



MARKET POWER AND PATENT STRATEGIES: EVIDENCE FROM RENAISSANCE VENICE*

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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. We combine detailed information on craft guilds and patents in Renaissance Venice and show a negative association between patenting activity and guild statutory norms that strongly restricted entry and price competition. Our analysis shows that the heterogeneity in patenting activity documented by the industrial organization literature is not a special feature of modern technologies, but is rather a persistent phenomenon affected by market power.

I. INTRODUCTION

PATENTS PROVIDE TEMPORARY MONOPOLY RIGHTS over a new technology that generate rents to the innovator and support private contracting. The industrial economics literature has documented a large variation in the rate

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of patenting across industries and in the perceived effectiveness of patents across firms (Schankerman and Pakes [1986]; Hall and Ziedonis [2001]; von Graevenitz *et al.* [2013]). 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 rely heavily 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]). 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]).

In this paper we use historical data to investigate whether the heterogeneity in patent strategies documented by the literature is a recent phenomenon driven by modern technology trends, or a persistent feature of innovation that can be linked to more fundamental economic forces. We exploit the introduction of the first regularized patent system, which appeared during the Renaissance in the Venetian Republic, to examine how market power and other local conditions relate to the propensity of inventors to use the new form of intellectual property. 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.

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 a 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. We show that the interplay of these institutional features implies that the level of patenting can vary substantially across guilds. 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. The market power generated by these 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 shows 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 an 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 types of formal and informal protection.

Taken together, our findings suggest that local economic and political conditions may have a substantial impact on intellectual property strategies. Patent strategies in Renaissance Venice's pre-industrial economy appear to be shaped by industry characteristics such as competition and barriers to entry. This suggests that the heterogeneity in patenting observed in modern

industries is not a unique feature of contemporary technologies, but rather a persistent phenomenon driven by basic economic forces.

The paper is organized as follows. Section II offers an overview of the related literature. Section III provides a brief description of the origin and functioning of the Venetian patent system. In Section IV, we develop a model showing the link between guild statutory norms and patenting. Section V describes the data and discusses the econometric specification. Section VI examines the empirical relationship between guild statutes and patenting. In Section VII, we confirm the results exploiting the quasi-exogenous variation in guild religious origins. Section VIII studies the relationship between guild locations and patenting. Section IX provides a discussion of the results and their implication for policy. Concluding remarks summarize and discuss our main findings. Extensions of the theoretical model and robustness of the empirical analysis are included in an online appendix available on the *Journal's* editorial web site.

II. RELATED LITERATURE

This paper is connected to various strands of the economics history and innovation literatures.

II(i). *Economic History*

The economic history literature on the role of craft guilds and their relationship with the patent system has stressed the important role of guilds in creating, protecting and transmitting technical knowledge in medieval Europe (*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 introducing a novel dataset on Venetian patents and guilds, which may also prove useful for future research.

Traditionally, historians have seen craft guilds as rent-seeking institutions that opposed many form of innovations (North [1981]; Olgivie [2007, 2014]), but recent studies have provided a more nuanced views recognizing that guilds were able to accommodate technological progress despite documented individual instances of resistance to innovation (Epstein [1998, 2004]; Molà [2000]).

While guild attitude toward innovation has been studied extensively, less attention has been devoted to their attitude toward patents. Examining the relationship between patents and inventions in England in the seventeenth and eighteenth centuries, MacLeod [1988] suggests that patents played several functions beyond providing intellectual property protection. In particular, she highlights the role of patents as a mechanism to avoid the restrictive

regulations and controls imposed by guilds. According to MacLeod, this role was particularly important for foreign inventors and immigrants and it explains guild distrust of patents, especially those of foreigners which were seen as of small innovative content. The theoretical model in our paper is consistent with the analysis of MacLeod [1988] as it stresses the role of patents to overcome entry barriers imposed by guild statutes, and it endogenously generates patent applications with lower surplus for guild outsiders.

Belfanti [2004, 2006] studies the relationship between guilds and patents in Northern Italy, focusing on their impact on circulation of technical knowledge across Italian cities. In his view, craft guilds and patents were complementary institutions whose combined effect shaped the circulation of ideas and mobility of skilled craftsmen. He stresses how guilds and patents provided alternative ways of extracting rents from innovations, which could be used within the same competitive context. Our analysis supports this idea by emphasizing how patents were more effective at providing rents when guild statutes were weaker.

Several other authors highlight the link between patents and bargaining among guild members after the development of a technological innovation, as well as the substantial variation in the attitude toward patents across industries. Turner [2008] describes the opposition of the London Clockmakers' Company to several horological patents, and highlights the concerns of guild members to avoid excessive advantage for patent owners and to ensure that new technologies were shared. Epstein [1998] indicates the balance of power between poorer craftsmen and wealthier artisans as a crucial element for innovation dynamics of manufacturing guilds. Pfister [2008], examining the introduction of the silk ribbon engine loom, emphasizes the key role of the guild power structures, together with the political context and the type of technology. Finally, Trivellato [2008], in her analysis of Venetian silk and glass production, emphasizes the crucial role of intra-guild interactions and the importance of statutory norms. Our study contributes to this literature describing how bargaining between patent holders and other guild members was shaped by statutory provisions, which are an important dimension of the heterogeneity driving the different reactions of guild to patents across technological and geographical contexts.

II(ii). *Economics of Innovation*

This paper contributes to the literature on the economics of innovation and the determinant of firms' intellectual property strategy. Anton and Yao [2004] examine the decision to patent or to keep secret an existing technology when patents offer limited protection against imitation. Lerner and Tirole [2004] analyze the decision of whether to participate in patent pools. Galasso [2012] studies the incentives to share patents through broad cross-license agreements, and Llanes and Poblete [2014] examine whether to include a patent in

a technology standard. Comino and Graziano [2015] study how grant examination affects patenting strategies. Schankerman and Schuett [2018] examine the effects of patent screening, renewal fees and courts on patenting behavior. Further theoretical research is surveyed in Llobet *et al.* [2012]. Our paper contributes to this literature by emphasizing the role of industry characteristics, such as competition and barriers to entry, in shaping firms' IP strategies.

Empirically, a number of studies in the industrial economics literature have documented substantial heterogeneity in patenting propensity across and within industries (*inter alia* see Schankerman and Pakes [1986]; Lerner [1994]; Schankerman [1998]; Hall and Ziedonis [2001]; Von Graevenitz *et al.* [2013]). These papers exploit data on firms in modern U.S. and Europe. The work of Moser [2005, 2012, 2013] confirms this heterogeneity in patenting with data from the XIXth century. We add to this research by examining patenting strategies in the Renaissance, when economic activity, industry composition and political structure were substantially different than those of modern times. Confirming the heterogeneity in patenting and its link with market power suggests that the economic forces driving IP strategies are persistent, rather than unique features of modern industries.

Our paper also adds to the literature on the relationship between competition and innovation (Aghion *et al.* [2005]; Cohen [2010]; Spulber [2013]) suggesting that market power may affect not only the level of innovation but also the propensity to rely on patent protection. Our analysis implies that patent based measures of innovation activity used in the literature may over-estimate or under-estimate the effect of market power when it simultaneously affects both innovation incentives and patenting strategies.

Our research is also related to studies that examine how occupational licensing rules affect technology adoption. Bridgman [2015] studies why unions may favor restrictive work regulations and how these regulations may induce resistance to technology adoption. The broad literature on occupational licensing is surveyed in Kleiner [2000]. The contribution of our analysis is to illustrate how occupational licensing and self-regulation may interact with the propensity to use intellectual property rights.

III. 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.

III(i). *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

Map 3.1. Venice's *Terraferma*.Figure 1
Venetian State Boundary

Notes: Source: Knapton [2013].

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 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 Nicolò 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 (Borelli [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, dyeing 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 per cent 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]).

III(ii). *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]).

As modern patent laws, the Venetian act provided the inventor with exclusive rights specifying geographical and time limits, it required disclosure

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

in exchange for monopoly rights, and it established an enforcement mechanism – which included fines and the requisition of the illegal goods – to prevent imitation. The intended effect of patent protection 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]). Hence, the patent act granted patentees the exclusive right to use their inventions but also the possibility of selling their patents or licensing them out. Also the patentability requirements closely resembled modern ones. Industrial applicability had to be shown by the inventor by means of a test of the new product or process (the ‘*esperienza*’) to illustrate, before granting the patent, the functioning of the invention. Novelty and non-obviousness requirements were explicitly mentioned in the patent act that established that the subject matter to be patented was required to be a ‘new and ingenious device’ (Mandich [1948]). However, 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]).²

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 (*Savi sopra le acque*) was involved. Patents were granted after Senatorial approval (Berveglieri [1995]; Mandich [1948]; Molà [2000]).³

The impact of the act on patenting was substantial. The number of patents granted by the Senate grew considerably, increasing from five *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

² The act established a patent length of ten 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.

³ The Senate was the dominant route for obtaining 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]). Data on these minor rights are not available, thus our analysis only focuses on patents granted by the Senate.

and operate in industries controlled by guilds (Mandich [1948]; Sichelman and O'Connor [2012]). For example, Florentine inventor Cosmo Scatini was granted a patent for high quality black silk dyeing, which permitted him to enroll in the dyers' guild of Venice (Belfanti [2004]).

Second, guilds were often involved in the patent granting decision process. Most of the times, this occurred in the *esperienza* phase when the patentability requirements were evaluated. 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 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, a 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] argues that successful experimentation with monopolies in mineral rights may have led Venetian authorities to legislate on patent rights. Prager [1952] suggests that it was the

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.* [2007a, 2017b] for recent contributions on these issues).

specificity of Venetian guilds that led the Senate to approve the patent act. Compared to other European states, many guilds in Venice were smaller, more fragmented and ‘...powerless to grant or to allow monopolies by action of their own’ (Prager [1952]: 131). It was therefore the inability of some Venetian guilds to secure enough returns to inventors that required monopolies to be issued by the State. Nard and Morris [2006] elaborate on Prager’s explanation by adding that a regularized patent system was an effective way of increasing commitment toward inventors.⁶ Our results below are supportive of this latter explanation of the approval of the patent act. We find that guilds with less monopoly power were the ones that patented more intensively.

IV. 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 a 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.

IV(i). *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 market power generated by 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.

⁶Venetian officeholders, also in key positions, held their office only for short periods of time. According to Nard and Morris [2006] in such a fluctuating political structure the issuance of patents on an *ad hoc* basis had little commitment power. For this reason a regularized patent system was preferred.

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 IV(iv)). We also assume that $c < \min \left\{ \frac{\pi}{3}, \kappa \right\}$ to focus on the cases in which the cost of obtaining a patent is not too large relative to the baseline surplus and the opposition cost.

IV(ii). *Patenting by a Guild Member*

We first study 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.⁷ Therefore, opposition is profitable if

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

which is satisfied if

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

⁷ 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 IV(iv).

Notice that $\frac{d\hat{\Delta}(\theta)}{d\theta} < 0$, which implies that guild members block patents of other guild members more often as their market power 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., $\Delta > \hat{\Delta}(\theta)$), then patenting is not profitable. Hence, applying for a patent may be beneficial only when there is no opposition (when $\Delta \leq \hat{\Delta}(\theta)$). 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

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

One can easily verify that, when $\kappa > c$, then $\tilde{\Delta}(\theta) < \hat{\Delta}(\theta)$.⁸ Moreover, $\frac{d\tilde{\Delta}(\theta)}{d\theta} > 0$, 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 guild's market power 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 $\Delta \in [\tilde{\Delta}(\theta), \hat{\Delta}(\theta)]$ with a probability equal to

$$P(\theta) = F(\hat{\Delta}(\theta)) - F(\tilde{\Delta}(\theta))$$

which decreases in θ .

⁸ Formally, $\tilde{\Delta}(\theta) < \hat{\Delta}(\theta)$ when $\kappa > \theta[c - \pi(1-\theta)]/(2-\theta)$, a condition which is satisfied when $\kappa > c$.

IV(iii). *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 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

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

One can easily check that $\hat{\Delta}_E(\theta)$ is decreasing in θ , i.e., opposition is more likely with high θ .⁹

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

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

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 a patent if

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

which occurs if

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

⁹For 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 outsider's patent with probability p .

One can easily check that, when $\pi > 3c$, $\tilde{\Delta}_E(\theta) < 0$ for each θ , which implies that, absent opposition, the external innovator always patents, no matter the strength of the guild statutes.¹⁰ 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's innovating, the likelihood of patenting is

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

which is also decreasing in θ .

IV(iv). 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 market power of a guild goes up, and the value of the monopoly rent generated by the patent decreases. Thus, guild's market power reduces 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 and therefore, high market power. Our model also shows that external innovators have stronger incentives to file patent applications when technologies generate very low surplus (Δ close to zero). This feature of the model is consistent with the accounts of MacLeod [1988] and Belfanti [2006] who describe the attempts of foreigners to use patents strategically in order to overcome guild's entry regulations.

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 online 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 online appendix, we relax this assumption

¹⁰ Assumption $\pi > 3c$ implies that $\tilde{\Delta}_E(0) = c - \pi < 0$, $\tilde{\Delta}_E(1) = (3c - \pi) / 4 < 0$ and $d\tilde{\Delta}_E(\theta)/d\theta > 0$.

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. Third, our model shows that innovations generating an intermediate increase in surplus are patented, while innovations with high Δ are not. This feature of the model is driven by the simplifying assumption that opposition is always successful. In the online appendix we relax this assumption and consider the case in which opposition leads to patent rejection only with some probability. In this extension patents are filed also for technologies with high surplus, and our main testable prediction still holds: the probability that a patent is granted decreases in θ . Finally, our model assumes that opposition cannot be avoided through side payments from the patentee to guild members. In the online 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.

V. 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 1400-1700.¹¹

¹¹ 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 Moiola [2004].

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 on 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 per cent 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 A-I shows the technological breakdown of these patents: mills account for roughly half of the inventions, followed by drainage devices (11 per cent), and hydraulic pumps (7 per cent). Interestingly, 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 Corporative*, and the patent technology classification provided by Berveglieri [1995].¹²

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.¹³

¹²We drop patents related to inventions that cannot be easily imputed to a guild in our sample (e.g., perpetual motion). In Section VI(ii) we discuss alternative empirical approaches that exploit all the patents in Berveglieri's sample.

¹³Moreover, 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 in a robustness exercise in Section VI(iii).

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 Corporative* 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.¹⁴

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 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 per cent. In Section VI(ii) we show that our results are robust to using patents granted up to 1600. Appendix Figure A-1 describes the evolution of patenting over time.¹⁵

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

¹⁴ There is also large variation in patenting across the *molineri* (millers) guilds. In fact, some of these guilds specialized in textile production, others ground grains into flour, others cut 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 guilds' activities spanned multiple technology areas.

¹⁵ We confirmed this pattern with our alternative patent data from Mandich [1936].

TABLE I
SUMMARY STATISTICS

	Obs.	Mean	Std. Dev.	Min	Max
Panel (a): Summary statistics at the guild level					
Patents	340	1.47	5.10	0	42
Strong internal regulation	340	0.21	0.40	0	1
Distance	340	59.9	77.67	0	422.10
Trade guild	340	0.46	0.49	0	1
Guild members	169	164.06	392.27	2	3390
		Num. of guilds	Patents per guild		
Panel (b): Statutory strength and patenting at the sector level					
Macro-sectors with low level of average strength of internal statutes (below 0.18)					
Food (production and retail)		42	1.57		
Wood and paper		11	0.82		
Transportation and drainage of canals		67	0.52		
Miscellanea		32	0.22		
Macro-sectors with intermediate level of average strength of internal statutes (0.18 - 0.30)					
Metals		28	0.61		
Shipbuilding		9	0.44		
Textile and clothing		73	0.38		
Retail (other than food)		16	0		
Macro-sectors with high level of average strength of internal statutes (above 0.30)					
Construction		14	0.21		
Glass making		7	0		
Barbers and apothecaries		13	0		
Leather products		28	0		

Notes: Panel (a) 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 Corporative* data.

Panel (b). Num. of guilds is the number of guilds classified in the sector following the *Istituzioni Corporative* data. Patents per guild is the average number of patents of the guilds belonging to the sector.

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 generate greater market power by being more severe than those of other guilds in the sample.¹⁶

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 kilometres) 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 per cent 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. Panel A shows that on average, there are 1.47 patents in the main technology field in which a guild operates, with a standard deviation of roughly five patents. About 21 per cent of the guilds in our data have strong internal regulation. In Panel B, guilds are aggregated into 12 macro-sectors based on the classification in the *Istituzioni Corporative* database. The table highlights a negative relationship between patenting and statute strength: macro-sectors with higher average value in the strong internal regulation variable show a lower patenting propensity as measured by the number of patents per guild.

Additional information on guilds is presented in the second panel of Appendix Table A-I. The table illustrates the geographical distribution of the guilds across the ten cities of the Venetian Republic in our sample. Roughly 50 per cent of the guilds are located in Venice. Verona, Padua, and Brescia are the cities with more guilds in the mainland (*Terraferma*).

V(i). *Econometric Specification*

Building on the theoretical analysis of Section IV, 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

¹⁶ 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 internal regulation of the guild. We typically model the conditional expectation of patenting activity as

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

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]).¹⁷

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.

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 per cent of the technologies presented at the 1851 World Fair in London were not patented. The extent of non-patented innovation is likely to have been 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.

¹⁷We confirm the robustness of our baseline results with alternative clustering of the standard errors at the city and the guild level.

Overall, these studies suggest that α speaks more to the propensity to use patents to protect technologies than to the propensity to innovate. Highlighting the link between market power and patent strategies has important implications for the empirical literature that typically measures innovation with patent counts. Patent based measures of innovation activity may over-estimate or under-estimate innovation effects when the variable of interest simultaneously affects innovation incentives as well as patenting strategies.

VI. EMPIRICAL RESULTS

VI(i). *Baseline Specification*

Table II 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 per cent 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.¹⁸

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

VI(ii). *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

¹⁸In 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.

TABLE II
GUILD INTERNAL REGULATION AND PATENTING

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

Notes: Poisson estimation with robust standard errors. * significant at 10 per cent, ** significant at 5 per cent and *** significant at 1 per cent. 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 Corporative* data. Trade guild = 1 if the guild is not involved in manufacturing.

include additional controls for city characteristics. In column 1 of Appendix Table A-II 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 Appendix Table A-II 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.¹⁹ The regression also includes industry effects for guilds in agriculture, construction, and textile. In column 3 of Appendix Table A-II 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.

¹⁹ 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 Appendix Table A-II 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 per cent of the sample there was no statutory change during the time period, for about 18 per cent of the guilds the statute was changed once, and for the remaining 1 per cent it was changed twice. In column 6 of Table A-II we show that our baseline estimates are robust to dropping guilds that change their statutes during our sample period. The coefficient is roughly 15 per cent larger than our baseline, confirming the idea that measurement error biases our estimates toward zero.²⁰

Our results may be driven by differences in patenting and guild structure between Venice and other cities in the Republic. In particular, one may

²⁰ We confirm this result in regressions: (i) that include a control for statutory changes, and (ii) consider changes over different time windows.

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 Appendix Table A-III drops from the sample the guilds located in Venice. Addressing similar concerns, column 2 of Appendix Table A-III drops the guilds involved in trade. For both of these exercises the sample size drops roughly 40 per cent, but the negative relationship between statutory strength and patenting is robust, with statistically significant coefficients and stable magnitude.

Columns 3 and 4 of Appendix Table A-III 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 three separate dummies, one for statutes limiting entry, one for statutes limiting competition, and the *Strong internal regulation* dummy which can be interpreted as the interaction between the two previous dummies. The estimates suggest that the negative association with patenting appears to be driven by guilds for which both types of statutory restrictions are jointly present, i.e., by the guilds with the most restrictive statutes. This finding is partly driven by the high degree of correlation between restrictions to entry and competition that we observe in the guilds' statutes. Most of the times in which statutes implement entry barriers, they also include limits to competition. This suggests that the variation required to identify the differential effects of entry barriers from those of limits to competition may not be present in our data.²¹

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 A-IV 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 on patenting. The larger the fraction of guilds with strong internal regulation the lower the number of

²¹ In fact, while nearly 60 per cent of the statutes restrict competition and one quarter implement barriers to entry, in only a few cases (12 out of 340) statutes restrict entry but not competition. We also construct an alternative statutory strength index ranging from 0 to 3, depending on the number of restrictions to entry and competition imposed by the statute. In a series of unreported regressions, we find that the association between this alternative index and patenting is non-linear confirming the idea that the effect is driven by the most stringent statutes.

patents for the industrial sector. The implied elasticity is -0.6 , a magnitude which is in line with our baseline estimates of Table II. This robustness test also confirms the positive correlation between patenting in the technology field and average distance of the guilds from Venice.²²

In addition, the regressions in Appendix Table A-IV 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.²³

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.

VI(iii). *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 innovators from Berveglieri [1995] who describes patents of foreign inventors and provides some information on their histories and business activities. Specifically, Berveglieri [1995] classifies an inventor as foreign if he is not Italian and shows that only 6.5 per cent of the patents in the sample were granted to foreign inventors. Importantly, the accounts in Berveglieri suggest that these foreign inventors did not belong to any guild before their patent application, so this sample only includes external innovators. Conversely, patenting by the other, non-foreign, inventors (we label them as 'local' in Table III) is likely to include both patenting by guild members and patenting by external inventors. Exploiting these data, columns 1 to 4 of Table III

²² 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 patenting propensity of each sector. Similarly, patents related to mills with multiple usages are imputed to sectors in which mills are used, proportionally to their sector-specific patents. Table A-IV 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.

²³ 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]).

TABLE III
INVENTORS' ORIGIN AND ALTERNATIVE PATENT DATA

Dependent Variable	(1)	(2)	(3)	(4)	(5)	(6)
	Patents Local	Patents Local	Patents Foreigners	Patents Foreigners	Patents Mandich	Patents Mandich
Strong internal regulation	-0.960*** (0.098)	-1.098** (0.429)	-0.029** (0.012)	-0.034* (0.020)	-1.372*** (0.317)	-1.266** (0.616)
log (Distance)	0.218*** (0.025)		0.006*** (0.001)		0.168*** (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 per cent, ** significant at 5 per cent and *** significant at 1 per cent. 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 Berveghieri [1995, 1999] columns 5-6 exploit patent data from Mandich [1936].

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 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.

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 per cent 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.

VII. INSTRUMENTING GUILDS' 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. 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*.²⁴

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 VII). 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 (Costantini [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 Mattio's (Mackenney [1994]).²⁵

Istituzioni Corporative shows that roughly 30 per cent 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

²⁴ 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.

²⁵ 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.

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 per cent. 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 A-V 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 IV 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 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.²⁶

²⁶We 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].

TABLE IV
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** (0.861)	-4.183* (2.720)	-4.387** (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 per cent, ** significant at 5 per cent and *** significant at 1 per cent. 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 Wooldridge [2002].

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 (Wooldridge [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 IV.²⁷

While the vast majority of the guilds in our sample were formed in the 14th and 15th centuries, 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 A-VI 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.

²⁷ 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.

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.

VII(i). *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 requirements to enter these guilds. One concern is that religion also has a direct impact on patenting. For instance, 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 U.S. States, Bénabou, 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. This finding is confirmed by Squicciarini [2019] but only for more modern times. The author exploits data on 19th-century France to examine the impact of religion on knowledge diffusion. She finds that religion was detrimental to knowledge diffusion only during the second industrial revolution when the Catholic Church was promoting an anti-scientific program against technical schools. Interestingly, religion had no effect in earlier periods, suggesting that the link between innovation and religiosity started to matter only in more modern times. While we cannot rule out the possibility of a direct negative effect of religion on innovation and patenting, there are a number of reasons why we do not expect this channel to play an important role in our setting, in line with Squicciarini [2019].

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 on the adoption of new technologies, production processes or property rights (Monticolo [1892]; Gasparini [1987]; Mackenney [1994]). This suggests a neutral attitude of confraternities towards innovation and patenting.

As additional supporting evidence, in column 3 of Appendix Table A-V 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.

VIII. 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 a stronger connection between the city and

the center of political power.²⁸ 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 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 obtained the nobility title and the city in which it resided. 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 while smaller cities, such as Udine or Treviso, had fewer than 30 families.²⁹

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 Treffer [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.³⁰

In column 1 of Table V 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

²⁸ 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 Treffer [2014] document the use of marriage alliances in Venice to monopolize the galley trade.

²⁹ Six observations had to be dropped from our sample because they are associated with smaller cities that were not covered by Schroeder [1830].

³⁰ 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).

TABLE V
NOBLE FAMILIES AND PATENTING

Dependent Variable	(1) Patents	(2) Patents	(3) Patents	(4) Patents
Strong internal regulation	-1.123*** (0.121)	-1.199*** (0.124)	-1.280*** (0.128)	-1.111*** (0.116)
log (Distance)	0.299*** (0.034)	0.318*** (0.020)	0.255** (0.115)	0.393*** (0.061)
log (Noble Families)	0.092*** (0.031)	0.470*** (0.094)	0.495*** (0.097)	0.639*** (0.219)
log (Population ₁₅₀₀)	0.102 (0.126)	-0.066 (0.070)	0.001 (0.139)	-0.353 (0.295)
Politically Connected Families		-1.595*** (0.361)	-1.700*** (0.375)	-2.168*** (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 per cent, ** significant at 5 per cent and *** significant at 1 per cent. 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*.

significant association between the presence of politically connected families and patenting, suggesting that formal intellectual property protection may have been a substitute for alternative forms of protection available to guilds with stronger political connections.³¹

There is the concern that the results of columns 1 and 2 might be 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

³¹ In this table standard errors are clustered at the city level as the main variable of interest only varies at the level of the city.

and the propensity to patent. An important determinant of growth and human capital for European cities in the 1400's 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 V, 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.³²

As a final robustness test, we examine the sensitivity of our results to our measure of geographical distance. Appendix Table A-VII 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 cities, and it is quite likely that omitted variables correlated with geographical and political distance are important for the propensity to patent. Nonetheless, the correlations reported in Table V 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

³² We obtain similar qualitative and quantitative estimates in regressions run on the smaller sample in which observations are collapsed at the city level.

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.

IX. 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 the share of guilds with strong statutes or active in trade (features that tend to reduce patenting

according to our findings) was larger in Padua than in Vicenza. 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 this more demanding specification, the synthetic controls generate cities similar to Vicenza and Padua in terms of population, number of guilds, average guild statutory strength, and industry composition. 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. These synthetic controls aim to reproduce the counterfactual trajectories of the two cities in the absence of a patent system.³³

Appendix Figure A-2 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.

³³ It is important to notice that our analysis does not compare cities in which guilds were operating in more dynamic sectors with cities in which guilds operated in less dynamic sectors. Instead, it compares a city with its synthetic version which is as similar as possible in terms of guild composition and industrial activity.

These figures are only illustrative and should not be over-interpreted as unobservable variables may have played a role. For example, the economic growth of Vicenza may have been driven by additional factors, such as a closer trade relationship with other cities outside the Venetian republic. Or the slower growth of Padua may have been affected by the temporary occupation of the city by the imperial troops of Maximilian of Austria in 1509. Nonetheless, the estimates suggest that the availability of patents may have had some impact on the economic growth of frontier cities and particularly so for cities where guilds had weaker statutes. In other words, patents could have helped guilds that faced greater difficulties in sharing and managing new technologies to become more dynamic.

X. CONCLUSIONS

In this paper we study the inventors' propensity to use patents 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. Thus, guilds with higher market power relied less on patenting to protect innovation. Second, we find that patenting was more frequent for guilds located in cities geographically distant from Venice and in cities with lower political connection suggesting a potential substitution between intellectual property rights and other forms of formal and informal protection.

The innovation literature 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 analysis shows that similar heterogeneity was present in Renaissance Venice, and that it was related to guilds' market power. Observing variation in the use of patents during the pre-industrial era, when the organization of economic activity was substantially different from the modern one, suggests that heterogeneity in patent strategies is a persistent phenomenon and not a unique feature of the modern economy. This has implications for our understanding of patenting in modern industries. First, our findings suggest that patent strategies are shaped by industry characteristics such as competition and barriers to entry. This is in sharp contrast to theories developed in the management literature which emphasize the role of technological features of modern industrial products.³⁴ Second, our analysis implies that het-

³⁴ For example, Cohen, Nelson and Walsh [2000] argue that patenting strategies in an industry depend substantially on whether product or process are comprised of numerous separately patentable elements (as, for example, in the semiconductor industry) versus relatively few (as, for example, in the chemical industry).

erogeneity in patent strategies is likely to be present in the future, as new industries emerge and existing ones lose their relevance. This is particularly important given the recent academic and policy debates suggesting that new industries are likely to appear over the next few decades because of the technological developments in artificial intelligence (Agrawal, Gans and Goldfarb [2019]).

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