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Resistance to technology adoption: The rise and decline of guilds ☆

Klaus Desmet [a], Stephen L. Parente [b,c,*]

[a] Department of Economics, Universidad Carlos III, 28903 Getafe (Madrid), Spain
[b] Department of Economics, University of Illinois at Urbana-Champaign, Urbana, IL 61801, United States
[c] CRENoS, Italy

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ABSTRACT

This paper analyzes the decision of a group of specialized workers to form a guild and block the adoption of a new technology that does not require their specialized input. The theory predicts an inverted-U relation between guilds and market size: for small markets, firm profits are insufficient to cover the fixed cost of adopting the new technology, and hence, specialized workers have no reason to form guilds; for intermediate sized markets, firm profits are large enough to cover the higher fixed costs, but not large enough to defeat workers' resistance, and so workers form guilds and block adoption; and for large markets, these profits are sufficiently large to overcome worker resistance and so guilds disband and the more productive technology diffuses throughout the economy. We show that this inverted-U relation between guilds and market size predicted by our theory exists in a dataset of Italian guilds from the 14th to the 19th century.

1. Introduction

According to Joel Mokyr (1990), the factor that most clearly demarcates the Malthusian era of stagnant living standards from the modern growth era is not the technological creativity of humanity, but rather the intensity of resistance to the introduction of new technologies by guilds and trade associations. Starting in the Middle Ages, these groups successfully blocked the adoption of countless cost-saving production techniques through both legal and illegal means. However, in the 18th century, their effectiveness began to wane, at least in Europe where the political establishment stopped supporting their causes, and by the middle of the 19th century, these groups had all but disappeared, thereby eliminating a main impediment to economic growth in Britain and the Continent.

Why did the successful resistance to the diffusion of new technologies by guilds and other trade associations start to end sometime in the 18th century and not earlier? A general consensus that has emerged, particularly among economic historians, is that guilds and other rent-seeking institutions in Europe declined once society realized that the application of

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* Corresponding author.
E-mail addresses: klaus.desmet@uc3m.es (K. Desmet), parente@illinois.edu (S.L. Parente).

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new ideas to the production of goods and services had a positive effect on humanity, and was thus not a zero-sum game. This shift in societal attitude, led by a handful of enlightened thinkers of the day, such as Francis Bacon, Robert Boyle, Adam Smith and David Hume, is what Mokyr (2005) labels the *Great Enlightenment*, Jacob (1981) the *Radical Enlightenment*, McCloskey (2010) the *Bourgeois Revaluation*, and Goldstone (2002) the *Engineering Culture*. Once these enlightened individuals educated society and shifted public policy on this matter, the deathlike grip guilds had held on technology adoption for the previous five centuries ended, and sustained economic growth followed.

In this paper, we offer a different story for the demise of the guilds. Successful resistance by the guilds, in our theory, ended not because a small number of enlightened individuals educated society about the net positive welfare gains associated with technological change. Instead, it ended naturally as markets in Europe expanded over time. When markets were small and competition was weak, as in the Middle Ages, guilds and other factor suppliers to the existing production processes had the ability to block the introduction of new production techniques, since profits of would-be-adopters were insufficient either to garner enough political influence to assist them in overcoming guild resistance or to defeat this resistance themselves. With the expansion of markets, these profits became sufficiently large so that would-be-adopters had enough economic power and political influence to break guild resistance. With one of their main raisons d'être gone, guilds had little choice but to disband.

Why would market size and the intensity of competition affect the ability of guilds to resist the introduction of cost-saving production processes? In our theory, market size and the intensity of competition, which go hand in hand, determine the number of goods that an economy can sustain. In a larger market, with a greater number of goods, competition toughens, the price elasticity of demand increases, and mark-ups fall. This means firms become larger, since each firm must sell more output to cover any fixed operating cost. Larger firm size is the key to ending guild resistance. As a would-be-adopter can spread any fixed adoption costs over a larger quantity of output, profits to adoption are greater. This means more resources available to an adopting firm for the purpose of overcoming the resistance of guilds to the new technologies. In this way, expanding markets make it more difficult for workers to block the adoption of new technology.

Would-be-adopters may overcome resistance via political and judicial channels, as their newfound economic power translates into political influence. There are several well documented cases where resistance ended only after government troops were sent in. For example, both the Lancashire Riots of 1779 and the Luddite uprisings of 1811–1813 were put down by the British army (Mokyr, 1990). More often, guild resistance ended following a ruling on a petition by worker groups on the legality of introducing new production processes. For example, in the cotton and woolen textile industries in England, Parliament separately ruled against spinners, combers, and shearers in their legal challenges to halt the adoption of cotton-spinning machinery, wool combing machines, and gig mills. Alternatively, would-be-adopters can overcome resistance through their own means by buying off some of the workers, in the form of wage concessions and severance payments. Another possibility is for would-be-adopters to move production operations to regions outside guild control. In the words of Mokyr (1990), "industry discovered the countryside", which was free from the tight rules imposed by guilds in cities. This has been cited as an important reason for why England's Industrial Revolution preceded the Continent's.

Our theory provides an explanation not only for the decline of guilds, but also for their rise. In our framework, specialized workers only form a guild when two conditions hold: adopting a new technology is profitable for the firm, but the profits are not enough to cover the cost of overcoming workers' resistance. This implies an inverted-U relation between guilds and market size. For small markets where competition is weak, firms have no desire to change their production process as profits from technology adoption are negative. Hence workers have no incentive to organize into guilds. For intermediate sized markets with modest competition, technology adoption is profitable in the sense of covering any fixed cost, but not sufficiently so to be able to break the resistance of guilds. Hence, guilds appear and block the introduction of cost-saving technologies in their industries. For large markets with intense competition, profits from technology adoption are sufficiently large to give firms enough firepower to either defeat guilds on their own or influence government policy in their favor. Consequently, guilds disband and more productive technology diffuses throughout the economy.

In addition to the vast literature on guilds, some of which we review in the next section, our paper relates to two other distinct literatures. First, it relates to the growing theoretical literature that examines the role of market size and competition for technological innovation. Relevant papers in this literature include Peretto (1998), Aghion et al. (2005), Vives (2008), and Desmet and Parente (2010). Second, it relates to the small but growing literature that formally models the formation and/or break-up of growth-inhibiting special interest groups. Important papers in this literature include Dowrick and Spencer (1994), Krusell and Rios-Rull (1996), Parente and Prescott (1999), Acemoglu et al. (2001), Lommerud et al. (2006), Parente and Zhao (2006), Dinopoulos and Syropoulos (2007), and Bridgman (2011). These papers emphasize different mechanisms. For instance, in Krusell and Rios-Rull (1996) and Dinopoulos and Syropoulos (2007) the distribution of skills across agents is important to the formation and break-up of these groups, whereas in Parente and Zhao (2006) the cost of introducing new goods is emphasized. Although they note the importance of the price elasticity of demand for resistance, neither Dowrick and Spencer (1994) nor Parente and Prescott (1999) nor Bridgman (2011) provide a mechanism whereby market size or any other factor affects the price elasticity of demand.

The rest of the paper is organized as follows. Section 2 serves to motivate our market size based theory of guilds and resistance by reviewing the relevant literature on the historical role of guilds and their demise. Sections 3 and 4 put forth a model to illustrate our mechanism and show how guild formation and technology adoption are affected by market size. Specifically, Section 3 describes the basic structure of the model without technology adoption or guild formation in order to illustrate the link between market size and firm size, whereas Section 4 introduces technology adoption and a game between would-be-adopters and industrial workers. Section 5 provides a formal test of our theory by exploring the presence of an inverted-U relationship between market size and guilds in Italian cities over the 1300 to 1850 period. Section 6 concludes the paper.

2. Literature review

In this section, we review some of the literature on guilds with the specific intent of motivating our theory. We seek to justify our view that guilds, in particular those associated with crafts, primarily acted as a negative force against technological change, and that expanding markets and increasing competition were fundamentally important to ending resistance and the guilds themselves.

The literature that views guilds as being adverse to economic development is extensive and as old as the study of economics itself. Adam Smith (1774) was strongly opposed to them; he saw guilds as major impediments to free markets, vigorously arguing that their long length of apprenticeships, seven years according to the *1563 Statute of Apprenticeship*, and their restrictions on the number of apprentices, limited the size of both the overall industry and the firm. Pirenne (1912), Cipolla (1976), Mokyr (1990) and others expanded on this view, emphasizing the more direct adverse effect guilds had on development by blocking the introduction of new goods and new production processes.

Instances where guilds inhibited development by resisting the introduction of new production techniques are well documented. Randall (1991), for example, describes in detail the fierce resistance to the introduction of the gig mill and scribbling machines in the woolen industry in the West of England (made up of the counties of Gloucestershire, Somerset, and Wiltshire) in the 18th century. This strong resistance was a major reason for the West of England's demise in the production of woolen cloth at the turn of the 18th century, and the loss of its dominant position to the West Riding of Yorkshire, which did not have organized guilds to block technological change. The rise of the Dutch city of Leiden two hundred years earlier was similar to the rise of the West Riding of Yorkshire. As documented by Ogilvie (2004), Leiden, which banned guilds, was highly innovative in the worsted industry, both in process and product innovation, introducing 180 new types of worsteds and innovative mechanical devices between 1580 and 1797.[1]

Expanding markets and greater competition clearly acted to weaken the ability of guilds to dictate which technologies could be used and how they could be used.[2] Well before decrees abolishing guilds were implemented, there is evidence that guilds were less influential in larger markets. Ogilvie (2004), for example, documents the case of Lille, a town in Northern France where the textile industry, faced with greater domestic competition in the late 17th century from rural unguilded Flemish weavers, relaxed guild training regulations, thus liberalizing the labor market and reducing costs. Often, greater openness and international trade were the reason for expanding markets, tougher competition and the weakening of guilds and their resistance. Randall (1991), for one, shows that the above-mentioned resistance to the scribbling machine in the West of England ended in 1795 in the wake of a trade boom.[3]

The effect of larger markets and greater competition on the ability of guilds to dictate technology use and choice can be seen by comparing the behavior of export and non-export industries in Europe, since the former dealt in integrated (more competitive) markets. Consistent with our theory, guilds tended to have a greater effective presence in non-export industries. For example, as shown by Stabel (2004), in the Flemish town of Oudenaarde in the 16th century, industries that competed on the international market penetrated into the countryside, hired rural workers, and created large-scale establishments. In contrast, industries that catered to the local market continued to be highly regulated, with far larger barriers in place for firms that did not employ guild members, and with much smaller sized firms on average. The 1541 census of Oudenaarde reveals that in non-export industries (such as tailors, shoemakers and bakers) masters employed one or two apprentices, whereas in the main export industry (tapestries) masters employed on average around 30 apprentices and journey-men. There are even examples of master weavers employing hundreds of artisans in the city and the countryside. All of this suggests that industries faced with more competition and larger markets adjusted by liberalizing entry, allowing establishments to become larger, and deregulating work practices.

Not everyone shares the view that guilds had a mostly negative effect on societal welfare by inhibiting economic development. For example, Hickson and Thompson (1991), Epstein (1998), and Epstein and Prak (2008) argue that guilds provided welfare-enhancing solutions to market failures associated with asymmetric information, externalities, free riding and the inter-generational transmission of knowledge. Although Ogilvie (2004) challenges their claim, providing evidence that information asymmetries and externalities were not important problems in the Middle Ages, the issue of whether guilds did or did not provide welfare-enhancing solutions to market failures is not essential to our theory. Importantly, none of these researchers wishes to revise history claiming that guilds always welcomed technological change. Epstein and Prak (2008),

[1] Wolcott (1994) provides an excellent example supporting this view, comparing productivity gains in the Indian cotton textile mills in the early 20th where labor was organized into powerful unions to those in the Japanese cotton textile mills where no such labor organization existed.

[2] Of course, another way of dealing with increased competition was for guilds to use their political power to try to stop it. According to Ehmer (2008), in the 15th and 16th centuries Austrian urban guilds tried to limit rural production by establishing a so-called *Bannmeile*, a radius surrounding the city where artisan production was to be completely prohibited. Another example of stifling competition was through guilds controlling the markets for raw materials (DuPlessis, 1991).

[3] In a different time and a different place, this is similar to what happened to the US iron ore industry in the 1980s, when it experienced productivity gains in the face of increased international competition from Brazil (Schmitz, 2005).

for example, in summarizing a large number of papers in their edited volume, conclude that the response of guilds to the introduction of new technology varied a lot by location, by the type of innovation and by the overall economic conditions. Specifically, they conclude that resistance was more likely in the case of labor-saving technology, in locations where the guilds penetrated the political landscape, and in economic downturns, leading Epstein (1998) to refer to guilds as *recession cartels*. This latter point is consistent with our theory. Indeed, an implication of our theory is that when markets expand and competition intensifies, either in the long run or over the business cycle, workers specialized in the old technology are far less likely to block innovation.

Additionally, the argument that expanding markets led to the demise of guilds is not without its detractors. Two criticisms, in particular, have been voiced against this hypothesis. A first criticism is that guilds did not disappear on their own because of an increase in market size, but because they were abolished by national laws and decrees (e.g., 1784 in the case of the Netherlands, 1791 in the case of France, and 1835 in the case of England). A second criticism is that in the medieval period guilds tended to be concentrated in the most densely populated areas (Mocarelli, 2008). With respect to this first criticism, there is nothing inconsistent with our theory and the formulation of a national policy outlawing guilds. A national policy could reflect the increasing and widening economic power of industry as markets expanded. It could also reflect the understanding by policy makers that the average household stood to gain from the introduction of new technologies but that not all firms or industries could overcome guild resistance on their own. Although our model mainly focuses on the ability of each individual firm to overcome the resistance by the guild in its industry, we do show in a series of numerical experiments that a government may want to decree all guilds illegal well before an individual industry would have large enough profits to overcome guild resistance.[4] With respect to the second criticism, it does not contradict our theory, which predicts an inverted-U relation between population size and guilds. In the early period, one would indeed expect guilds to be more present in the then larger markets, as documented by Mocarelli (2008).

3. The model

We now proceed to demonstrate our theory in the simplest structure possible. In this section, we present the basic structure of the model, which does not include the technology decision by firms or the guild formation decision by workers. We postpone these elements until Section 4 for several reasons. First, the technology adoption and guild formation decisions introduce additional strategic elements to the economy, which increase the complexity of the model, both in its description and analysis. Second, it is easier to see how a larger market works to increase firm size when these decisions are excluded.

The basic structure consists of an agricultural sector, an industrial sector, and two households types, skilled and unskilled. The agricultural sector is competitive and produces a homogeneous good according to a constant returns to scale technology that uses unskilled labor as its only input. This sector's good serves as the economy's numéraire. The industrial sector is monopolistically competitive and produces a set of differentiated products according to an increasing returns to scale technology using skilled labor as its only input. The increasing returns come from a fixed operating cost, which implies that each differentiated good is produced by one firm. Free entry into the industrial sector determines the number of differentiated products, or industries, in the economy.

We now proceed to describe households and firms, and their respective maximization problems. Additionally, we define the symmetric equilibrium and establish the link between market size and firm size.

3.1. Households

The economy consists of measure N households, of which fraction μ are skilled households and fraction $1-\mu$ are unskilled households. These fractions are parameters of the model. We use the subscript $j \in \{U, S\}$ to denote a household type. The measure of each type of household is denoted by $N_S = \mu N$ and $N_U = (1-\mu)N$, respectively.

3.1.1. Endowments

Each household is endowed with one unit of time, which it uses to work. An unskilled household can only work in the agricultural sector. In contrast, a skilled household can work in either sector, although its skills do not give it any advantage in agriculture. On account of this assumption, the two household types may have different incomes and hence different consumption allocations.

3.1.2. Preferences

Preferences are the same across household types, and are defined over a homogeneous good, associated with agriculture, and a discrete set of differentiated industrial goods V. For the set of industrial goods, households have CES preferences. Let c_{ja} denote consumption of the agricultural good and let c_{jv} denote consumption of differentiated variety $v \in V$ by the type j household. The utility of a household of type $j \in \{U, S\}$ is then

[4] In the case of France, Mokyr (1990, p. 259) suggests that an economy-wide ban of all guilds was necessary because regulations in one industry often affected other industries.

$$U = c_{ja}^{1-\alpha}\left[\left(\sum_{v \in V}(c_{jv})^{\frac{\sigma-1}{\sigma}}\right)^{\frac{\sigma}{\sigma-1}}\right]^{\alpha}, \tag{1}$$

where $0 < \alpha < 1$ is the share of income spent on industrial goods, and $\sigma > 1$ is the elasticity of substitution between any two varieties of industrial goods.

In contrast to the standard Spence–Dixit–Stiglitz preferences with a continuum of varieties, and thus a constant price elasticity of demand, the discrete construct gives rise to a positive link between the number of varieties and the price elasticity of demand. As shown by Yang and Heijdra (1993), this is the result of price setting firms internalizing the effect of their choices on the aggregate price level.[5] This feature will be key in establishing a positive link between market size and firm (or industry) size. Since larger markets sustain a larger number of goods, the price elasticity of demand will increase, mark-ups will drop, and firm (or industry) size will increase.

We importantly note that there are several alternative preference constructs that also give rise to this elasticity mechanism. These include the ideal variety models of Salop (1979) and Lancaster (1979) that are themselves variants of Hotelling's (1929) spatial competition model; the quasi-linear utility with quadratic subutility preferences of Ottaviano et al. (2002); and the translog utility function of Feenstra (2003).[6] Whereas we could adopt any of these alternatives to demonstrate our theory, we choose the one of Yang and Heijdra (1993) for the sole reason that it allows for straightforward algebraic results.[7]

3.1.3. Utility maximization

Let I_j denote the income of household $j \in \{U, S\}$ and let p_v denote the price of industrial variety $v \in V$ in units of the agricultural good, the economy's numéraire. Then the budget constraint faced by a household of type j is:

$$I_j \geqslant c_{ja} + \sum_{v \in V} p_v c_{jv}. \tag{2}$$

A household of type j maximizes (1) subject to (2). The assumption of Cobb–Douglas preferences implies that each household spends fraction α of its income on the differentiated goods and fraction $1-\alpha$ on the agricultural good. Specifically, the first-order conditions are:

$$c_{ja} = (1-\alpha)I_j \tag{3}$$

and

$$c_{jv} = \frac{\alpha I_j p_v^{-\sigma}}{\sum_{v \in V} p_v^{1-\sigma}}. \tag{4}$$

Aggregate demand for the agricultural good is thus

$$C_a = (1-\alpha)(I_U N_U + I_S N_S) \tag{5}$$

and aggregate demand for each differentiated good is

$$C_v = \frac{\alpha(I_U N_U + I_S N_S)p_v^{-\sigma}}{\sum_{v=1}^{V} p_v^{1-\sigma}}. \tag{6}$$

3.2. Agricultural sector

3.2.1. Technology

The farm sector is perfectly competitive. The farm technology is linear in unskilled labor. Let Q_a denote the quantity of agricultural output of the stand-in farm, and L_a the corresponding agricultural labor input. The production function is

$$Q_a = A_a L_a, \tag{7}$$

where A_a is agricultural TFP.

[5] The intuition is as follows. The greater the number of varieties, the larger a firm's scope to steal business from its competitors when dropping its price, because those competitors have jointly a bigger market share. Formally, a firm's demand depends on how its price compares to the aggregate industrial price level. If a firm does *not* take into account how a drop in its own price affects the overall price level, then the perceived increase in demand would be independent of the number of firms. However, if a firm does take the aggregate price effect into account, then for a given drop in its own price, the relative price decline will be larger the more firms there are, simply because the denominator will go down by less. As a result, the price elasticity of demand will increase in the number of varieties.

[6] None of these alternative constructs requires that firms internalize the effect of their choices on the aggregate price level.

[7] Desmet and Parente (2010, 2012) use the Lancaster construct in two other contexts related to development, whereas Peretto (1998) uses the Yang and Heijdra construct in a model of industrialization.

3.2.2. Profit maximization

Profit maximization yields

$$w_a = A_a, \tag{8}$$

where w_a is the agricultural wage rate.

3.3. Industrial sector

3.3.1. Technology

The industrial sector is monopolistically competitive and produces different varieties. The technology is increasing returns to scale, and uses skilled labor as its only input. The increasing returns stem from a fixed operating cost κ in terms of skilled labor. The technology's marginal product is represented by the letter A_m. Let Q_v be the quantity of variety v produced by a firm, and L_v be the skilled labor input. Then the output of the firm producing good v is

$$Q_v = A_m[L_v - \kappa]. \tag{9}$$

3.3.2. Profit maximization

On account of the fixed operating cost, κ, each variety is produced by a single firm, who is a monopolist.[8] Each firm chooses the price that maximizes its profits, taking the decisions of all other firms, the wage level and aggregate income as given.

Using (9), the profits of the firm producing variety v, denoted by Π_v, can be written as

$$\Pi_v = p_v C_v - w_m\left[\kappa + \frac{C_v}{A_m}\right], \tag{10}$$

where w_m denotes the industrial wage rate and C_v is aggregate demand given by (6). The profit-maximizing price is a mark-up over the marginal unit cost $1/A_m$. Namely,

$$p_v = \frac{w_m}{A_m}\frac{\varepsilon_v}{\varepsilon_v - 1}, \tag{11}$$

where ε_v is the price elasticity of demand for variety v,

$$\varepsilon_v = -\frac{\partial C_v}{\partial p_v}\frac{p_v}{C_v}.$$

In deriving the price elasticity of demand, we follow Yang and Heijdra (1993) and assume that each monopolist internalizes the effect of its price on the aggregate industrial price index, $P_v = \sum_{v=1}^{V} p_v^{1-\sigma}$. This is in contrast to the standard Spence–Dixit–Stiglitz approach that effectively assumes that firms are measure zero in the economy. Starting from aggregate demand for variety v, (6), it is easy to show that the price elasticity of demand is:

$$\varepsilon_v = -\frac{\partial C_v}{\partial p_v}\frac{p_v}{C_v} = \sigma - (\sigma - 1)\frac{p_v^{1-\sigma}}{\sum_{v=1}^{V} p_v^{1-\sigma}}. \tag{12}$$

If each industrial firm charges the same price, as they will in a symmetric equilibrium, the expression for the elasticity reduces to

$$\varepsilon_v = \sigma - \frac{(\sigma - 1)}{V}. \tag{13}$$

Thus, the price elasticity of demand in a symmetric equilibrium is increasing in the number of varieties, V. This is a key result of the model for understanding the effect of market size on firm size.

3.4. Symmetric equilibrium

We next define the symmetric equilibrium for this economy, which we refer to as the *Symmetric Nash Equilibrium with the Original Technology* or the *Original Technology Equilibrium* for short. In such an equilibrium, each type of household maximizes its utility; both agricultural and industrial firms maximize their profits; and the goods and labor markets clear. In addition, industrial firms must earns zero profits on account of there being free entry into the industrial sector.[9] An industrial firm's

[8] Since the different goods (say, cotton, wool, silk, etc.) can be thought of as different industries, we can interpret firms as industries. Alternatively, we could model preferences for industrial goods in a two-tier fashion: Spence–Dixit–Stiglitz between industries (say, cotton, wool, silk, etc.) and again Spence–Dixit–Stiglitz within industries (fine cotton, coarse cotton, etc.).

[9] Given that there are a finite number of firms, the exact condition is that all active firms make profits $\geqslant 0$, whereas any additional firm would make profits < 0.

decisions can thus be modeled as a two-stage game. In the first stage, firms decide whether to enter the industrial sector. In the second stage, they decide what price to charge for their variety and how many workers to hire. All firms take all other firms' decisions as given. The zero profit condition determines the number of varieties in the symmetric equilibrium.

For the equilibrium to be interesting in terms of studying guild formation and resistance to technology adoption in the next section, skilled workers must do better than their counterparts, i.e., $w_m > w_a$. This follows provided $\alpha > \mu$. To see this, suppose that all skilled households work in industry. Since there are no profits in equilibrium, the income of skilled and unskilled households are, respectively, $I_U = w_a$ and $I_S = w_m$. Together with expressions (5) and (6), this implies that $w_m = (A_a(1-\mu)\alpha)/(\mu(1-\alpha))$. Since $w_a = A_a$, a necessary and sufficient condition for $w_m > w_a$ is that $\alpha > \mu$. With this parametric assumption, there are two separate labor markets, and hence, two labor market clearing conditions:

$$V L_v = N_S, \tag{14}$$

$$L_a = N_U. \tag{15}$$

To see how the number of varieties is determined in equilibrium, the zero profit condition of an industrial firm is

$$p_v Q_v - w_m\left[\kappa + \frac{Q_v}{A_m}\right] = 0. \tag{16}$$

Eq. (16), together with the expression for the price, (11), implies that

$$Q_v = (\varepsilon_v - 1)\kappa A_m. \tag{17}$$

From Eq. (17) and the production function it follows that

$$L_v = \kappa\varepsilon_v. \tag{18}$$

Using the labor market clearing condition, the total number of varieties then satisfies

$$V = \frac{N_S}{\kappa\varepsilon_v}. \tag{19}$$

From the above expression, (19), and the expression for the elasticity of demand, (13), we arrive at the expression for the number of varieties in terms of exogenous parameters:

$$V = \frac{\mu N + \kappa(\sigma - 1)}{\kappa\sigma}. \tag{20}$$

Eq. (20) establishes the result that larger markets (in terms of population) support a larger number of varieties, which in turn implies, by (13), a higher price elasticity of demand. By (11), this leads to mark-ups being lower, and by (18), it follows that industrial firms are larger both in terms of workers and output. As we shall see in the next section, this positive link between firm size and the economy's population has important implications for technology adoption.

We are now ready to define the *Symmetric Nash Equilibrium with the Original Technology*.

Definition Symmetric Nash Equilibrium with the Original Technology. *For a given population N with a share μ of skilled households and a share $1-\mu$ of unskilled households with $\alpha > \mu$, a Symmetric Nash Equilibrium with the Original Technology is a collection of household variables $(c^*_{ja}, c^*_{jv}, I^*_j)$, $j \in \{S, U\}$, a sequence of firm variables $\{Q^*_v, Q^*_a, C^*_v, C^*_a, L^*_v, L^*_a, p^*_v, \varepsilon^*_v\}$, and a sequence of aggregate variables $\{w^*_a, w^*_m, V^*\}$, that satisfy*

(i) *utility maximization conditions given by* (5) *and* (6);
(ii) *firm profit maximization conditions given by* (7), (8), (11) *and* (12);
(iii) *market clearing conditions*
  (a) *goods market clearing: $C^*_a = Q^*_a$ and $C^*_v = Q^*_v$,*
  (b) *labor market clearing given by* (14) *and* (15);
(iv) *zero profit condition of industrial firms given by* (16).

4. Technology adoption and guilds

In this section we extend the model so as to allow for the possibility of technology adoption and guild formation. Essentially, we envision a world in which the *Original Technology Equilibrium* has prevailed up until the current period when a new technology unexpectedly appears. The new technology is superior to the old in that it has a higher marginal productivity, but inferior in that it entails a higher fixed cost. In particular, the new technology has a marginal product $(1+\gamma)$ times greater than that of the old technology, A_m, and requires a total fixed cost in units of labor equal to $\kappa e^{\phi\gamma}$, where $\phi > 0$.[10] The output of a firm producing variety v using the more productive technology is then

[10] As a result, the fixed cost is increasing and convex in the marginal productivity increase, γ.

$$Q_v = A_m(1+\gamma)\left[L_v - \kappa e^{\phi\gamma}\right]. \tag{21}$$

The new technology differs from the old technology in one other important way: it does not require any specialized labor inputs to operate. Thus, a firm that uses the new technology can employ unskilled households at a lower wage, without any loss in productivity.[11]

When deciding whether to adopt the new technology, a firm is not just trading off a lower marginal cost with a higher fixed cost. A firm's decision is also affected by the absence or presence of a firm guild, whose sole purpose is to block the adoption of the new technology.[12] The guild has no additional power; it has no say on wages or the number of workers employed by the firm. The industrial wage rate is determined by the relevant labor demand and supply. If all firms switch to the new technology, skilled households are not more valuable than unskilled households to firms in the economy. In that case there is a single labor market, and hence a single wage equal to the agricultural wage. If not all firms adopt the new technology, there continues to be a separate wage rate for skilled and unskilled workers.

The decision by a firm to adopt the new technology and the decision by workers to form a guild are strategic, and, thus, made within the context of a game. In what follows, we describe the game, then establish the conditions for the symmetric subgame perfect equilibria, and finally show how the incentive to form a guild and the existence of the various subgame perfect equilibria relate to the size of the market.

4.1. Industry game: timing of decisions and formation of guilds

The game consists of three stages. In the first stage, a (potential) firm decides whether to enter the industry. In the second stage, a firm's (potential) workers decide whether to establish a guild.[13] In the third stage, the firm decides whether to adopt the new technology, what price to charge for its product, and how many workers to hire. Each worker in a firm with a guild suffers a disutility cost $\rho > 0$. One can interpret this as an effort cost on the part of the guild members. For a firm that faces a guild, but still wants to adopt the new technology, it needs to pay a cost $\Omega > 0$ to defeat the guild.[14] In contrast to the other fixed costs, Ω is not in units of labor, but in units of the numéraire.

In the real world this cost Ω of defeating a guild could be wages to security forces hired to prevent striking workers from breaking machines. It could also constitute lobbying expenditures or political contributions that attempt to persuade government officials not to listen to labor's pleas for protection. For the purpose of illustrating our theory, it is not important that we take a stand on the exact manner in which the use of the resources are spent to defeat a guild; all that matters is that greater market size gives would-be-adopters more firepower to defeat any workers that might try to organize to block the adoption of the new technology. To the extent that these are lobbying costs, we abstract from any political elements in the economy. That is, we do not explicitly model the political economy, i.e., the process by which workers and would-be adopters compete for political support.

Fig. 1 depicts the game in its extensive form. The tree has four branches, which we refer to, starting from the top, as Branch 1 to Branch 4. The payoff to the firm are its profits, Π_v. These profits are lowered by the cost of defeating the guild, Ω, if the firm adopts and a guild forms (Branch 1). The worker's payoff depends on the wage rate he earns as well as the disutility of belonging to a guild. For notational convenience, we express the worker's payoff not in terms of his wage, but in terms of the indirect utility implied by his wage. This we denote in Fig. 1 by $U(w)$. If the firm does not adopt, it pays its workers the going industrial wage, w_m (Branch 2 and Branch 4). If the firm switches to the new technology, it pays its workers the going agricultural wage, w_a (Branch 1 and Branch 3).[15] Of course, if a guild exists, the worker's payoff, expressed in terms of his indirect utility, is net of the guild cost, ρ (Branch 1 and Branch 2).

4.2. Subgame perfect symmetric Nash equilibria

In what follows we limit our focus to symmetric subgame perfect Nash equilibria. In the absence of the new technology, there was only one such equilibrium, which we referred to as the *Original Technology Equilibrium* in Section 3.4. Once the new technology becomes available, there are four potential equilibria. However, it is immediate from the payoff structure that the outcome with a guild and adoption associated with Branch 1 is not subgame perfect. If a firm is willing to pay

[11] This is true for both the variable workers associated with the variable cost and the overhead workers associated with the fixed cost.

[12] Note that, as mentioned before, we interpret different goods as representing different industries, so that we can think of firms as industries. In that sense guilds act at the level of industries. If we were to adopt a two-tier structure of the industrial sector, with the upper-tier representing different industries and the lower-tier different varieties within industries, there would be a difference between firms and industries, in which case guilds could be modeled at the industry level, rather than at the firm level. Our model can be viewed as a reduced form of this more complex setup. We leave this extension for future work.

[13] In the case of an existing firm, the entity that establishes the guild are the firm's original workers. In the case of a new firm, the entity that establishes the guild is a nameless labor relation committee that maximizes the welfare of the skilled workers who will work in the firm. This abstraction is akin to the way newly entering firms are modeled; no agent is typically identified as the decision maker with respect to the profit maximizing behavior of entering firms.

[14] Here we are assuming that Ω is a constant. Assuming, instead, that the cost of defeating a guild is a linear function of the number of guild members, i.e., $\Omega = \omega L_v$, would not change any of the results.

[15] We are assuming that original workers do not have the possibility of switching to other industrial firms when their firm adopts the new technology.

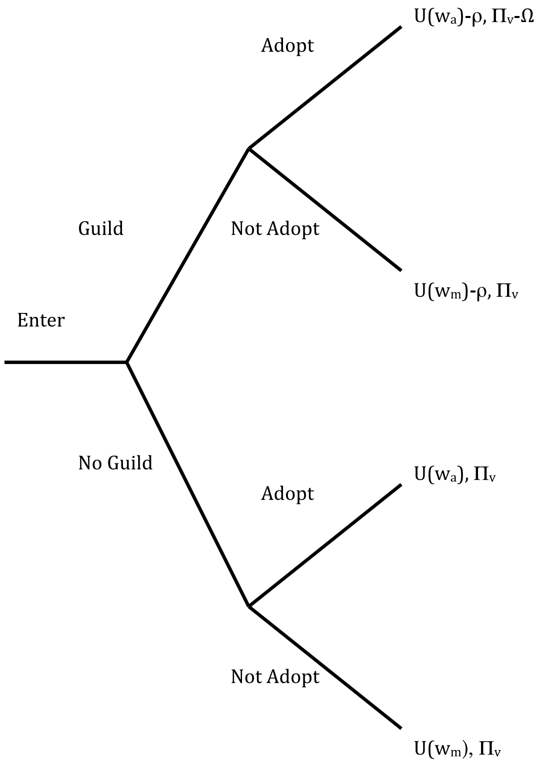

Fig. 1. Technology adoption.

the cost of defeating a guild, it will adopt the new technology regardless of whether there is a guild. In both cases, skilled households working in the firm will earn the agricultural wage. There is, thus, no benefit to being part of a guild since this would imply an additional utility cost ρ to the firm's workers. As a result, the equilibrium with firms adopting the new technology in the presence of guilds is not subgame perfect.

This leaves us with three remaining symmetric subgame perfect Nash equilibria. We refer to the one associated with Branch 4 as the *No-Adoption/No-Guilds Equilibrium*; the one associated with Branch 3 as the *Adoption/No-Guilds Equilibrium*; and the one associated with Branch 2 as the *No-Adoption/Guilds Equilibrium*. For the purpose of characterizing the necessary equilibrium conditions, it is important to note that the equilibrium prices and allocations in both the *No-Adoption/No-Guilds* and the *No-Adoption/Guilds* equilibria are identical to those corresponding to the *Original Technology Equilibrium*. Thus, all the equilibrium conditions in the definition of the *Original Technology Equilibrium* also apply to the *No-Adoption/No-Guilds* and the *No-Adoption/Guilds* equilibria. There are of course two additional subgame perfect equilibrium conditions that must hold in the *No-Adoption/No-Guilds* and the *No-Adoption/Guilds* equilibria. These refer to no firm having an incentive to adopt the new technology, and no skilled households having an incentive to either form a guild (in the *No-Adoption/No-Guilds Equilibrium*) or dissolve a guild (in the *No-Adoption/Guilds Equilibrium*).

We now proceed to characterize the no deviation condition for firms that use the old technology. To do so, we solve the profit maximization of a firm producing variety v that deviates from the *No-Adoption/No-Guilds* or the *No-Adoption/Guilds* equilibria.[16] Namely,

$$\arg\max_{p'_v} \left\{ p'_v Q'_v - w_a^* \left[\frac{Q'_v}{A_m(1+\gamma)} + \kappa e^{\phi\gamma} \right] \right\} \tag{22}$$

$$\text{s.t.} \quad Q'_v = \frac{\alpha(w_a^* N_U + w_m^* N_S)(p'_v)^{-\sigma}}{(V^* - 1)(p_v^*)^{1-\sigma} + (p'_v)^{1-\sigma}}, \tag{23}$$

where variables with a prime refer to choices made by the deviating firm and asterisks refer to the *No-Adoption/No-Guilds* or *No-Adoption/Guilds* equilibrium prices. Note that the firm takes aggregate income in the economy, $w_a^* N_U + w_m^* N_S$, as given.[17] The profit maximizing price is a mark-up over the marginal cost, namely,

[16] This is of course equivalent to deviating from the *Original Technology Equilibrium*, since, as we mentioned, the prices and allocations are the same in all three equilibria.

[17] Strictly speaking, the deviating firm will affect aggregate income, but as long as the industrial sector is small relative to the agricultural sector, this effect will be minimal, so we ignore it. Alternatively, we could assume a continuum of industrial sectors, with each sector having a finite number of firms. In that case, each industrial firm would be small compared to the aggregate economy, but large compared to other firms in its sector.

$$p_v' = \frac{w_a^*}{A(1+\gamma)} \frac{\varepsilon'}{\varepsilon' - 1}. \tag{24}$$

Given aggregate demand for the firm's variety and the price choices of other industrial firms, the elasticity of a deviating firm is

$$\varepsilon' = \sigma - (\sigma - 1)\frac{(p_v')^{1-\sigma}}{(V-1)(p_v^*)^{1-\sigma} + (p_v')^{1-\sigma}}. \tag{25}$$

Eq. (25) anticipates one of the main results of the paper. In particular, the above expression suggests that the profits of a deviating firm will be larger in larger markets. This follows as a higher level of population leads to more firms, and thus a greater price elasticity of demand.[18] This implies larger firms that can more easily bear the higher fixed cost of the new technology. In addition, the higher price elasticity of demand also implies that the price drop associated with technology adoption will have a proportionately greater effect on revenues and profits if the economy's population is higher. This insight will be key when proving the relation between market size, technology adoption and guild formation.

As stated above, one of the two necessary conditions for subgame perfection in both the *No-Adoption/No-Guilds* and the *No-Adoption/Guilds* equilibria is that no individual firm wants to deviate and adopt the new technology. In the case of the *No-Adoption/No-Guilds Equilibrium*, this requires that the profits from deviating are negative, i.e., $\Pi_v' < 0$, and in the case of the *No-Adoption/Guilds Equilibrium*, this requires that the profits from deviating are positive but insufficient to pay the cost of defeating the guild, i.e., $0 < \Pi_v' < \Omega$. The second no deviation condition applies to the decision of forming a guild or not. In the case that $\Pi_v' < 0$, it is obvious that a guild will not be established; the firm has no incentive to adopt, so there is no point in having a guild that entails a disutility cost for workers. So no additional condition needs to be specified in the *No-Adoption/No-Guilds Equilibrium*. In the case that $0 < \Pi_v' < \Omega$, a guild will be established as long as the difference in indirect utility associated with the higher industrial wage compensates for the disutility incurred by forming a guild, i.e., as long as $U(w_m^*) - U(w_a^*) > \rho$. For this condition to hold, μ must be sufficiently small, compared to α.

We can now define the necessary conditions for the subgame perfect *Symmetric Equilibrium with No Adoption and No Guilds* (referred to as the *No-Adoption/No-Guilds Equilibrium* for short) and the subgame perfect *Symmetric Nash Equilibrium with No Adoption and Guilds* (referred to as the *No-Adoption/Guilds Equilibrium* for short).

Definition Symmetric Nash Equilibrium with No Adoption and No Guilds. *A Symmetric Nash Equilibrium with No Adoption and No Guilds is the same as a Symmetric Nash Equilibrium with the Original Technology with the additional condition that* $\Pi' < 0$ *where* $\Pi_v' = p_v' Q_v' - w_a^*[\frac{Q_v'}{A_m(1+\gamma)} + \kappa e^{\phi\gamma}] < 0$, *with* Q_v', p_v' *and* ε' *given by* (23), (24) *and* (25).

Definition Symmetric Nash Equilibrium with No Adoption and Guilds. *A Symmetric Nash Equilibrium with No Adoption and Guilds is the same as a Symmetric Nash Equilibrium with the Original Technology with the additional conditions* (i) *that* $\Omega > \Pi_v' > 0$, *where* $\Pi' = p_v' Q_v' - w_a^*[\frac{Q_v'}{A_m(1+\gamma)} + \kappa e^{\phi\gamma}]$, *with* Q_v', p_v' *and* ε' *given by* (23), (24) *and* (25) *and* (ii) *that* $U(w_m^*) - \rho > U(w_a^*)$.

This leaves us to define the *Adoption/No-Guilds Equilibrium*. In this case all industrial firms use the new technology. As such, there is no longer any relevant distinction between skilled and unskilled households since both can be employed in either sector. Wages therefore equalize across sectors. For this equilibrium to be subgame perfect, it must be that no firm wants to go back to the old technology. Such a deviating firm must hire skilled workers, as the old technology uses specialized labor inputs. However, because skilled workers earn the same wage as unskilled workers, a deviating firm can hire as many skilled workers as it likes at the going wage rate. For no firm to return to the old technology, the profits of doing so must be negative. It is obvious that in this case no guild would be established, since workers' wages are unaffected by the firm's technology decision. In light of this discussion, we have the following definition of the *Symmetric Nash Equilibrium with Adoption and No Guilds* (referred to as the *Adoption/No-Guilds Equilibrium* for short).

Definition Symmetric Nash Equilibrium with Adoption and No Guilds. *For a given population N, a Symmetric Nash Equilibrium with Adoption and No Guilds is a collection of household variables* $(c_{ja}^{**}, c_{jv}^{**}, I_j^{**})$, $j \in \{U, R\}$, *a sequence of firm variables* $\{Q_v^{**}, Q_a^{**}, C_v^{**}, C_a^{**}, L_v^{**}, L_a^{**}, p_v^{**}, \varepsilon_v^{**}\}$, *and a sequence of aggregate variables* $\{w_a^{**}, w_m^{**}, V^{**}, N_u^{**}, N_a^{**}\}$, *that satisfy*

(i) *utility maximization conditions given by* (5) *and* (6);
(ii) *firm profit maximization conditions given by* (7), (8), (12), *and*

$$p_v^{**} = \frac{w_m^{**}}{A_m(1+\gamma)} \frac{\varepsilon_v^{**}}{\varepsilon_v^{**} - 1}; \tag{26}$$

[18] Alternatively we could have modeled the industrial sector as a monopolist, in which case the link between market size and firm size would have been immediate. We chose our more elaborate setup instead, because there is ample empirical evidence of both the number of firms increasing with the size of the market and the elasticity channel (see Desmet and Parente, 2010, for a further discussion).

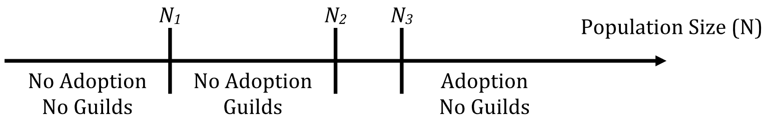

Fig. 2. Market size, technology adoption and guilds.

(iii) *market clearing conditions*
  (a) *goods market*: $C_a^{**} = Q_a^{**}$ *and* $C_v^{**} = Q_v^{**}$;
  (b) *labor market*:

$$V^{**}L_v^{**} + L_a^{**} = N, \tag{27}$$

$$w_m^{**} = w_a^{**}; \tag{28}$$

(iv) *zero profit condition of industrial firms given by*

$$p_v^{**}Q_v^{**} - w_m^{**}\left[\kappa e^{\phi\gamma} + \frac{Q_v^{**}}{A_m(1+\gamma)}\right] = 0; \tag{29}$$

(v) *no firm wants to go back to the original technology,* $\Pi_v'' < 0$, *where* Π_v'' *is given by*

$$\underset{p_v''}{\arg\max}\ \left\{p_v''Q_v'' - w_m^{**}\left[\frac{Q_v''}{A_m} + \kappa\right]\right\} \tag{30}$$

$$\text{s.t.}\quad Q_v'' = \frac{\alpha(w_a^{**}N)(p_v'')^{-\sigma}}{(V^{**}-1)(p_v^{**})^{1-\sigma} + (p_v'')^{1-\sigma}}. \tag{31}$$

4.3. Guilds and market size

We now explore how the existence of guilds relates to market size, which in our model is equivalent to population. We do this by increasing the measure of households in the economy, keeping the share of skilled households, μ, constant.[19] We establish that these changes give rise to an inverted-U relationship between population size and the existence of guilds. Specifically, for low populations, guilds do not exist and the old technology is used; for intermediate sized populations, guilds form and block the use of the new technology; and for sufficiently large populations, guilds cease to exist and the new technology is used. We start by giving the intuition for this relationship, and then prove the results analytically.

When the population is small, there are few firms, the price elasticity of demand is low, and the size of firms is small. A firm is therefore not able to bear the higher fixed cost of the new technology without making negative profits. Thus, when the population is small, $\Pi_v' < 0$, and no firm wants to switch to the new technology. In that case, there is no reason for a guild to form. Therefore, for a low level of population, the relevant equilibrium is the *No-Adoption/No-Guilds Equilibrium*. When the population reaches an intermediate size, firms are large enough to make positive profits from adopting the new technology, but not so large that the profits are able to pay the cost of defeating the guild, i.e., $0 < \Pi_v' < \Omega$. In that case, a guild will be established, and the firm will not adopt. Hence, for an intermediate level of population, workers will form guilds to block adoption. The equilibrium that exists is the *No-Adoption/Guilds Equilibrium*. When the population reaches a large enough size, the profits from adoption are high enough to pay the cost of defeating the guild, i.e., $\Pi_v' > \Omega$. The firm will adopt the new technology, independently of what workers do. If so, workers will prefer not to pay the cost of forming a guild. In that case, the guild disappears and the firm switches to the new technology. Whether all firms adopt the new technology and all guilds disappear depends on the market size. Only if the population is sufficiently large can we be sure to have an *Adoption/No-Guilds Equilibrium*.

Fig. 2 summarizes the relation between market size, technology adoption and guilds. Until the population reaches threshold N_1, none of the firms adopts the new technology and there are no guilds, so the equilibrium is the *No-Adoption/No-Guilds* one. Once N_1 is reached, guilds that block technology adoption appear in all firms as any industry that did not have a guild would want to adopt the new technology. The equilibrium that prevails is the *No-Adoption/Guilds* one. Above threshold N_2, some (but not necessarily all) firms switch to the new technology and guilds disappear in those firms. Above threshold N_3 there are no more guilds and all firms use the new technology, so that we get the *Adoption/No-Guilds Equilibrium*. Note that N_3 may be to the right or to the left of N_2, so that there may be a population range where either both equilibria exist or neither exists.[20]

[19] Alternatively, keeping the population constant while increasing the share of skilled households would also result in lower mark-ups and larger firms. We do not entertain this type of increase in market size, although it seems to have been relevant in the case of the United Kingdom: although by 1650 its population had only recovered to its 1340 level, the fraction living in urban areas was significantly higher.

[20] In the latter case, a non-symmetric equilibrium would exist where some firms use the new technology and others use the old technology.

4.4. Population size, technology adoption and guild formation

We now prove that $N_2 > N_1$. We also show that there exists a threshold N_3 above which all firms adopt and no guilds exist. These analytical results form the basis for our claim that there is an inverse-U relationship between market size and the existence of guilds, which is the focal point of the empirical analysis in Section 5.

Proposition 1. *There exist three thresholds, N_1, N_2 and N_3, such that below threshold N_1 the No-Adoption/No-Guilds Equilibrium exists, between thresholds N_1 and N_2 the No-Adoption/Guilds Equilibrium exists, and above threshold N_2 at least some firms adopt the new technology and their corresponding guilds disappear. In addition, there exists a threshold N_3 above which the Adoption/No-Guilds Equilibrium exists.*

Proof. See Appendix A. □

The intuition for this proof is the one we gave when discussing Fig. 2.

Corollary. *There is an inverted U-relationship between population size and the existence of guilds.*

From Proposition 1, it follows that when the population is small (below N_1), there are no guilds; when the population is of intermediate size (between N_1 and N_2) guilds are omnipresent; and when the population is large, guilds start disappearing. When the population is greater than N_2 at least some guilds disband, whereas when the population is greater than both N_3 and N_2, then no more guilds are left.

4.4.1. Numerical experiments

We now parameterize the model and numerically solve for the subgame perfect symmetric equilibria. We do this for several reasons. First, it is useful to show how the different cutoffs depend on the parameters of the model, such as the fraction of the population that is skilled, the fixed cost associated with the new technology, and the cost of overcoming guild resistance. Second, as discussed before, N_3 could be smaller or larger than N_2. We want to show this, and comment on the possibility of having either multiple symmetric equilibria (if N_3 is smaller than N_2) or no symmetric equilibria (if N_3 is larger than N_2). Third, since in many European countries guilds were abolished by the state, we would like to explore the possible incentive of governments to outlaw technology-blocking institutions before markets did on their own.

We note that the parameterization is not done in the context of a calibration exercise.[21] In light of the game elements, the model structure is too abstract to make a calibration exercise meaningful. The following experiments are therefore suggestive, and are not intended as a statement on why growth took off sometime in the 18th century.

Fig. 3 (Panel a) shows what happens when we increase the new technology's fixed cost parameter ϕ. This is an interesting experiment to undertake since numerous economic historians claim that institutions in Europe resulted in lower entry and adoption costs than elsewhere. Not surprisingly, as adoption becomes less expensive, the cutoffs for the three symmetric equilibria decrease. This finding is rather intuitive: when adoption is less costly, it is more likely.

But not all cutoffs decrease by the same amount as ϕ drops. As can be seen, N_3 decreases by more than N_2. The intuition is as follows. When the fixed cost associated with the new technology drops, the difference in fixed costs across the two technologies becomes smaller. This makes it more likely for there to be a population range that is large enough to sustain the symmetric equilibrium with adoption but not large enough to overcome the costs of defeating the guilds if firms are using the original technology. That is, it becomes more likely for there to be multiple equilibria, where both the *Adoption/No-Guilds* and the *No-Adoption/Guilds* equilibria are possible. Consistent with this, Fig. 3 (Panel a) shows that for high values of ϕ, N_3 is greater than N_2, whereas for low values of ϕ, N_3 is smaller than N_2. That is, when ϕ is large, there is a population range for which no symmetric equilibrium exists. In that case, some firms will be using the old technology and others the new technology. In contrast, when ϕ is low, there is a population range which sustains both the *Adoption/No-Guilds* and the *No-Adoption/Guilds* equilibria.

Fig. 3 (Panel b) explores how the cutoffs vary with the cost of overcoming resistance, Ω. As can be seen, the only cutoff that is affected by a change in the cost of overcoming resistance is N_2. With a higher cost of defeating the guilds, the range of population sizes for which the *No-Adoption/Guilds Equilibrium* exists is greater. This is intuitive: with a greater Ω, the profits of a deviating firm have to be that much greater in order to justify adoption and defeat the guild. Though intuitive, we mention this result because many economic historians point to the ease by which firms in Europe, especially in Britain, could set up shops in areas outside of guild control as being important for the *Industrial Revolution*. A lower cost associated with setting up operations with the new technology in the countryside can be interpreted as having a lower cost of overcoming resistance.

Fig. 3 (Panel c) demonstrates the effect of a shrinking skill premium on the decline of guilds by seeing how the cutoffs depend on the fraction of skilled households, μ. With more skilled workers in the population, the difference between the

[21] For the benchmark exercise we choose the following parameter values: $\alpha = 0.4$, $\mu = 0.29$, $\phi = 1.3$, $\Omega = 0.85$, $A_a = 1.5$, $A_m = 1$, $\sigma = 2.8$, $\kappa = 0.1$, $\rho = 0.05$, and $\gamma = 0.72$.

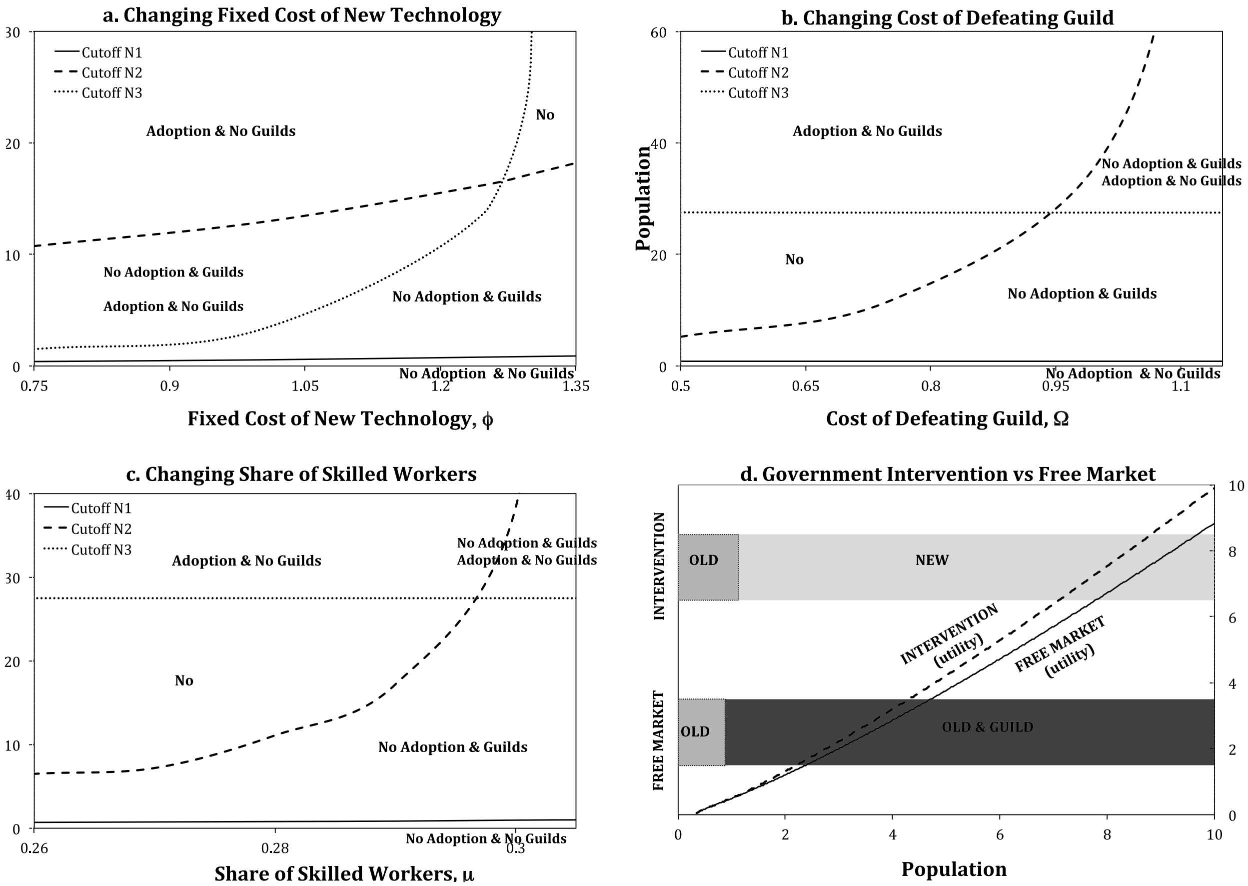

Fig. 3. Numerical exercises.

industrial wage rate and the agricultural wage rate falls. Interestingly, a higher wage premium (i.e., smaller μ) implies that guilds appear for a narrower range of population sizes. The intuition is that with a high wage premium, the profits of a deviating firm associated with adoption are higher because of the larger reduction in wage costs associated with being able to hire unskilled households. For lower wage premiums (i.e., larger μ), the opposite happens: a deviating firm stands less to gain by adopting since unskilled workers are not much cheaper than skilled workers.

Before ending this section, it is informative to see how the outcome would change were we to allow for some form of government intervention. Suppose the government objective is to maximize average household utility, $\mu U(c_{Sa}, c_{Sv}) + (1-\mu)U(c_{Ua}, c_{Uv})$.[22] In light of the historical events, we ask ourselves whether a government would ever have an incentive to abolish the guilds. It is obvious that whenever there are multiple equilibria (i.e., when $N_3 < N_2$), such a policy may be useful. This corresponds to the regions in Fig. 3 (Panels b and c) where both the *No-Adoption/Guilds* and the *Adoption/No-Guilds* equilibria exist. For the numerical experiments corresponding to those regions, the average household utility is always higher under the *Adoption/No-Guilds* than under the *No-Adoption/Guilds* equilibrium. That is, the average household would be better off if all firms adopted, but it is possible that all firms face guilds and no one adopts. If so, by outlawing guilds, the government can make the economy move to the "good" equilibrium, where all firms use the new technology and the average household is better off.

In the absence of multiple equilibria (i.e, when $N_3 \geqslant N_2$), the effect of a law abolishing guilds would be less dramatic. Although some firms would switch to the new technology, not all would do so. Since we are not able to solve for asymmetric equilibria, we cannot say whether a government would want to implement such a policy. For this reason we consider an alternative government policy that dictates which of the two production technologies industrial firms must use. Panel d in Fig. 3 displays the relevant results.[23] For each level of population, it shows whether the old or new technology is used in the economy with and without government intervention, and it plots the average household utility associated with the relevant equilibrium. In the economy with a government, the average household utility is equal to that attained in the *No-Adoption/No-Guilds Equilibrium* when the old technology is used and equal to that attained in the *Adoption/No-Guilds*

[22] This is equivalent to maximizing average household consumption.

[23] For this economy, $N_3 = N_2$. The parameter values are the same as in the benchmark except that $\mu = 0.296$.

Equilibrium in the case the new technology is used. As can be seen, with government intervention the new technology is used for smaller populations compared to when there is no government intervention. Additionally, as the figure shows, the welfare cost of having a guild that blocks the new technology increases with population size, so that the incentive for the government to step in, and impose the new technology increases as the market expands. The rising welfare cost of sticking with the old technology suggests that it may take too long for the economy on its own to get rid of the guilds. This justifies a policy where government effectively outlaws guilds by imposing technology standards on industrial firms.

5. Empirical analysis: The case of Italian guilds

Section 2 sampled a small fraction of case studies showing that expanding markets and increasing competition were fundamental to ending guild resistance to new technologies, eventually ushering in the demise of the guilds themselves. Such anecdotal evidence, albeit informative, nevertheless does not constitute a formal test of theory. For this reason, we proceed to more rigorously test our theory of guilds.

Recall that in our theory there are no guilds in very small markets or very large markets; guilds do not exist in very small markets because adoption is unprofitable for firms, and guilds do not exist in very large markets because firms have sufficient resources to defeat worker resistance. Guilds only appear in medium-sized markets to block technology adoption by individual industries in order to avoid the original workers becoming worse off. Our theory, thus, predicts an inverted U-relationship between market size and the existence of guilds.[24]

To test this prediction, we analyze the relation between guild existence and city size in Italy. The implicit assumption is that city size is a good measure of market size. Our main data source is a unique dataset on Italian guilds, the *Corporazioni* database, compiled by a large group of Italian researchers.[25] This database covers 1385 Italian guilds in 55 cities from the 14th to the 19th century. It contains relevant information, such as the guild's city, state, date of foundation, and date of disappearance.

Although impressive in its coverage, the *Corporazioni* database is deficient in two respects for the purpose of this analysis. First, it does not include the city size. We therefore combine the data on guilds with information on city sizes from the *Italian Urban Population 1300–1861* database of Malanima (2005). These data are only available for a limited number of years, however. For intermediate years, we interpolate, assuming a constant rate of population growth. Appendix B provides further details of the data we use. Second, for a limited number of guilds, the *Corporazioni* database fails to give a date of disappearance. For these guilds, we assign a date of disappearance using the listed disappearance dates of other guilds in the same city, if such information is available. For example, in Padova, there were 46 guilds, 32 of which disappeared between 1805 and 1807. For the remaining 14 guilds in Padova for which we have no information, we therefore take 1806 as the year of disappearance. In some cases, we have no specific information about the dates of disappearance of any of the guilds of a city, but we still know when guilds were abolished at the state level. For example, we have no information about the dates of disappearance of any of the guilds in Catanzaro, but we do know that the Kingdom of Naples, which Catanzaro belonged to, abolished guilds in 1821. In this case, we take 1821 as the date of disappearance of all guilds in Catanzaro.

The example of the abolishment of guilds in the Kingdom of Naples raises an important issue: most guilds disappeared by law, rather than out of their own accord. Indeed, of all the guilds for which the dataset specifies the reason of their disappearance, only 10 percent ceased to exist voluntarily, whereas 90 percent were abolished. Although in our model guilds voluntarily choose to disband, we do not view this pattern as a contradiction because governments would have been unable to abolish guilds unless they had already become sufficiently weakened and the industrial base sufficiently strengthened. In addition, as we discussed in our numerical exploration of the theory, guilds may have been too slow in disbanding and firms too slow in adopting new technology, compared to what was socially optimal. This justifies the possible intervention of governments in speeding up the disappearance of guilds.

In a first look at the data, we calculate the average size of cities with guilds and without guilds between 1350 and 1850. As shown in Fig. 4, until the middle of the 18th century, the smaller cities had no guilds, whereas the larger ones did. Cities without guilds had on average a population of around 10,000, whereas cities with guilds had an average size slightly above 35,000. When guilds started to disappear in the latter part of the 18th century, the size difference between these two types of cities began to decline, and by 1825 the cities with no guilds had actually become larger than those with guilds. This suggests that on average guilds disappeared earlier in cities with larger populations. As further evidence, note that in 1750 the average size of cities with guilds was 40,000, lower than the average threshold of 45,000 at which guilds disappeared.

Fig. 4 is therefore largely consistent with an inverted-U relationship between city sizes and guilds predicted by our theory: absence of guilds in smaller cities (10,000 and below) and in larger cities (45,000 and above), and prevalence of guilds in medium-sized cities (between 10,000 and 45,000). Given the substantial cross-city heterogeneity, these results

[24] Of course, as mentioned before, in reality guilds did more than just resist technology adoption. They were often in charge of, for example, training and quality control. But in as far as these other roles of guilds are unrelated to market size, then our model would still predict an inverted-U relationship between market size and the existence of guilds.

[25] The database is part of the project *Istituzioni corporative, gruppi professionali e forme associative del lavoro nell'Italia moderna e contemporanea*.

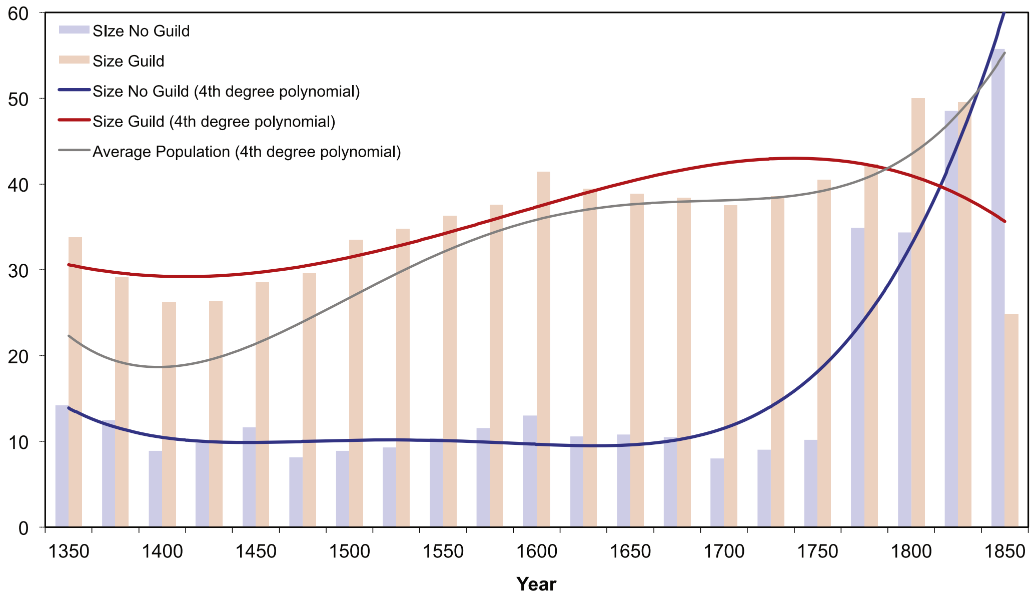

Fig. 4. Guilds and city sizes.

Table 1
Guilds and city size (unit of observation: city-year).

Dependent variable: having a guild	(1)	(2)	(3)	(3 bis)	(4)	(5)	(6)	(7) drop if population <10,000
Log(Pop)	0.948 [0.187]***	3.683 [0.953]***	4.579 [1.401]***	4.579 [1.566]***	2.490 [1.087]**	2.629 [1.376]*	5.774** [2.409]	5.435 [2.073]***
Log(Pop)^2		−0.435 [0.132]***	−0.501 [0.191]***	−0.501 [0.217]**	−0.254 [0.158]	−0.186 [0.202]	−0.253 [0.373]	−0.614 [0.278]**
Constant	−1.905 [0.584]***	−5.901 [1.617]***	−12.811 [2.615]***	−12.811 [3.327]***	−2.677 [1.803]	−8.471 [2.381]***	−17.244 [4.023]***	−14.349 [3.642]***
Half century fixed effects	NO	NO	YES	YES	NO	YES	NO	YES
State fixed effects	NO	NO	NO	NO	YES	YES	NO	NO
Year fixed effects	NO	NO	NO	NO	NO	NO	YES	NO
City fixed effects	NO	NO	NO	NO	NO	NO	YES	NO
Pseudo-R^2	0.0904	0.1149	0.3939		0.1697	0.4941	0.6509	0.3944
Observations	24,795	24,795	24,795	24,795	24,795	24,795	24,795	19,819

Standard errors clustered at the city-level in brackets, except in column (3 bis) where bootstrapped with 1000 replications.
* Significant at 10%.
** Significant at 5%.
*** Significant at 1%.

have to be interpreted with caution, and a more in-depth analysis is required before concluding that the data are indeed consistent with the theory.

To explore the suggestive relation of Fig. 4 further, we use a logit model to estimate how the probability of having at least one guild in the city depends on city size. The unit of observation is a city-year, and the observations go from 1300 to 1850. Table 1 shows the results. Standard errors have been clustered at the city-level to correct for serial correlation, and are reported in brackets. They are computed using the Huber–White cluster–robust covariance matrix. Column (1) shows the results for the full sample when only the log of city size is used as a regressor. It suggests that large cities were on average more likely to have a guild. However, given that our theory predicts a non-monotonic relation between guild existence and market size, we introduce a quadratic term in the estimation in Column (2). Consistent with what we expect, the linear term continues to be positive whereas the quadratic term is negative. Both coefficients are statistically significant at the 1% level.

How robust is this inverted-U relationship? To investigate the sensitivity of our results, we start by adding time dummies (for each half century) and state dummies (for the different Italian states). The inclusion of time dummies and state dummies is motivated by the possibility that public sentiment and policy towards guilds may have differed across time and across states. As can be seen in Columns (3)–(5), controlling for time does not change the results, whereas including state dummies weakens the relation, with the quadratic term no longer being statistically significant, though still having the

Table 2
Guilds and city size (unit of observation: city-half century averages).

Dependent variable: having a guild	(1)	(2)	(3)	(3 bis)	(4)	(5)	(6)	(7) drop if population <10,000
Log(Pop)	0.382	2.801	4.757	4.757	1.757	3.951	7.975	6.404
	[0.145]***	[0.786]***	[1.282]***	[1.365]***	[0.955]*	[1.591]**	[3.524]**	[2.247]***
$Log(Pop)^2$		−0.368	−0.586	−0.586	−0.211	−0.442	−0.634	−0.799
		[0.109]***	[0.169]***	[0.182]***	[0.140]	[0.225]**	[0.500]	[0.296]***
Constant	−0.435	−4.092	−11.116	−11.116	−1.673	−9.291	−4.634	−14.171
	[0.515]	[1.362]***	[2.542]***	[2.691]***	[1.595]	[2.892]***	[7.061]	[4.202]***
Time fixed effects	NO	NO	YES	YES	NO	YES	YES	YES
State fixed effects	NO	NO	NO	NO	YES	YES	NO	NO
City fixed effects	NO	NO	NO	NO	NO	NO	YES	NO
Pseudo-R^2	0.0181	0.0435	0.4208		0.0973	0.5423	0.7233	0.4533
Observations	588	588	588	588	576	576	552	429

Standard errors clustered at the city-level in brackets, except in column (3 bis) where bootstrapped with 1000 replications.
Observations are based on half-century averages.
* Significant at 10%.
** Significant at 5%.
*** Significant at 1%.

right sign. The same is true when in Column (6) we include both time dummies (for each year, rather than for each half century) and city dummies. This suggests that part of the inverted-U relationship we are picking up in Column (3) comes from cross-state or cross-city variation, rather than within-city across-time variation. This is not entirely surprising, since in quite a few cases guilds were abolished by the state, affecting all cities within the state. For example, the Kingdom of Naples abolished guilds in 1821. This did not only affect the city of Naples itself, but also other cities such as Catanzaro and Aversa. As a result, the within-state variation between size and guilds is relatively weak, so that we need to rely on the cross-state variation in the average sizes of cities to pick up the inverted-U relation.

Another possible concern is that very small cities may not have guilds, not because of the reasons in our theory, but because of the existence of fixed setup costs.[26] This does not seem to be driving the results though. When running our specification of Column (3) on the subset of cities with a population above 10,000, the results do not change, as can be seen in Column (7). That fixed setup costs are not that high can also be seen from the fact that there are several examples of cities with a population of just 5,000 that have guilds.

As mentioned before, all results report clustered standard errors at the city-level, using the Huber–White cluster–robust covariance matrix. As argued by Bertrand, Duflo and Mullainathan (2004), an alternative is to use a covariance matrix based on block bootstrap in which entire cities are sampled with replacement, thus keeping them in a block. Using the same specification as in Column (3), block bootstrapped errors are reported in Column (3 bis). Standard errors are slightly higher, but the quadratic relation between city size and guilds continues to be statistically significant at the 5% level.

The population data from Malanima (2005) are only available for 1300, 1400, 1500, 1600, 1700, 1800 and 1861. As discussed before, for all intermediate years we are interpolating, assuming constant population growth rates. This implies that measurement error in any of the years will affect all intervening years. This obviously worsens any concern about the errors being serially correlated. In addition to clustering the standard errors at the city-level, we amend this issue in two further ways. First, we compute half-century averages for our data, and re-run our regressions.[27] The results are reported in Table 2. When comparing with the same columns in Table 1, the results are virtually unchanged. For example, when controlling for both time and state fixed effects, the quadratic relationship continues to be statistically significant.

Second, we re-run our regressions on only those years for which we have data from Malanima (2005).[28] Results are reported in Table 3. As can be seen, the results are similar, but the statistical significance is stronger. In particular, when including state or city fixed effects, the quadratic term continues to be statistically significant at the 10% level.

To visualize this quadratic relation between size and guilds, Fig. 5 shows the predicted probability of having a guild in function of city size. The estimated relation is based on Column (3) of Table 2. For comparison purposes, we also compute the share of cities of a given population size that have a guild. When doing so, we have discretized the population sizes at the level of one decimal. These shares are indicated by the small triangles in Fig. 5. As can be seen, the inverted-U relation between city size and guilds is readily apparent.

In general, once guilds disappeared in a city, they did not revive afterwards. A (partial) exception is Rome, where guilds were initially abolished in 1801, to later be re-allowed by Pope Pius IX in 1852. However, this did not seem to have led

[26] Another related potential concern at the other end is that large markets did not have guilds because the cost of organizing guilds and maintaining guilds was higher there. Olson (1965), in emphasizing the free rider problem, is in this spirit. In terms of the model, this concern could be handled by assuming that the disutility cost of belonging to a guild was increasing in the market size.

[27] Given that having a guild is a 0–1 variable, we set it to 1 if a city had a guild in 25 years or more of each half-century.

[28] Only for 1850 do we take the interpolated population between 1800 and 1861.

Table 3
Guilds and city size (unit of observation: city in years available from Malanima, 2005).

Dependent variable: having a guild	(1)	(2)	(3)	(4) drop if population <10,000
Log(Pop)	4.493	3.553	6.406	4.033
	[1.204]***	[1.328]***	[2.203]***	[1.783]**
Log(Pop)^2	−0.496	−0.332	−0.450	−0.438
	[0.175]***	[0.194]*	[0.267]*	[0.249]*
Constant	−10.328	−8.087	−15.924	−9.443
	[1.967]***	[2.260]***	[4.311]***	[3.064]***
Time fixed effects	YES	YES	YES	YES
State fixed effects	NO	YES	NO	NO
City fixed effects	NO	NO	YES	NO
Pseudo-R^2	0.4422	0.5125	0.6184	0.3958
Observations	315	315	315	229

Standard errors clustered at the city-level in brackets.
Based on years from Malanima: 1300, 1400, 1500, 1600, 1700, 1800, 1850.
* Significant at 10%.
** Significant at 5%.
*** Significant at 1%.

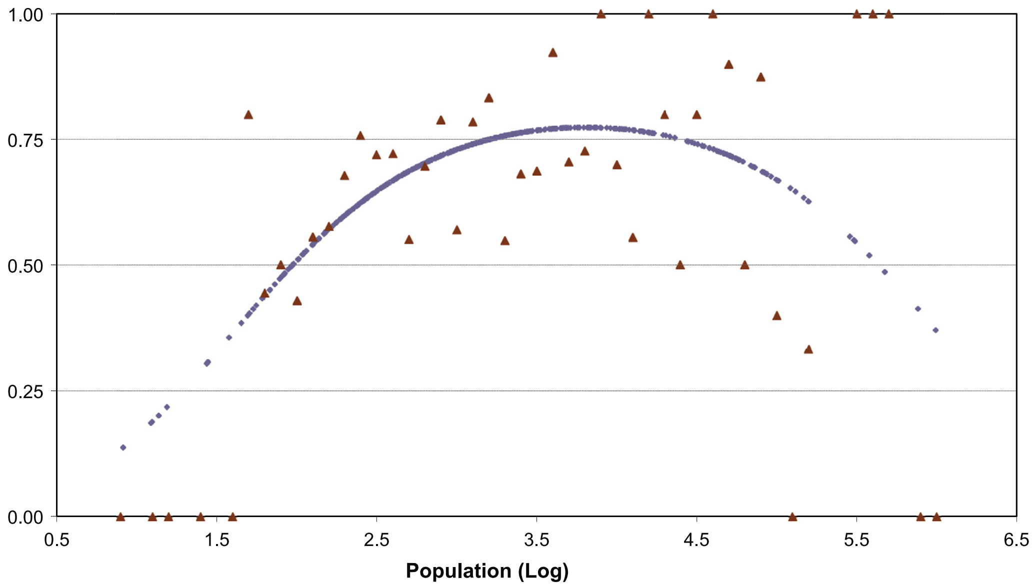

Fig. 5. Probability of having a guild.

to a true resurrection of guilds. Instead, it was more of an attempt on the part of the Catholic Church to slow down the rise of non-religious workers' associations. In reality, the new guilds ended up being more of mutual aid societies, and the few that revived were again abolished in 1864 (Fortunati, 2011; Agócs, 1988). Since our analysis goes from 1300 to 1850, this episode does not affect us. In addition, it is not clear whether the guilds that were re-created should be considered as guilds or not. Still, we re-ran our regressions, extending the dataset beyond 1850 under two alternative assumptions — Rome having guilds after 1852 and Rome not having guilds after 1852. The results (not reported here) are unchanged.

Our analysis has focused on the question of whether a city has at least one guild. In principle, our data would allow us to also consider this relation at the sectoral level, and use city-sector-time, rather than city-time, as the unit of observation. However, since in essentially all cities all guilds disappeared at the same time, this analysis would not be informative, and we therefore focused on city-time as the relevant unit of observation.

6. Conclusion

In this paper, we have proposed a theory for why guilds proved to be such an obstacle to technological change prior to the 18th century in Western Europe, but not after. In our theory, the organization of workers into guilds was an optimal response to the discovery of new production processes, which if adopted, would have reduced workers' earnings. The framework predicts an inverted-U relation between market size and guild presence. Guilds do not exist in very small markets because adoption is unprofitable for firms, and guilds do not exist in very large markets because workers with skills specialized in the original technology can be defeated if they challenge their firm's attempts to innovate. Guilds only appear in medium-sized markets to block technology adoption by individual firms in order to avoid the industry's original skilled workers becoming worse off. We have confirmed the presence of an inverted U-relationship in the data when analyzing the relation between market size and the existence of Italian guilds between 1300 and 1850.

Given the empirical success of our theory, we see several valuable lines of research to pursue. First, whereas we have analyzed the incentives of an individual firm and its workers to deviate from the symmetric equilibrium with no adoption, and discussed the incentives to deviate from a symmetric equilibrium with adoption, we did not analyze intermediate cases where only a fraction of the industries had guilds. Studying asymmetric equilibria is technically challenging, but would provide a more comprehensive picture of the history of guilds, allowing us to account for a more gradual decline of guilds over time. Second, in our theory we do not distinguish between firms and industries. Extending the model by considering a two-tier industrial sector structure, with the top-tier representing industries, and the bottom-tier firms, would allow us to have industry-level guilds that are common to different firms, and thus add a greater degree of realism. Additionally, this extension would allow us to consider a guild's decision to block the introduction of a new variety of good within their industry, something that occurred frequently. Third, in the empirical part we have focused our analysis on the relation between market size and guild existence, without providing direct evidence of guilds blocking technology adoption. Unfortunately, data on what individual guilds did and how that changed over time is not available for a broad cross-section. However, a potentially interesting area of future research would be to study strikes and their reasons through time. All three lines of research have the potential to give us a clearer understanding of the historical role of technology-blocking institutions, the pre-1700 era of stagnant living standards, and the post-1700 era of rising living standards.

Appendix A. Proof of Proposition 1

To simplify notation, we drop the v subscript in the rest of the proof.

A.1. Preliminary expressions

We start by deriving some expressions for the *No-Adoption/No-Guilds Equilibrium* and for the deviating firm in the *No-Adoption/No-Guilds Equilibrium*. The profit expression (gross of fixed costs) of a firm in the *No-Adoption/No-Guilds Equilibrium* is[29]:

$$\bar{\Pi}^* = \left(p^* - \frac{w_m^*}{A_m}\right)Q^* = w_m^*\kappa, \tag{32}$$

where

$$w_m^* = \frac{A_a(1-\mu)\alpha}{\mu(1-\alpha)}. \tag{33}$$

The profit expression (gross of the fixed cost) of a firm that deviates from the *No-Adoption/No-Guilds Equilibrium* is:

$$\bar{\Pi}' = \left(p' - \frac{A_a}{A_m(1+\gamma)}\right)Q'. \tag{34}$$

The marginal cost of a firm in the *No-Adoption/No-Guilds Equilibrium* is

$$mc^* = \frac{w_m^*}{A_m} = \frac{A_a\alpha(1-\mu)}{A_m(1-\alpha)\mu}. \tag{35}$$

The marginal cost of a firm that deviates from the *No-Adoption/No-Guilds Equilibrium* is

$$mc' = \frac{A_a}{A_m(1+\gamma)}. \tag{36}$$

The marginal cost of a firm that deviates from the *No-Adoption/No-Guilds Equilibrium* relative to a firm that does not is

$$\delta = \frac{mc'}{mc} = \frac{(1-\alpha)\mu}{(1+\gamma)\alpha(1-\mu)}. \tag{37}$$

Since $\alpha > \mu$ and $\gamma > 0$, we know that $\delta < 1$. Moreover, for a given set of parameters δ is constant, and does not depend on N. The price of a firm in the *No-Adoption/No-Guilds Equilibrium* is

$$p^* = \frac{\varepsilon^*}{\varepsilon^* - 1}\frac{A_a\alpha(1-\mu)}{A_m(1-\alpha)\mu} \tag{38}$$

[29] Profits, net of fixed costs, are of course zero.

whereas the price of a firm that deviates from the *No-Adoption/No-Guilds Equilibrium* is

$$p' = \frac{\varepsilon'}{\varepsilon' - 1} \frac{A_a}{A_m(1+\gamma)}. \tag{39}$$

The price of a firm that deviates from the *No-Adoption/No-Guilds Equilibrium* relative to that of a firm that does not is

$$\frac{p'}{p^*} = \beta(N) = \frac{\varepsilon'}{\varepsilon' - 1} \frac{\varepsilon^* - 1}{\varepsilon^*} \delta. \tag{40}$$

Since the relative price depends on the elasticities, and the elasticities depend on N, it follows that β is a function of N. The general expression of elasticity is:

$$\varepsilon = \sigma - (\sigma - 1) \frac{p^{1-\sigma}}{\sum_{j=1}^{V} p_j^{1-\sigma}}, \tag{41}$$

where V is the number of firms. The elasticity of a firm that deviates from the *No-Adoption/No-Guilds Equilibrium* is then

$$\varepsilon' = \sigma - (\sigma - 1) \frac{p'^{(1-\sigma)}}{(V^* - 1)p^{*1-\sigma} + p'^{(1-\sigma)}}. \tag{42}$$

Step 1: For a given price drop, the proportional increase in profit margin of the deviating firm increases in *N*.

We compare two economies, economy 1 and economy 2, with populations N_1 and N_2 and $N_2 > N_1$, and therefore, $V_2^* > V_1^*$. For a given level of elasticity, Eq. (40) implies that the deviating firm lowers its price. However, this will make the elasticity change. From (42) it is easy to see that $\partial\varepsilon'/\partial p' > 0$. This, together with Eq. (40), then implies that

$$\frac{p'}{p^*} = \beta(N) > \delta. \tag{43}$$

In economy 1, denote $\beta = \beta_1$ and $p' = p'_1$. We now compare the relative drop in the profit margin of the deviating firm in economy 1 and economy 2 for a given relative price β_1. The profit margin of the deviating firm relative to the profit margin in the *No-Adoption/No-Guilds Equilibrium* is then:

$$\frac{\beta_1 p_i^* - \delta mc^*}{p_i^* - mc^*} \tag{44}$$

where p_i^* is the price in the *No-Adoption/No-Guilds Equilibrium*. The derivative of this expression with respect to p_i^* is negative. Given that $V_2^* > V_1^*$, we know that in the *No-Adoption/No-Guilds Equilibrium* $\varepsilon_2^* > \varepsilon_1^*$ and therefore $p_2^* < p_1^*$. This implies that the relative profit margin is greater in economy 2 than in economy 1. In other words,

$$p'_i - mc' = \zeta_i\left(p_i^* - mc^*\right) \tag{45}$$

where $\zeta_1 < \zeta_2$. Since $\beta_1 > \delta$, this implies that for a given price drop, the proportional increase in the profit margin is greater in economy 2 than in economy 1.

Step 2: For a given price drop, the proportional increase in quantities sold of the deviating firm increases in *N*.

To show that for a given price drop, the proportional increase in quantities sold of the deviating increases in N, it suffices to show that for any given relative price $\beta_1 \leqslant \beta' \leqslant 1$, the elasticity in economy 2 is greater than in economy 1. For a given β' we can re-write the elasticity expression of the deviating firm (42) in economy i as:

$$\varepsilon'_i = \sigma - (\sigma - 1) \frac{(\beta' p_i^*)^{1-\sigma}}{(V_i^* - 1)p_i^{*1-\sigma} + (\beta' p_i^*)^{1-\sigma}} = \sigma - (\sigma - 1) \frac{\beta'^{(1-\sigma)}}{(V_i^* - 1) + \beta'^{(1-\sigma)}}. \tag{46}$$

The derivative of ε'_i with respect to V_i^* is positive, so that for any given $\beta_1 \leqslant \beta' \leqslant 1$, the elasticity in economy 2 is always greater than in economy 1. Therefore, along the price path from p_i^* to $\beta_1 p_i^*$, the relative increase in Q is always greater in economy 2 than in economy 1.

Step 3: For a given price drop, the proportional increase in profits increases in *N*.

In Step 1 and Step 2, we took the optimal price decrease in economy 1, and showed that for that same price decrease, the proportional increase in the profit margin and the proportional increase in the quantity sold were both greater in economy 2 than in economy 1. Therefore, the proportional increase in profits is greater in economy 2 than in economy 1. If one were to compute the optimal price decrease in economy 2, this conclusion would hold *a fortiori*. All these results relate to the gross profits. Since in economy 1 and economy 2 the initial net profits in the *No-Adoption/No-Guilds Equilibrium* are zero, the initial gross profits must be equal in both economies. It therefore follows that if in economy 2 the gross profits increase more than in economy 1, the net profits from deviating will be higher in economy 2 than in economy 1.

Step 4: The two thresholds N_1 and N_2 are such that $N_2 > N_1$.

From the previous steps we know that Π' is increasing in N. The economy is in the *No-Adoption/No-Guilds Equilibrium* if $\Pi' < 0$; the economy is in the *No-Adoption/Guilds Equilibrium* if $\Omega > \Pi' > 0$; and at least one firm has an incentive to deviate from the *No-Adoption/Guilds Equilibrium* if $\Pi' > \Omega$. There will be two thresholds, N_1, where the economy switches from the *No-Adoption/No-Guilds Equilibrium* to the *No-Adoption/Guilds Equilibrium*, and N_2, where at least one firm has an incentive to deviate from the *No-Adoption/Guilds Equilibrium* and adopt the new technology. Since Π' is increasing in N, it follows that $N_2 > N_1$.

Step 5: There is a third threshold, N_3, above which the *Adoption/No-Guilds Equilibrium* exists.

Proving this requires us to go through Step 1–Step 4 for the case of deviation from the *Adoption/No-Guilds Equilibrium*.

A.2. Preliminary expressions

We start by writing down a number of expressions for the *Adoption/No-Guilds Equilibrium* and for the deviating firm in the *Adoption/No Guilds Equilibrium*. The profit expression (gross of fixed costs) of a firm in the *Adoption/No-Guilds Equilibrium* is:

$$\bar{\Pi}^{**} = \left(p^{**} - \frac{w_m^{**}}{A_m(1+\gamma)}\right)Q^{**} = w_m^{**}\kappa e^{\phi\gamma}, \tag{47}$$

where

$$w_m^{**} = w_a^{**} = A_a. \tag{48}$$

The profit expression (gross of the fixed cost) of a firm that deviates from the *Adoption/No Guilds Equilibrium* is:

$$\bar{\Pi}'' = \left(p'' - \frac{A_a}{A_m}\right)Q''. \tag{49}$$

The marginal cost of a firm in the *Adoption/No Guilds Equilibrium* is

$$mc^{**} = \frac{A_a}{A_m(1+\gamma)}. \tag{50}$$

The marginal cost of a firm that deviates from the *Adoption/No-Guilds Equilibrium* is

$$mc'' = \frac{A_a}{A_m}. \tag{51}$$

The marginal cost of a firm that deviates from the *Adoption/No-Guilds Equilibrium* relative to a firm that does not is

$$\frac{mc''}{mc} = 1+\gamma. \tag{52}$$

The price of a firm in the *Adoption/No-Guilds Equilibrium* is

$$p^{**} = \frac{\varepsilon^{**}}{\varepsilon^{**}-1}\frac{A_a}{A_m(1+\gamma)} \tag{53}$$

whereas the price of a firm that deviates from the *Adoption/No-Guilds Equilibrium* is

$$p'' = \frac{\varepsilon''}{\varepsilon''-1}\frac{A_a}{A_m}. \tag{54}$$

The price of a firm that deviates from the *Adoption/No-Guilds Equilibrium* relative to that of a firm that does not is

$$\frac{p''}{p^{**}} = \beta(N) = \frac{\varepsilon''}{\varepsilon''-1}\frac{\varepsilon^{**}-1}{\varepsilon^{**}}(1+\gamma). \tag{55}$$

Since the relative price depends on the elasticities, and the elasticities depend on N, it follows that β is a function of N. The elasticity of a firm that deviates from the *Adoption/No-Guilds Equilibrium* is then

$$\varepsilon'' = \sigma - (\sigma-1)\frac{p''^{(1-\sigma)}}{(V^{**}-1)p^{**1-\sigma} + p''^{(1-\sigma)}}. \tag{56}$$

Step 5.1: For a given price increase, the proportional drop in profit margin of the deviating firm increases in N. We compare two economies, economy 1 and economy 2, with populations N_1 and N_2 and $N_2 > N_1$, and therefore, $V_2^{**} > V_1^{**}$. For a given level of elasticity, Eq. (55) implies that the deviating firm increases the price. However, the elasticity will change. From (56) it is easy to see that $\partial\varepsilon''/\partial p'' > 0$. This, together with Eq. (55), then implies that

$$\frac{p''}{p^{**}} = \beta(N) < (1+\gamma). \tag{57}$$

In economy 2, denote $\beta = \beta_2$ and $p'' = p''_2$. We now compare the relative change in the profit margin of the deviating firm in economy 1 and economy 2 for a given relative price β_2. The profit margin of the deviating firm relative to the profit margin in the *Adoption/No-Guilds Equilibrium* is then:

$$\frac{\beta_2 p_i^{**} - (1+\gamma)mc^{**}}{p_i^{**} - mc**} \tag{58}$$

where p_i^{**} is the price in the *Adoption/No-Guilds Equilibrium*. The derivative of this expression with respect to p_i^{**} is positive. Given that $V_2^{**} > V_1^{**}$, we know that in the *Adoption/No-Guilds Equilibrium* $\varepsilon_2^{**} > \varepsilon_1^{**}$ and therefore $p_2^{**} < p_1^{**}$. This implies that the relative profit margin is smaller in economy 2 than in economy 1. In other words,

$$p''_i - mc'' = \zeta_i\big(p_i^{**} - mc^{**}\big) \tag{59}$$

where $\zeta_1 > \zeta_2$. Since $\beta_2 < (1+\gamma)$, this implies that for a given price increase, the proportional drop in the profit margin is greater in economy 2 than in economy 1.

Step 5.2: For a given price increase, the proportional drop in quantities sold of the deviating firm increases in N. To show that for a given price increase, the proportional drop in quantities sold of the deviating firm increases in N, it suffices to show that for any given relative price $\beta_2 \geqslant \beta' \geqslant 1$, the elasticity in economy 2 is greater than in economy 1. For a given β' we can re-write the elasticity expression of the deviating firm (56) in economy i as:

$$\varepsilon''_i = \sigma - (\sigma-1)\frac{(\beta'' p_i^{**})^{1-\sigma}}{(V_i^{**}-1)p_i^{**1-\sigma} + (\beta'' p_i^{**})^{1-\sigma}} = \sigma - (\sigma-1)\frac{\beta''^{(1-\sigma)}}{(V_i^{**}-1) + \beta''^{(1-\sigma)}}. \tag{60}$$

The derivative of ε''_i with respect to V_i^{**} is positive, so that for any given $\beta_1 \geqslant \beta' \geqslant 1$, the elasticity in economy 2 is always greater than in economy 1. Therefore, along the price path from p_i^{**} to $\beta_1 p_i^{**}$, the relative decrease in Q is always greater in economy 2 than in economy 1.

Step 5.3: For a given price increase, the decrease in profits increases in N. In Steps 5.1 and 5.2, we took the optimal price increase in economy 2, and showed that for that same price increase, the proportional decrease in the profit margin and the proportional decrease in the quantity sold were both greater in economy 2 than in economy 1. Therefore, the proportional decrease in gross profits is greater in economy 2 than in economy 1. If one were to compute the optimal price increase in economy 1, which would be lower, this conclusion would hold *a fortiori*. All these results relate to gross profits. Since in economy 1 and economy 2 the initial net profits in the *Adoption/No-Guilds Equilibrium* are zero, the initial gross profits must be equal in both economies. It therefore follows that if in economy 2 the gross profits drop more than in economy 1, the net profits from deviating will be lower in economy 2 than in economy 1.

Step 5.4: There exists a threshold, N_3, above which the Adoption/No-Guilds Equilibrium equilibrium exists. From the previous step, it follows that if population is large enough, the profits from a firm that deviates from the *Adoption/No-Guilds Equilibrium* and goes back to the old technology become negative. Denote that threshold N_3. Above N_3, we have the *Adoption/No-Guilds Equilibrium*. □

Appendix B. Data appendix

The data on guilds come from the *Corporazioni* database. It gives information on 1385 Italian guilds in 55 cities from 1300 to 1850. We use information on the guild's city, state, date of foundation and date of disappearance. In our empirical analysis we construct for each city-year an "alive" variable, which takes the value 1 when the city-year has a guild, and the value 0 when it does not. A guild is therefore "alive" between its birth year (date of foundation) and its death year (date of disappearance). One issue is what to do with guilds that have an unknown birth year and/or an unknown death year. We drop all guilds with an unknown birth year. As for guilds with an unknown death year, we distinguish between different cases. If the city has other guilds in the *Corporazioni* database with known death years, we use the average death year of the guilds with known death years as the death year of those with unknown death years. This is a reasonable strategy, since in most cities all guilds disappeared either in the same year or over the span of a few years. This is so because in the vast majority of cases guilds were abolished by law and these laws typically applied to all guilds. Of those guilds for which we know the reason of disappearance, less than 10% disbanded out of their own accord, and more than 90% were abolished by law. If the city has no other guilds in the *Corporazioni* database with known death years, we tried to collect information on the abolishment of guilds at the city-level. Whenever such information was available, we used that as the death year of all guilds in the city. Doing so allowed us to include death years for Como (1787), Lodi (1787), Pavia (1787), Ancona (1801), Ascoli Piceno (1801), Forli (1801), Viterbo (1801), Chioggia (1805), Vicenza (1805), Aversa (1821), Cava Dei Tirreni (1821), Catanzaro (1821), Catania (1822), Messina (1822), and Modica (1822).

The population of cities comes from *Italian Urban Population* 1300–1861 database of Malanima (2005). This database gives population data at 100-year intervals, except for 1861. For intermediate years we interpolate population levels, assuming constant annual growth rates between intervening years. For four cities, we have no information about the death years of any of the guilds, and for another six cities, we have no information about their populations. This leaves us with information on 45 cities, spanning the time period 1300–1850.

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