha(\theta)(\pi + \Delta)}{2}$$

which is satisfied if

$$\Delta > \widehat{\Delta}(\theta) = \frac{2}{\alpha(\theta)}\kappa.$$

Notice that $\frac{d\widehat{\Delta}(\theta)}{d\alpha} < 0$ which combined with $\alpha'(\theta) > 0$ implies that, as the strength of the internal statute increases, guild members block patents of other guild members more often. If the innovator anticipates opposition it will not apply for a patent. If, instead, $\Delta \leq \widehat{\Delta}(\theta)$ the guild member will patent when:

$$\pi + \Delta - \frac{\alpha(\theta)\pi}{2} + \frac{\alpha(\theta)(\pi + \Delta)}{2} - c > \frac{2\alpha(\theta)(\pi + \Delta)}{2}$$

or

$$\Delta > \widetilde{\Delta}(\theta) = \frac{2\left(c - \pi(1 - \alpha(\theta))\right)}{2 - \alpha(\theta)}.$$

Notice that $\widetilde{\Delta}(\theta) > 0$ only if $\alpha(\theta)$ is large enough. Moreover $\frac{d\widetilde{\Delta}(\theta)}{d\alpha} > 0$ which combined with our assumption that $\alpha'(\theta) > 0$ implies that, as the strength of the internal statute increases, guild members patent only their more valuable innovations and the propensity to patent decreases in θ. This also shows that our results on opposition and patenting by guild members presented in the text are robust to assuming a more general relationship between rent-sharing and θ.

Consider now the case of an external innovator. A guild member finds opposing the patent more profitable than accommodating it when:

$$2\alpha(\theta)\frac{(\pi + \Delta)}{2} - \kappa > \frac{\pi}{2}\alpha(\theta) + \frac{\alpha(\theta)(\pi + \Delta)}{3}$$

or

$$\Delta > \widehat{\Delta}_E(\theta) = \frac{3}{2\alpha(\theta)}\left(\kappa - \frac{\alpha(\theta)\pi}{6}\right)$$

It is easy to see that $\widehat{\Delta}_E(\theta)$ is decreasing in $\alpha(\theta)$. This, combined with our assumption that $\alpha'(\theta) > 0$, implies that the likelihood of opposition increases in θ. When $\Delta \leq \widehat{\Delta}_E(\theta)$ and the external innovator anticipates the patent will not be opposed, patenting is more profitable than entry without patent if

$$\pi + \Delta - \alpha(\theta)\pi + \frac{\alpha(\theta)(\pi + \Delta)}{3} - c > \beta(\theta)\frac{2\alpha(\theta)(\pi + \Delta)}{3}$$

that occurs if

$$\Delta > \widetilde{\Delta}_E(\theta) = \frac{3c - 3\pi + 2\pi\alpha(\theta) + 2\pi\alpha(\theta)\beta(\theta)}{\alpha(\theta) - 2\alpha(\theta)\beta(\theta) + 3}$$

Given that $\alpha(0) = \beta(1) = 0$ and $\alpha(1) = \beta(0) = 1$, it follows that $\widetilde{\Delta}_E(0) = (3c - 3\pi)/3$ and $\widetilde{\Delta}_E(1) = (3c - \pi)/4$ which are both negative because $\pi > 3c$. Moreover, we have that

$$\begin{aligned}\frac{d\widetilde{\Delta}_E(\theta)}{d\theta} &= 3\frac{3\pi - c + 2\beta(\theta)c}{(\alpha(\theta) - 2\alpha(\theta)\beta(\theta) + 3)^2}\alpha'(\theta) \\ &\quad + 6\alpha(\theta)\frac{c + \pi\alpha(\theta)}{(\alpha(\theta) - 2\alpha(\theta)\beta(\theta) + 3)^2}\beta'(\theta)\end{aligned}$$

which is positive under the following condition:

$$-\frac{\alpha'(\theta)}{\beta'(\theta)} \geq \frac{2(\alpha(\theta)(c + \pi\alpha(\theta)))}{3\pi - c + 2\beta(\theta)c}$$

The right hand side of the above inequality is bounded by $(2c + 2\pi)/(3\pi - c)$ which in turn is bounded by 1 because $\pi > 3c$. This implies that $|\alpha'(\theta)| \geq |\beta'(\theta)|$ is a sufficient condition for $\frac{d\widetilde{\Delta}_E(\theta)}{d\theta} \geq 0$. In other words, patenting decreases in θ when changes in the statute strength have greater impact on rent sharing than on entry.

Generalized licensing negotiations

In the baseline setting, the innovating firm has the full bargaining power during the licensing negotiations and it appropriates the whole surplus of the innovation (while the other guild members obtain the status-quo profits $\theta\pi/2$). In this Appendix, we generalize the analysis assuming that the surplus is shared according to a parameter $\gamma \in [0, 1]$. More specifically, during the period of validity of the patent, the innovating firm obtains its status–quo profits plus a share γ of the innovation surplus, $\pi+\Delta-\theta\pi$; the remaining $(1-\gamma)$ share is appropriated by the other guild member(s). Parameter γ represents the bargaining power of the inventor during the licensing negotiations. Note that $\gamma = 1$ corresponds to the baseline setting.

Below, we show that the comparative static results of the baseline setting are still valid in this more general framework provided γ is large enough. Consider first the case of innovation by a guild member. The other guild member opposes the patent if

$$\frac{2\theta(\pi+\Delta)}{2} - \kappa > \frac{\theta\pi}{2} + (1-\gamma)(\pi+\Delta-\theta\pi) + \frac{\theta(\pi+\Delta)}{2}.$$

When choosing not to oppose the patent, in the first period, the guild member obtains $\theta\pi/2 + (1-\gamma)(\pi+\Delta-\theta\pi)$, the status-quo profits plus a share $(1-\gamma)$ of the innovation surplus. Hence, opposition is optimal if

$$\Delta > \hat{\Delta}(\theta) = \frac{2\kappa + 2(1-\gamma)(1-\theta)\pi}{(\theta - 2(1-\gamma))}.$$

A simple inspection of $\hat{\Delta}(\theta)$ reveals that $\frac{d\hat{\Delta}(\theta)}{d\theta} < 0$: the larger is θ the more likely that guild members oppose patents by other guild members.

Consider now the patenting decision. When $\Delta \leq \hat{\Delta}(\theta)$, patenting generates an overall profit

$$\frac{\theta\pi}{2} + \gamma(\pi+\Delta-\theta\pi) + \frac{\theta(\pi+\Delta)}{2} - c.$$

In the first period, the firm obtains the status-quo profits, $\theta\pi/2$, plus the share γ of the innovation surplus $(\pi+\Delta-\theta\pi)$. Hence, patenting is more profitable than non-patenting only if

$$\frac{\theta\pi}{2} + \gamma(\pi+\Delta-\theta\pi) + \frac{\theta(\pi+\Delta)}{2} - c > \frac{2\theta(\pi+\Delta)}{2}$$

or

$$\Delta > \tilde{\Delta}(\theta) = \frac{2\left(c - \gamma\pi(1-\theta)\right)}{(2\gamma-\theta)}.$$

Notice that $\tilde{\Delta}(\theta) > 0$ when θ and γ are large enough; moreover, $\frac{d\tilde{\Delta}(\theta)}{d\theta} > 0$, which implies that the propensity to patent reduces with the strength of the statutes.

Let us focus now on the case of innovation by a non-guild member. In this case, patent opposition is profitable for a guild member when

$$\frac{2\theta(\pi+\Delta)}{2}-\kappa>\frac{\theta\pi}{2}+\frac{(1-\gamma)}{2}(\pi+\Delta-\theta\pi)+\frac{\theta(\pi+\Delta)}{3}$$

By accommodating the patent, in the first period, a guild member obtains its status-quo profits plus half of $(1-\gamma)(\pi+\Delta-\theta\pi)$. Therefore, a guild member chooses to oppose a patent by an external if

$$\Delta>\hat{\Delta}_E(\theta)=\frac{3c-\pi\left(3\gamma(1-\theta)-\theta+2\theta^2\right)}{(3\gamma-\theta+2\theta^2)}.$$

It can be easily verified that $\frac{d\hat{\Delta}_E(\theta)}{d\theta}<0$ which implies that the larger θ the more likely is guild members opposition to patents of external innovators.

In turn, for $\Delta\leq\hat{\Delta}_E(\theta)$, patenting is optimal for the external innovator if

$$\gamma(\pi+\Delta-\theta\pi)+\frac{\theta(\pi+\Delta)}{3}-c>(1-\theta)\frac{2\theta(\pi+\Delta)}{3},$$

or

$$\Delta>\tilde{\Delta}_E(\theta)=\frac{3c-\pi\left(3\gamma(1-\theta)-\theta+2\theta^2\right)}{(3\gamma-\theta+2\theta^2)}.$$

From the above expression it follows that $\tilde{\Delta}_E(\theta)<0$ if $\gamma>\frac{3c+\pi\theta(1-2\theta)}{3\pi(1-\theta)}$; hence, the external innovator always prefers to patent provided that γ is large enough.

Settling patent opposition

The patent opposition process described in Section 3 leads to an important inefficiency: patents with large Δ are opposed and, therefore, inventors refrain from patenting their innovations. This fact reduces the overall surplus generated by the innovation at $t=1$ from $\pi+\Delta$ to $\theta(\pi+\Delta)$. Since we are considering a game of complete information, one may wonder whether our results are still valid when we allow for efficient negotiations about the opposition decision. To address this issue, in this Appendix we assume that, once the patent is granted, the innovator and the guild member/s negotiate over the opposition decision. Specifically, we assume that the innovator makes a take-it-or-leave-it offer about how to share the two-period overall surplus. If the proposal is accepted, then the patent is not opposed; otherwise, opposition takes place.[31]

Suppose that the innovator is a guild member. In this case, during the negotiations the innovator offers to the other guild member an overall payoff equal to $\theta(\pi+\Delta)/2+\theta(\pi+\Delta)/2-\kappa$,

[31] In the analysis, we assume that, in case of rejection, patent opposition is profitable. If this is not the case, then the analysis of the patenting decision coincides with that presented in the baseline model when $\Delta\leq\widehat{\Delta}(\theta)$ (internal innovator) or $\Delta\leq\widehat{\Delta}_E(\theta)$ (external innovator).

i.e. the payoff that the latter would obtain in the case of opposition; clearly, such a proposal is accepted. Hence, by choosing to patent the invention, the innovator obtains $\pi + \Delta + \theta(\pi + \Delta) - c - \theta(\pi + \Delta)/2 - \theta(\pi + \Delta)/2 + \kappa = \pi + \Delta - c + \kappa$, a payoff which does not depend on θ. By contrast, by not patenting, the innovator obtains $\theta(\pi + \Delta)/2 + \theta(\pi + \Delta)/2$, a payoff which increases with θ. Comparing the two payoffs, patenting is optimal when

$$(1 - \theta)(\pi + \Delta) - c + \kappa > 0$$

which decreases in θ. Therefore, also if we allow for negotiations over patent opposition, when the innovator is a guild member patenting becomes less likely as θ gets larger.

Suppose now that the innovator is an outsider. During the negotiations the innovator offers the two guild members an overall payoff equal to $2(\theta(\pi + \Delta)/2 + \theta(\pi + \Delta)/2) - \kappa$, i.e. the payoff they would obtain jointly if one of them were to oppose the patent. By patenting the innovator obtains a payoff $\pi + \Delta + \theta(\pi + \Delta) - c - 2(\theta(\pi + \Delta)/2 + \theta(\pi + \Delta)/2) + \kappa$, that is $(\pi + \Delta)(1 - \theta) + \kappa - c$. By contrast, when choosing not to patent, the innovator obtains $(1 - \theta)\frac{2\theta(\pi+\Delta)}{3}$. Comparing the two payoffs, patenting is optimal when

$$(1 - \theta)\frac{(\pi + \Delta)(3 - 2\theta)}{3} - c + \kappa > 0$$

a condition which is less likely to hold as θ grows larger. Therefore, also in the case of external innovator, patenting is decreasing in θ.

Figure 1. Venetian State Boundary

Map 3.1. Venice's *Terraferma*.

(Source: Knapton, 2013)

Table 1. Summary statistics

	Obs.	Mean	Std. Dev.	Min	Max
Patents	340	1.47	5.10	0	42
Strong internal regulation	340	0.21	0.40	0	1
Distance	340	59.90	77.67	0	422.10
Trade guild	340	0.46	0.49	0	1
Guild members	169	164.06	392.27	2	3390

NOTES: Unit of observation is a guild i located in city j. Patents is the total number of patents granted from 1474 to 1550 in the technology sector of the guild. Distance= distance from Venice in Km. Strong internal regulation =1 if guild has internal rules which restrict competition, grant privileges to sons of members, and restrict rights of foreign members. Trade guild =1 if the guild is not involved in manufacturing. Guild members = number of registered members as reported in the "Istituzioni Cooperative" data.

Table 2 . Guild internal regulation and patenting

	(1)	(2)	(3)	(4)
Dependent Variable	Patents	Patents	Patents	Patents
Strong internal regulation	-0.750***	-0.995***	-1.133***	-1.717***
	(0.151)	(0.103)	(0.439)	(0.610)
log(Distance)		0.224***		
		(0.026)		
log (Guild members)				0.256
				(0.191)
Trade guild	-4.535***	-4.357***	-4.355***	-5.268***
	(0.710)	(0.708)	(0.848)	(1.042)
City Effects	No	No	Yes	Yes
Observations	340	340	340	169

NOTES: Poisson estimation with robust standard errors. * significant at 10 percent, ** significant at 5 percent and *** significant at 1 percent. Strong internal regulation =1 if guild has internal rules which restrict competition, grant privileges to sons of members, and restrict rights of foreign members. Distance= distance from Venice in Km. Guild members = number of registered members as reported in the "Istituzioni Cooperative" data. Trade guild =1 if the guild is not involved in manufacturing.

Table 3. Inventors' origin and alternative patent data

	(1)	(2)	(3)	(4)	(5)	(6)
Dependent Variable	Patents Local	Patents Local	Patents Foreigners	Patents Foreigners	Patents Mandich	Patents Mandich
Strong internal regulation	-0.960***	-1.098**	-0.029**	-0.034*	-1.372***	-1.266**
	(0.098)	(0.429)	(0.012)	(0.020)	(0.317)	(0.616)
log(Distance)	0.218***		0.006***		0.168***	
	(0.025)		(0.001)		(0.037)	
City Effects	No	Yes	No	Yes	No	Yes
Observations	340	340	340	340	340	340

NOTES: Poisson estimation with robust standard errors. * significant at 10 percent, ** significant at 5 percent and *** significant at 1 percent. All regressions include a dummy for Trade guilds. Strong internal regulation =1 if guild has internal rules which restrict competition, grant privileges to sons of members, and restrict rights of foreign members. Distance= distance from Venice in Km. Patents local= patents granted to Italian inventors. Patents foreigners= patents granted to non-Italian inventors. Columns 1-4 exploit patent data from Berveglieri (1995, 1999) columns 5-6 exploit patent data from Mandich (1936).

Table 4. Religious confraternities and guild internal strength

	(1)	(2)	(3)	(4)
Dependent Variable	Strong guild	Patents	Patents	Patents
Estimation	OLS	OLS	2SLS	2SLS
Religious confraternity	0.150***			
	(0.045)			
Strong internal regulation		-1.958**	-4.183*	-4.387**
		(0.861)	(2.720)	(2.191)
City Effects	Yes	Yes	Yes	Yes
Observations	340	340	340	340
First stage F-test			7.85	13.21
Instrument			Religious confraternity	Probit regression

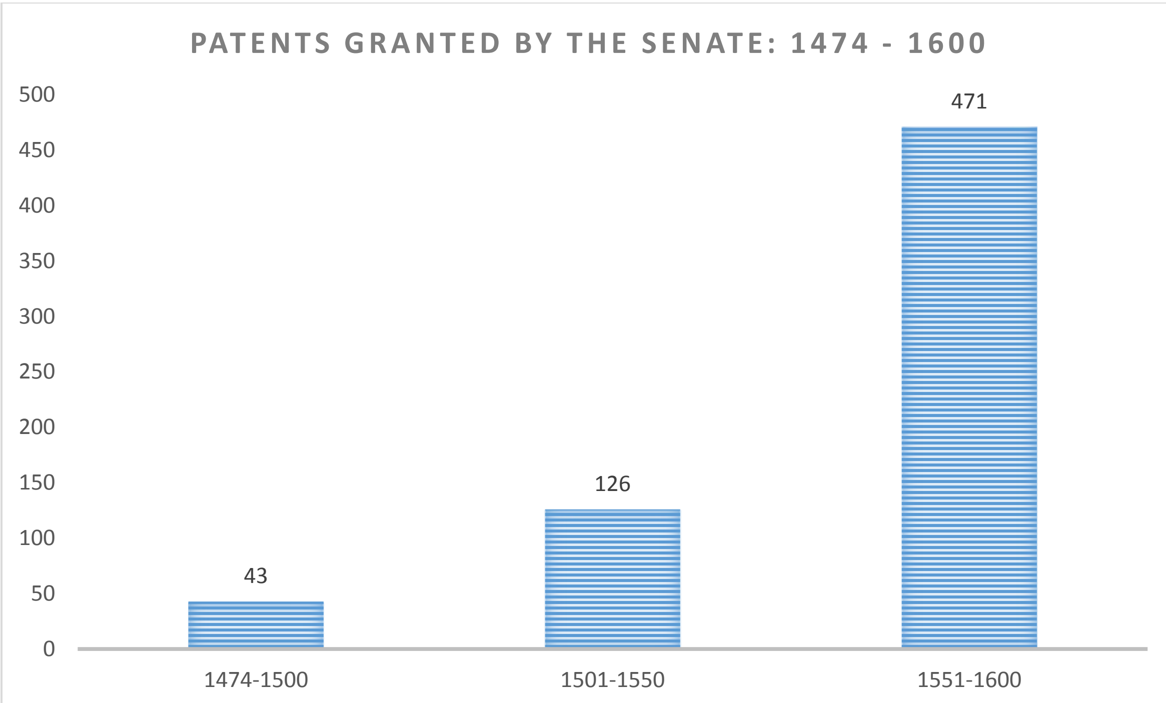
NOTES: OLS estimation with robust standard errors. * significant at 10 percent, ** significant at 5 percent and *** significant at 1 percent. All regressions include a dummy for Trade guilds. Religious confraternity =1 if guild is linked to a religious institution. Strong internal regulation =1 if guild has internal rules which restrict competition, grant privileges to sons of members, and restrict rights of foreign members. In column 4 IV is predicted value from probit regression as in Wooldrige (2002).

Table 5. Noble families and patenting

	(1)	(2)	(3)	(4)
Dependent Variable	Patents	Patents	Patents	Patents
Strong internal regulation	-1.123***	-1.199***	-1.280***	-1.111***
	(0.121)	(0.124)	(0.128)	(0.116)
log(Distance)	0.299***	0.318***	0.255**	0.393***
	(0.034)	(0.020)	(0.115)	(0.061)
log(Noble Families)	0.092***	0.470***	0.495***	0.639***
	(0.031)	(0.094)	(0.097)	(0.219)
log($Population_{1500}$)	0.102	-0.066	0.001	-0.353
	(0.126)	(0.070)	(0.139)	(0.295)
Politically Connected Families		-1.595***	-1.700***	-2.168***
		(0.361)	(0.375)	(0.822)
log(Books)				0.146
				(0.102)
City Effects	No	No	No	No
Drop Venice	No	No	Yes	No
Observations	334	334	173	334

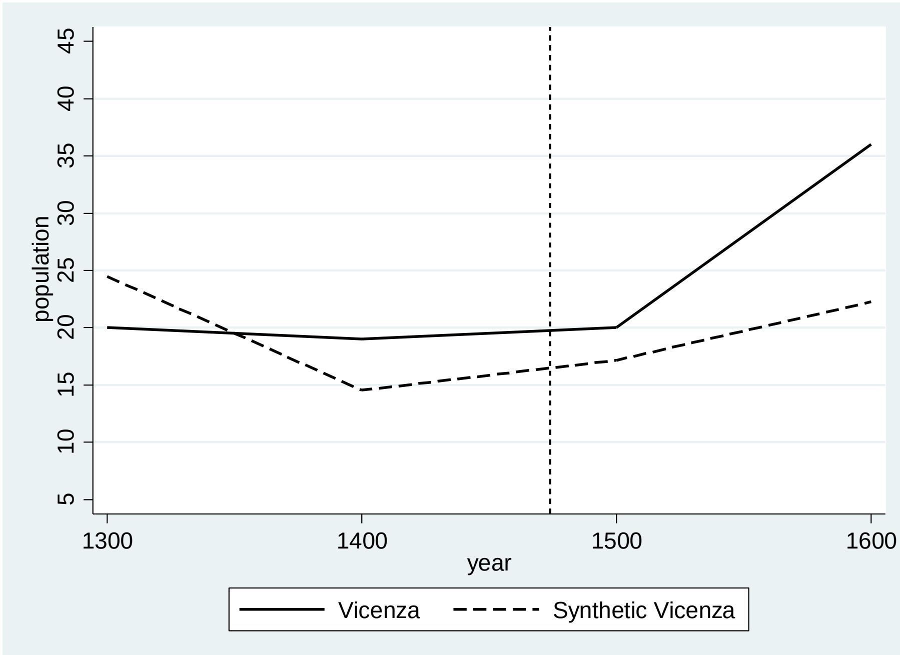
NOTES: Poisson estimation with robust standard errors clustered at the city level. * significant at 10 percent, ** significant at 5 percent and *** significant at 1 percent. All regressions include a dummy for Trade guilds. Strong internal regulation =1 if guild has internal rules which restrict competition, grant privileges to sons of members, and restrict rights of foreign members. Distance= distance from Venice in Km. Noble families = number of noble families in the city as registered by Schroeder (1830). Population= inhabitants in 1500 as estimated by Malanima (1998). Politically connected families=1 if there is at least one family in the city which belongs to the Great Council or is linked through marriages to a family in the Great Council. Books= number of printed books in the city in 1500, information from "Incunabula Short Title Catalogue".

Figure A1. Patenting over time



Source: Berveglieri (1995)

Figure A2. Population growth in Vicenza and Padua



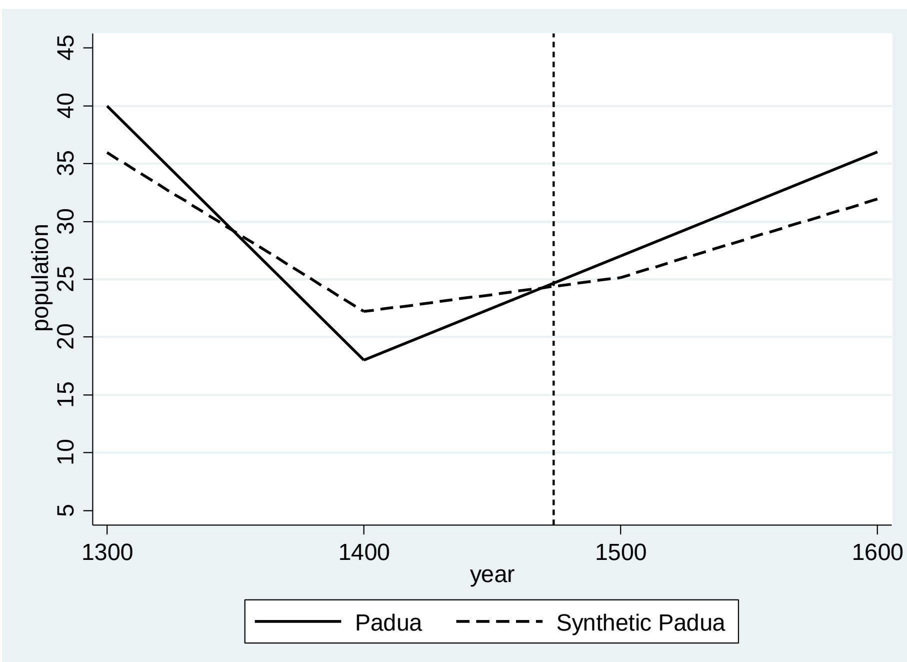


Table A1. Additional summary statistics

Panel (a): Patents by technology sector 1474-1550

Mills	
cereals	42
metals	6
textiles	9
wood saws	6
multiple usage	22
Fabrics	8
Paint	4
Bread and food	1
Pottery and Porcelain Vases	1
Agricultural machines	4
Drainage, mud removal	20
Hydraulic pumps	11
Armour and weapons	7
Arsenal	3
Mining	3
Perpetual Motion	3
Miscellaneous	19
Total	169

Source: Berveglieri (1995)

Panel (b): Number of guilds in the different cities

	Total	Strong	Trade
Ascoli	2	0	0
Bergamo	4	3	1
Brescia	31	13	10
Chioggia	8	1	3
Padua	39	2	19
Treviso	16	1	8
Udine	13	0	5
Venice	161	16	88
Verona	54	33	19
Vicenza	12	2	5

NOTES: Information on guilds active in the Venetian Republic before 1600. Guilds is the number of guilds active in the different cities. Strong is the number of guilds with a strong internal regulation. Trade is the number of guilds not involved in manufacturing.

Table A2. Robustness I

	(1)	(2)	(3)	(4)	(5)	(6)
Dependent Variable	Patents	Patents	Patents 1474-1600	Patents	Patents	Patents
Strong internal regulation	-1.010***	-0.948**	-0.728**	-0.837**		-1.307***
	(0.098)	(0.431)	(0.318)	(0.359)		(0.486)
Placebo					0.282	
					(0.394)	
log(Distance)	0.259***					
	(0.068)					
log $(Population_{1500})$	-0.013					
	(0.476)					
log $(Population_{1400})$	0.176					
	(0.769)					
log$(Population_{1300})$	-0.054					
	(0.383)					
Apprenticeship		0.120				
		(0.307)				
log(Age)		0.047				
		(0.164)				
Mills				2.044***		
				(0.325)		
City effects	No	Yes	Yes	Yes	Yes	Yes
Industry effects	No	Yes	No	No	No	No
Drop guilds with change in statute	No	No	No	No	No	Yes
Observations	340	340	340	340	340	275

NOTES: Poisson estimation with robust standard errors. * significant at 10 percent, ** significant at 5 percent and *** significant at 1 percent. Regressions include dummy for Trade guilds. Strong internal regulation =1 if guild has internal rules which restrict competition, grant privileges to sons of members, and restrict rights of foreign members. Placebo=1 if the statute includes: (i) a list of manufacturing activities precluded to women, (ii) the name of the guild's patron saint and (iii) a description of the hierarchical structure of the guild. Distance= distance from Venice in Km. Population data are from Malanima (1998). Apprenticeship=1 if the "Istituzioni Corporative" database documents an apprenticeship requirement. Age= age of the guild in 1600. Mills=1 if guild activities involve the use of mills. Industry effects are dummies for guilds in agricolture, textile and construction. Column (6) drops guilds with changes in statutes in the period 1474-1550.

Table A3. Robustness II

	(1)	(2)	(3)	(4)
Dependent Variable	Patents	Patents	Patents	Patents
Strong internal regulation	-1.211**	-1.189***		-1.182***
	(0.482)	(0.451)		(0.454)
Statutory strength index			-0.549**	
			(0.221)	
Only limits entry or competition				-0.317
				(0.466)
City effects	Yes	Yes	Yes	Yes
Drop guilds of Venice	Yes	No	No	No
Drop trade guilds	No	Yes	No	No
Observations	179	182	340	340

NOTES: Poisson estimation with robust standard errors. * significant at 10 percent, ** significant at 5 percent and *** significant at 1 percent. Regressions include dummy for Trade guilds. Strong internal regulation =1 if guild has internal rules which restrict competition, grant privileges to sons of members, and restrict rights of foreign members. Statutory strength index =0 if no restrictions, =1 if restrictions only to entry or to competition, =2 if restrictions both to entry and competition.

Table A4. Sector-level regressions

	(1)	(2)	(3)	(4)
Dependent Variable	Patents	Patents	Patents	Patents
Sample	all	drop multi-sector patents	all	drop multi-sector patents
Average Strong internal regulation	-4.808***	-4.459***	-2.820**	-2.345**
	(1.483)	(1.486)	(1.219)	(1.214)
Average log(Distance)	0.757***	0.767***	0.944**	0.954**
	(0.271)	(0.271)	(0.458)	(0.452)
log (Number of guilds)	-1.800***	-1.685***	-1.867***	-1.848***
	(0.595)	(0.617)	(0.604)	(0.631)
Non-manufacturing sector			-4.048***	-4.326***
			(1.414)	(1.552)
Average log(City Population)			0.344	0.260
			(1.261)	(1.237)
Observations	51	51	51	51
Mean depentent variable	3.31	2.17	3.31	2.17

NOTES: Poisson estimation with robust standard errors. * significant at 10 percent, ** significant at 5 percent and *** significant at 1 percent. Unit of observation is an industry sector. The dependent variable is the number of patents for the industry sector. In columns 1 and 3 each of the 169 patents from Berveglieri (1995) is assigned to one sector, a restricted sample of 111 patents is used in columns 2 and 4. Average strong internal regulation = fraction of guilds in the sector with strong internal statute. Number of guilds = number of guilds active in the industrial sector.

Table A5. Exogeneity of religious origin

	(1)	(2)	(3)	(4)
Dependent Variable	Religious confraternity	Religious confraternity	Religious confraternity	Religious confraternity
Age	0.001			0.001
	(0.001)			(0.001)
Age^2	-0.001			-0.001
	(0.001)			(0.001)
Apprenticeship		0.046		0.055
		(0.042)		(0.042)
Number of statutory changes 1474-1550			0.022	0.041
			(0.044)	(0.045)
Textiles				-0.062
				(0.045)
Construction				-0.096
				(0.120)
Agriculture				0.032
				(0.055)

NOTES: OLS regression with robust standard errors. * significant at 10 percent, ** significant at 5 percent and *** significant at 1 percent. The dependent variable is filtered with city effects and a dummy for trade guilds. Apprenticeship=1 if the "Istituzioni Corporative" database documents an apprenticeship requirement. Age= age of the guild in 1600. Number of statutory changes 1474-1550 = number of times the statute of the guild changed during the period 1474-1550, as reported in the "Istituzioni Cooperative" data. Textile, Construction and Agriculture are industry dummies.

Table A6. IV Robustness: old guilds

	(1)	(2)	(3)
Dependent Variable	Patents	Patents	Patents
Estimation	2SLS	2SLS	2SLS
Strong internal regulation	-4.746**	-4.848**	-4.788**
	(2.279)	(2.309)	(2.379)
Old guild		1.777	
		(2.240)	
City Effects	Yes	Yes	Yes
Age quartile dummies	Yes	Yes	Yes
Drop oldest guilds	No	No	Yes
Observations	340	340	323
First stage F-test	15.13	15.43	13.98
Instrument	Probit regression	Probit regression	Probit regression

NOTES: OLS estimation with robust standard errors. * significant at 10 percent, ** significant at 5 percent and *** significant at 1 percent. All regressions include a dummy for Trade guilds. Religious confraternity =1 if guild is linked to a religious institution. Strong internal regulation =1 if guild has internal rules which restrict competition, grant privileges to sons of members, and restrict rights of foreign members. IV is predicted value from probit regression as in Wooldrige (2002). Old guilds =1 for guilds above 95th percentile of age distribution.

Table A7. Alternative distance measures

	(1)	(2)	(3)
Dependent Variable	Patents	Patents	Patents
Strong internal regulation	-1.199***	-1.178***	-1.203***
	(0.124)	(0.119)	(0.125)
log(Distance)	0.318***		
	(0.020)		
log(Distance) - Roman roads		0.322***	
		(0.018)	
log(Distance) - Modern roads			0.340***
			(0.022)
log(Noble Families)	0.470***	0.338***	0.419***
	(0.094)	(0.092)	(0.093)
log(Population$_{1500}$)	-0.066	0.045	0.027
	(0.070)	(0.071)	(0.072)
Politically Connected Families	-1.595***	-1.011***	-1.333***
	(0.361)	(0.377)	(0.351)
City Effects	No	No	No
Observations	334	334	334

NOTES: Poisson estimation with robust standard errors. * significant at 10 percent, ** significant at 5 percent and *** significant at 1 percent. All regressions include a dummy for Trade guilds. Strong internal regulation =1 if guild has internal rules which restrict competition, grant privileges to sons of members, and restrict rights of foreign members. Distance= distance from Venice in Km. Noble families = number of noble families in the city as registered by Schroeder (1830). Population= inhabitants in 1500 as estimated by Malanima (1998). Politically connected families=1 if there is at least one family in the city which belongs to the Great Council or is linked through marriages to a family in the Great Council. Books= number of printed books in the city in 1500, information from "Incunabula Short Title Catalogue". Roman road distance from McCormick et al (2013). Modern road distance from Google Maps.