

Resistance to Technology Adoption: The Rise and Decline of Guilds*

Klaus Desmet
Universidad Carlos III

Stephen L. Parente
University of Illinois

May 2011

Abstract

This paper analyzes the decision of workers specialized in the current technology to form guilds and block the adoption of a more productive technology that does not require their specialized inputs. We show that there is an inverted-U relation between guilds and the size of the market. When markets are small, firms do not want to adopt the more productive technology as profits cannot cover the fixed R&D costs. Hence, workers have no need to form guilds. For intermediate size markets, firm profits are large enough to cover the fixed R&D costs, but not large enough to compensate the existing workers for lower earnings, and so workers form guilds and block adoption. For large markets, these profits become sufficiently large to either compensate workers for lower earnings or defeat any resistance put up by workers. Hence, guilds disband and the more productive technology diffuses throughout the economy. We verify that this inverted-U relation between guilds and market size exists in a data set on Italian guilds from the Middle Ages.

Keywords: technology adoption; resistance to technology; guilds; competition; market size; special interest groups.

1 Introduction

According to Joel Mokyr (2005), the factor that most clearly demarcates the Malthusian era of stagnant living standards from the modern growth era is the intensity of resistance to the introduction of new technologies and goods by subgroups of society. Prior to the 18th century, this resistance was widespread and fierce; after, however, it became isolated and weak. In Western Europe, the first region of the world to escape its Malthusian trap, guilds and various other trade associations provided most of this resistance. Starting in the Middle Ages, these groups successfully blocked the adoption of many new technologies and goods through both legal and illegal means up until the 18th century, when their influence began to wane. By the middle of the 19th century, these groups

*We thank Luca Mocarelli for kindly providing the data on Italian guilds, and George Deltas for useful comments and insights. We acknowledge the financial support of Fundación Ramón Areces, and the hospitality of VIVES while writing this paper. Desmet: Department of Economics, Universidad Carlos III. E-mail: klaus.desmet@uc3m.es; Parente: Department of Economics, University of Illinois at Urbana-Champaign. E-mail: parente@illinois.edu.

had all but disappeared, thereby eliminating a main impediment to technological change and the *Industrial Revolution*.

Why did the guilds and other trade associations end their resistance sometime in the 18th century and not earlier? The answer of Mokyr (2005) to this question is that guilds and other rent-seeking institutions in Europe declined because of what he calls the *Industrial Enlightenment*, namely, the realization by individuals such as Adam Smith and David Hume that technological change was not a zero sum game, but rather one which effectively expanded the size of the pie. These enlightened thinkers understood what should have been long known, and their influence in society opened the door to technological progress.

In this paper, we offer a different interpretation to the end of resistance and the demise of the guilds. Specifically, we argue that resistance before the 18th century and non-resistance after the 18th century were optimal responses by guilds in light of market conditions. When markets were small and competition was weak, as in the Middle Ages, guilds and other factor suppliers to the existing production processes had both the incentive and the ability to block these changes. As they stood to experience reduced earnings, they had a clear incentive to resist the introduction of new technologies or goods. But they also had the ability to do so because the would-be adopting firms did not have sufficient resources to counter the guilds' legal and illegal challenges. However, with the gradual expansion of markets and the intensification of competition through time, these conditions were eventually reversed. Guilds lost their incentive and ability to resist. As resistance was no longer an optimal response, guilds disbanded, their main *raison d'être* gone.

Why would market size and the intensity of competition affect the incentive and ability of guilds to resist process innovation? 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. With a greater number of goods, competition toughens, the price elasticity of demand increases, and mark-ups are reduced, meaning that all firms must sell more output to cover any fixed operating cost. Larger firm size is the key to ending guild resistance, as it implies larger profits from process innovation because a firm can spread any fixed costs of technology adoption over a greater quantity of output. As profits of an innovating firm are increasing in market size, an adopting firm is more easily able to overcome any resistance. It can do so by using these profits to either compensate the original factor suppliers for lost earnings, thereby reducing the incentives of guilds to resist, or by spending resources to counter legal and illegal challenges employed by these factor suppliers, thereby weakening their ability to successfully block the introduction of new technology. Thus,

in our theory a guild only exists if profits from innovating are positive but insufficient to either compensate factor suppliers specialized in the old production processes or to break resistance.

The implication of our theory is an inverted-U relation between guilds and market size. When markets are small, and hence competition is weak, firms have no desire to innovate as profits are negative, and hence workers have no incentive to organize into guilds. For intermediate sized markets, process innovation is profitable, but not sufficiently so to compensate current workers for lost earnings or to defeat their resistance. Hence, guilds appear and block process innovation. For large markets, profits from innovation are sufficiently large to compensate current workers or break their resistance. Consequently, guilds disband and more productive technology diffuses throughout the economy.

Our paper clearly relates to a 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 Krusell and Rios-Rull (1996), Parente and Prescott (1999), Parente and Zhao (2006) and Dinopoulos and Syropoulos (2007). These other papers rely on 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) emphasize the cost of introducing new goods. Only Parente and Prescott (1999) note the importance of the price elasticity of demand for the break-up of groups. They do not, however, provide a mechanism whereby market size or any other factor affects its value.

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 historic role of guilds and their demise. Section 3 describes the basic structure of the model. Section 4 analyzes how the decisions of a single firm and its workers to deviate from an equilibrium where no industry in the economy adopts the more productive technology are affected by market size. Section 5 provides a formal test of our theory by examining whether there exists an inverted-U relationship between market size and guilds using an Italian dataset of guild formations and deaths spanning a 500 year period. Section 6 concludes the paper.

2 Literature Review

In this section, we review some of the literature on guilds with the purpose of motivating our theory. Specifically, 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 mar-

kets 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 guilds. Smith 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 production processes.

Instances where guilds inhibited development by resisting the introduction of new goods and new production processes 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 and incentives of guilds to dictate which technologies could be used and how they could be used.² 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 reduc-

¹Wolcott (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.

²Of course, another way of dealing with increased competition is 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 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).

ing 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 Binfield (2004), for another, shows that the most famous example of worker resistance, the Luddite riots between 1811 and 1817, was a response to changes in openness. The mill workers associated with the Luddites were only anti-technology after the British government cut off trade with France via the *Prince Regent's Order in Council of 1811* in response to the Napoleonic War. Following the removal of this order in 1817, this resistance and violence ended.⁴

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 Stable (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.

Recently, the view that guilds lowered society's welfare by inhibiting economic development has been challenged by a number of authors, particularly Hicks and Thompson (1991) and Epstein (1998). They argue that guilds provided solutions to market failures associated with asymmetric information, externalities and free riding. Moreover, they suggest that guilds were flexible institutions, tending to resist the introduction of labor-saving innovation in times of economic downturns,

³In 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).

⁴Wage concessions, abatement in food prices and military force were also contributing factors to ending the Luddite resistance according to Binfield (2004).

but not in times of economic booms, leading Epstein (1998) to refer to them as *recession cartels*. With respect to the first argument, Ogilvie (2004) provides compelling evidence that information asymmetries and externalities were not important problems in the Middle Ages. With respect to guilds being recession cartels, this is exactly what our theory predicts: 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 experience reduced earnings and firms are far better able to challenge any resistance.⁵

Additionally, the argument that expanding markets led to the demise of guilds is not without its detractors. Two criticisms have been voiced against this hypothesis. First, most guilds did not disband out of their own accord but were abolished through laws and decrees, and second, in the medieval period guilds tended to be concentrated in the most densely populated areas (Mocarelli, 2008). With respect to this first criticism, we point out that decrees outlawing guilds would not have had much meaning unless guilds were sufficiently weakened. With respect to the second criticism, we point out that this is not inconsistent since our theory 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. We do this in the simplest structure possible. More specifically, we consider a static economy comprised of three sectors: a household sector, an agricultural sector and an industrial sector. The household sector is comprised of rural households and urban households. The agricultural sector is competitive and produces a homogenous good according to a constant returns to scale technology using 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 labor as its only input. Each differentiated good is produced by one firm. Each firm can be thought of as a separate industry. Free entry into the industrial sector determines the number of

⁵It is true that our model does not consider cyclical phenomena. Nor is there any flexibility in our model: guilds either exist and resist technology adoption, or they disband. Even if guilds were flexible enough, there is no doubt that expanding markets and greater competition left them in a weakened position in terms of restricting market access by allowing urban guilds to hire rural workers, and that eventually, the competition from rural areas and non-guilded cities led to the demise of guilds, which all but disappeared by the early 19th century. This sequence of events is largely consistent with our theory. Although we could give guilds a broader role in the model by introducing an intermediate state of having more flexible (or weakened) guilds, we refrain from doing so as to keep our main point as straightforward as possible.

differentiated products in the economy.

To begin, we study the model economy when there is no opportunity to adopt a more productive technology by industrial firms. We postpone technology adoption to the next section for several reasons. First, there is a fundamental issue of how the number of industries and firms in the economy are determined, especially as it relates to increases in the size of the market. Related, there is the issue of how a particular group of workers specialized in the current production process, who constitute the potential guild, come to be. These issues are clearer if we start with a version of the model where there is a single technology available to produce the differentiated goods, and hence no technology adoption decision.

We now proceed to describe each of the three sectors in detail, and the relevant maximization problems of their respective agents. Additionally, we define a symmetric equilibrium without guilds.

3.1 Household Sector

Endowments. The economy consists of measure N households, of which fraction μ are urban households and fraction $1 - \mu$ are rural households. These fractions are parameters of the model. We use the subscript $j \in \{U, R\}$ to denote a household type. The measure of each type of household is denoted by $N_U = \mu N$ and $N_R = (1 - \mu)N$, respectively. Each household is endowed with one unit of time, which it spends working. The urban households are the only ones with the necessary skills to work with the current technology in the industrial sector. On account of this assumption, the two household types will have different incomes and hence different consumption allocations.

Preferences. Preferences of each type of household are identical, being defined over a homogeneous good, associated with agriculture, and a differentiated set of goods, associated with industry. Within the industrial goods, households have CES preferences over a finite number of products V . 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 $j \in \{R, U\}$ is then

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

where α is the share of income spent on industrial goods, and σ is the elasticity of substitution between any two varieties of industrial goods. We assume that $\sigma > 1$ and that $\alpha > \mu$. (The latter assumption guarantees that the urban wage will be higher than the rural wage in the case that industrial firms use the original technology.)

In contrast to the standard Spence-Dixit-Stiglitz preferences with a continuum of varieties, and thus a constant price elasticity of demand, the finiteness of the number of goods in the preferences we use implies 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. 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.

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 (2001).⁶ Whereas any of these alternative constructs could easily be used to demonstrate our theory, we use the one of Yang and Heijdra (1993) for the sole reason that it allows for straightforward algebraic results.⁷

Utility Maximization. Denote household income by I_j , with $j \in \{R, U\}$. Let p_v denote the price of industrial variety $v \in V$ in units of the agricultural good. Then the budget constraint faced by a household of type j is:

$$I_j \geq c_{ja} + \sum_{v \in V} p_v c_{jv}. \quad (2)$$

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:

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

and

$$c_{j\hat{v}} = \frac{\alpha I_j p_{\hat{v}}^{-\sigma}}{\sum_{v \in V} p_v^{1-\sigma}}. \quad (4)$$

Aggregate demand for the agricultural good is thus

$$C_a = (1 - \alpha)(I_R N_R + I_U N_U) \quad (5)$$

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

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

and aggregate demand for each differentiated good is

$$C_{\hat{v}} = \frac{\alpha(I_R N_R + I_U N_U) p_{\hat{v}}^{-\sigma}}{\sum_{v=1}^V p_v^{1-\sigma}}. \quad (6)$$

3.2 Agricultural Sector

Technology. The farm sector is perfectly competitive. Farms produce a single, non-storable consumption good that serves as the economy's numéraire. The farm technology is constant returns to scale, and uses labor. Urban and rural workers are equally productive in the farm technology. 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

$$Q_a = A_a L_a \quad (7)$$

where $A_a > 1$.

Profit Maximization. Since the agricultural price is set as numéraire, the profit maximization problem of farms yields

$$w_a = A_a \quad (8)$$

where w_a is the agricultural wage rate.

3.3 Industrial Sector

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

$$Q_v = A[L_v - \kappa]. \quad (9)$$

Profit Maximization. On account of the fixed operating cost, κ , each variety is produced by a single firm, who is a monopolist. Since the different goods (say, cotton, wool, silk, etc.) can be thought of as different industries, we can interpret firms as industries.⁸ Each firm chooses the

⁸Alternatively, 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.).

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 \hat{v} , denoted by $\Pi_{\hat{v}}$, can be written as

$$\Pi_{\hat{v}} = p_{\hat{v}} C_{\hat{v}} - w_m \left[\kappa + \frac{C_{\hat{v}}}{A} \right], \quad (10)$$

where w_m denotes the industrial wage rate and $C_{\hat{v}}$ is aggregate demand given by (6). The profit-maximizing price is a mark-up over the marginal unit cost $1/A$. Namely,

$$p_{\hat{v}} = \frac{w_m}{A} \frac{\varepsilon_{\hat{v}}}{\varepsilon_{\hat{v}} - 1}, \quad (11)$$

where $\varepsilon_{\hat{v}}$ is the price elasticity of demand for variety \hat{v} ,

$$\varepsilon_{\hat{v}} = - \frac{\partial C_{\hat{v}}}{\partial p_{\hat{v}}} \frac{p_{\hat{v}}}{C_{\hat{v}}}.$$

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 \hat{v} , (6), it is easy to show that the price elasticity of demand is:

$$\varepsilon_{\hat{v}} = - \frac{\partial C_{\hat{v}}}{\partial p_{\hat{v}}} \frac{p_{\hat{v}}}{C_{\hat{v}}} = \sigma - (\sigma - 1) \frac{p_{\hat{v}}^{1-\sigma}}{\sum_{v=1}^V p_v^{1-\sigma}}. \quad (12)$$

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

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

Thus, the price elasticity of demand in a symmetric equilibrium is increasing in the number of varieties, V .

3.4 Symmetric Equilibrium

We now define the symmetric Nash equilibrium for this economy. We refer to this equilibrium as the *Free Market Symmetric Nash Equilibrium (FMSE)*. In the *FMSE*, each type of household maximizes utility; agricultural firms maximize profits; and industrial firms maximize profits. Free entry into the industrial sector ensures that industrial firms earn zero profits in equilibrium. Finally, the goods markets and labor markets must clear. As the industrial technology only uses urban labor,

there are two separate labor markets. Provided that $\alpha > \mu$ and $A_a > 1$, we have $w_m > w_a$ in equilibrium, so that the two labor market clearing conditions are:⁹

$$VL_v = N_U. \quad (14)$$

$$L_a = N_R. \quad (15)$$

The zero profit condition in the industrial sector is

$$p_v Q_v - w_m \left[\kappa + \frac{Q_v}{A} \right] = 0. \quad (16)$$

This condition determines the number of varieties in the symmetric equilibrium. To see this, note that (16), together with the expression for the price, (11), implies that

$$Q_v = (\varepsilon_v - 1) \kappa A. \quad (17)$$

From equation (17) and the production function it follows that

$$L_v = \kappa \varepsilon_v \quad (18)$$

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

$$V = \frac{N_u}{\kappa \varepsilon_v}. \quad (19)$$

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

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

Equation (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 *Free Market Symmetric Nash Equilibrium (FMSE)*

⁹To see how $\alpha > \mu$ is sufficient to guarantee that $w_m > w_a$, suppose that all urban households work in industry. Since there are no profits, the income of rural and urban households are, respectively, $I_R = w_a$ and $I_U = w_v$. Together with expressions (5), and (6), this implies that $w_m = (A_a(1 - \mu)\alpha)/(\mu(1 - \alpha))$. The assumption $\alpha > \mu$, together with $A_a > 1$, implies that $w_m > 1$, which is consistent with all urban households working in industry.

Definition of the Free Market Symmetric Nash Equilibrium (FMSE). For a given population N with a share μ of urban households and a share $1 - \mu$ of rural households, a symmetric equilibrium 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 $\{w_a^*, w_v^*, V^*\}$, that satisfy

(i) utility maximization conditions given by (5) and (6).

(ii) firm profit maximization conditions given by (11), (7), (8), (12), (17), (18), (19).

(iii) market clearing conditions

(a) goods market: $C_a^* = Q_a^*$ and $C_v^* = Q_v^*$.

(b) labor market:

$$V^* L_v^* = N_U \quad (21)$$

$$L_a^* = N_R \quad (22)$$

(iv) zero profit condition of industrial firms given by (16).

4 Technology Adoption and Guilds

We now introduce the possibility of industrial firms adopting a more productive technology. Specifically, we consider the choice of a single firm to incur a fixed R&D cost in order to lower its marginal cost assuming that no other industries upgrade their technology. Thus, we are analyzing the incentive of a single industry to deviate from the *Free Market Symmetric Equilibrium*. Besides being more productive, the new technology has the advantage that it requires no specialized labor inputs to operate. This is in contrast to a firm's original technology, that only uses the labor input of urban households. Thus, an additional advantage of switching to the more productive technology is that an adopting firm can hire rural households at a lower wage rate. In deciding whether to upgrade, a firm trades off a higher fixed cost with a lower marginal cost.¹⁰

Adoption could lead to negative or positive profits. If the adopting firm makes negative profits, the firm would obviously never want to switch to the more productive technology. If the

¹⁰The classification of households between urban and rural as well as the classification of goods between agriculture and industry is arbitrary. We could have equally classified workers as skilled versus unskilled, or as insiders versus outsiders.

adopting firm makes positive profits, we assume that the firm's original workers, i.e., those urban household who are employed by the firm in the *Free Market Symmetric Equilibrium*, have a right to all of the profits. Thus, an adopting firm affects the incentives of its workers to form a guild and block the more productive technology. If the profits from adoption are sufficient to compensate the original workers for lost earnings, there will be no incentive to create a guild, but if they are insufficient, a guild will form to prevent the use of the more productive technology. Compensating workers for a drop in income is akin to a severance payment, a common occurrence today in both rich and poor countries.

Alternatively, we could have assumed that profits are used by the firm to counter the legal and illegal methods guilds employed to block the adoption of new technologies. For example, the profits could pay for legal fees incurred in courts; for security forces to prevent sabotage and pickets; and even for military force, as was used in conjunction with wage concessions and some abatement in food prices to end the Luddite riots.¹¹ Although feasible, we do not model this use of profits for two reasons. First, doing so would complicate the model, adding another layer that specifies the worker technology for resisting and the firm technology for countering this resistance. Second, the extra layer would not change any of the results and intuition: to the extent that firm profits can be used to challenge the attempts of guilds to block technology adoption, greater profits imply a greater challenge by firms, and thus a smaller chance for guilds to be successful.

4.1 Superior Technology

We assume that at some point a new technology is unexpectedly discovered. The new technology is superior to the old in that it has a higher marginal productivity but it also has a higher fixed cost. In particular, the marginal product of the new technology is $(1 + \gamma)$ times greater than the old technology level, A , and requires a fixed cost in labor equal to $\kappa e^{\phi\gamma}$. This higher fixed cost reflects the R&D cost associated with adoption. Remember that the old technology can only employ urban households, as implicitly they are the only ones that have the necessary skills for this technology. In contrast, the more productive technology is not specialized in this sense and so can employ both rural and urban households at the same productivity level. This applies to both production workers and overhead workers for the fixed cost. The output of a firm producing variety v using the more productive technology is then

$$Q_v = A(1 + \gamma)[L_v - \kappa e^{\phi\gamma}]. \tag{23}$$

¹¹In the latter case, the profits would be taxed by the government, which would then provide the troops.

4.2 Profits of a Deviating Firm that Adopts

We now analyze the decision of a firm producing variety v to deviate from the symmetric equilibrium $FMSE$ and adopt the new technology. We use a prime to denote the choices of this deviating firm. A firm that deviates increases its marginal productivity and can hire cheaper workers (because in the symmetric equilibrium $w_m^* > w_a^*$), but it also increases its fixed cost in terms of workers. An industrial firm has an incentive to adopt if by doing so it realizes positive profits. In other words, a firm will deviate if $\Pi'_v > 0$ where Π'_v equals

$$\begin{aligned} \arg \max_{p'_v} & \quad \{p'_v Q'_v - w_a^* [\frac{Q'_v}{A(1+\gamma)} + \kappa e^{\phi\gamma}]\} \\ \text{s.t.} & \quad Q'_v = \frac{\alpha(w_a^* N_R + w_m^* N_U)(p'_v)^{-\sigma}}{(V^* - 1)(p_v^*)^{1-\sigma} + (p'_v)^{1-\sigma}} \end{aligned}$$

where the deviating firm takes aggregate income in the economy, $w_a^* N_R + w_m^* N_U$, as given. The profit maximizing price is a mark-up over the marginal cost, namely,

$$p'_v = \frac{w_a^*}{A(1+\gamma)} \frac{\varepsilon'}{\varepsilon' - 1}, \quad (24)$$

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

$$\varepsilon' = \sigma - (\sigma - 1) \frac{(p'_v)^{1-\sigma}}{(V^* - 1)(p_v^*)^{1-\sigma} + (p'_v)^{1-\sigma}}, \quad (25)$$

The above expression suggests that profits of a deviating firm will be larger in larger markets. A higher level of population leads to a greater price elasticity of demand, and thus to larger firms that can more easily bear the fixed cost of technology adoption. 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.

4.3 Guilds

We empower a firm's original set of workers, L_v^* , to form a guild. The sole purpose of a guild is to block the adoption of the more productive technology. Two conditions must therefore hold for guilds to exist. First, an individual industry must have an incentive to deviate from $FMSE$ and adopt the new technology, i.e., $\Pi'_v > 0$. If not, there would be nothing for the guild to block. Second, the profits generated by the technology are not sufficient to compensate the original workers

from earnings losses, i.e., $\pi'_v + w_a^* < w_m^*$, where $\pi'_v = \Pi'_v/L_v^*$. If not, workers would be better off with adoption, and would thus have no reason to form a guild. 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.¹² To keep things as simple as possible, constituting a guild is costless.

4.4 Guilds and Population Size

We now explore how the existence of guilds relates to the size of the market, which in our model is equivalent to the size of the population. In particular, we examine how the decision of an industry to deviate and adopt the new technology changes with the economy's population, and associated with this, whether guilds form and block the use of the more productive technology. In increasing the measure of households in the economy, we keep the share of urban households, μ , constant.¹³ 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 less productive technology is used; for intermediate-sized populations, guilds exist and block the use of the more productive technology; and for sufficiently large populations, guilds cease to exist and the more productive 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 deviating 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, $\Pi'_v < 0$, no firm wants to deviate, and there is no need for the original workers to form a guild to resist technology adoption. When the population reaches an intermediate size, firm size is large enough to make positive profits, i.e., $\Pi'_v > 0$. However, these positive profits are not enough to keep the original workers from experiencing a reduction in earnings, namely, $\pi'_v + w_a^* < w_m^*$. Consequently, the original workers will create a guild to block technology adoption. When the population reaches a large enough size, the profits of the deviating firm will be both positive and large enough to

¹²If 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.

¹³Alternatively, keeping the population constant while increasing the share of urban 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 its 1340 level, the fraction living in urban areas was significantly higher.

maintain the jobs and wages of the original workers. That is, $\pi'_v + w_a^* > w_m^*$. At this point there is no longer a need to resist technology adoption, and the guild disappears. Hence, when population size is small or large, there is no guild, whereas if the population size is intermediate there is a guild.

With this intuition in hand, we proceed to establish these results analytically. This is done in two steps. First, we show that profits per original skilled worker of a deviating firm is increasing in N . Second, we use this result to show that there is an inverted-U relation between population size and guild existence.

Proposition 1 *Profits per original skilled worker by a deviating firm are increasing in N .*

Proof See Appendix A.1.

Proposition 2. *There is an inverted U-relationship between population size and the existence of guilds.*

Proof See Appendix A.2.

4.5 Adoption Decision when All Other Industries Have Adopted

In the previous section we considered the incentive of a single industry to deviate from an equilibrium with no adoption. An alternative would be to analyze the incentive for a firm to switch to the new technology when all other firms have already done so. Indeed, in some historical examples, such as the introduction of the gig mill in the West of England, the decision of the guild to end its resistance and to disband only came after the technology became widely used in another region of the country (Randall, 1991).

It is easy to study this case by defining a symmetric equilibrium with adoption, and analyzing the incentive of an individual firm to deviate and return to the less productive technology. If a firm's workers become better off by deviating, then we would say that an industry has no incentive to adopt the more productive technology, even if all other industries have. Although solving this problem has to be done numerically, and goes beyond the presentation of this paper, we find qualitatively the same results:¹⁴ only if markets are large enough is the no-deviation condition satisfied,

¹⁴Results for this case are available upon request.

meaning that no firm has an incentive to go back to the less productive technology. This implies that in large enough markets, an individual firm will want to adopt the more productive technology if all other firms already have. The intuition for this result is the same as before: in larger markets returning to the old technology is less beneficial because the drop in the fixed cost matters less (because firms are larger) and the reduction in sales due to the price increase is greater (because of the higher price elasticity of demand).

5 Empirical Analysis: The Case of Italian Guilds

We now proceed to examine the plausibility of our theory by analyzing a dataset on Italian guilds. In our model guilds only appear if technology adoption benefits the firm, in the sense of generating positive profits, but hurts the original workers, in the sense of lowering wage earnings. The implication of our theory is that 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 workers with skills specialized in the initial technology can be sufficiently compensated, or defeated by their industry if they try to resist. 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.¹⁵

To test this prediction of our theory, we analyze the relation between guild existence and city sizes in Italy. The analysis makes use of two data sources. The first is the *Corporazioni* database, compiled by a large group of Italian researchers, that covers 1385 Italian guilds in 55 cities from the 14th to the 19th century. The *Corporazioni* database contains an impressive amount of information including the guild's city, state, sector, date of foundation, and date of disappearance.¹⁶ It does not include the city size, however, and for this reason we combine this database with information on city sizes from the *Italian Urban Population 1300-1861* database of Malanima (2005).

Before turning to the empirical analysis, there are a couple of issues worth mentioning. First, we take the city population as the relevant market for a city guild. This assumption is clearly more

¹⁵Of course, as mentioned before, in reality guilds did more than just resisting 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.

¹⁶The database is part of the project *Istituzioni corporative, gruppi professionali e forme associative del lavoro nell'Italia moderna e contemporanea*.

appropriate for non-tradeable than for tradeable goods. In the case of tradeable goods, a city might not have a guild in a given sector due to regional specialization. Thus, the more disaggregated the sectors are, the more likely it is that not all cities have guilds in all sectors. Second, a city also may not have a guild on account of costs to forming and maintaining a guild. In as far as these costs are primarily fixed, larger cities are more likely to see guild formation. In analyzing the rise of guilds, this factor will bias the results in our favor (bigger cities would tend to get guilds earlier), but in analyzing the disappearance of guilds, this would bias the results against us (bigger cities would be able to maintain guilds longer). Despite these possibilities, fixed costs do not seem too much of an issue, as there are several examples of cities with a population of just 5,000 that have guilds.¹⁷

1400			1400		
Lowest Quintile	Population (000s)	Guild Existence	Highest Quintile	Population (000s)	Guild Existence
Chioggia	5	YES	Milano	100	YES
Asti	5	NO	Venezia	85	YES
Aversa	6	NO	Genova	50	YES
Siracusa	6	NO	Firenze	37	YES
Como	6	NO	Bologna	35	YES
Catania	6	NO	Cremona	30	YES
Viterbo	6	NO	Brescia	30	YES
Cagliari	6	NO	Roma	30	NO
Pisa	7	YES	Napoli	30	NO
Udine	7	YES	Perugia	20	YES
1850			1850		
Lowest Quintile	Population (000s)	Guild Existence	Highest Quintile	Population (000s)	Guild Existence
AscoliPiceno	11.2	YES	Napoli	399.1	NO
Como	12.5	YES	Roma	181.1	NO
L'Aquila	13	NO	Milano	180.5	NO
Viterbo	14.6	YES	Palermo	161.5	NO
Perugia	15.2	YES	Torino	148.8	NO
Aversa	15.6	YES	Venezia	117.5	NO
Catanzaro	16	YES	Genova	116.5	NO
Faenza	16.6	NO	Firenze	107.2	NO
Siracusa	16.8	NO	Bologna	85.6	NO
Lodi	17.6	YES	Catania	60.8	YES

Table 1: Ranking of Cities and Guilds in 1400 and 1850

To begin, we compare the prevalence of guilds in the year 1400 (a time period when many guilds were being born) and in the year 1850 (a time period when many guilds were dying). In

¹⁷The minimum population threshold in the dataset is 5,000.

both years, we divide cities into quintiles by population size and then determine for each quintile the fraction of those cities that had a guild. The results are shown in Table 1. In 1400, only 30 percent of cities in the lowest quintile had guilds whereas 90 percent of cities in the highest quintile had guilds. In 1850, this pattern is reversed; 70 percent of the cities in the lowest quintile had guilds whereas only 10 percent of the cities in the highest quintile had guilds.

This change in the fraction of cities with guilds in the top and the bottom quintiles mainly reflects the fact that all cities grew in size in the centuries that separate 1400 and 1850. The small cities of 1850, therefore, were similar in size to the medium-sized cities of 1400, whereas the large cities of 1850 were much larger than those of 1400. This explains why the average size of cities with guilds did not change that much between 1400 and 1850. In 1400 the average size of cities with guilds was 18,360 whereas in 1850 it was 22,300. What changed instead is the difference in average size of cities without guilds; in 1400 the average size of cities without guilds was 8,600, whereas in 1850 it was 45,010. Taken both years together, the smallest cities (i.e., the small ones of 1400) and the largest cities (i.e., the large ones in 1850) had no guilds, whereas the intermediate sized cities (i.e., the large ones in 1400 and the small ones in 1850) did. These results suggest an inverted-U relation between city size and the existence of guilds.

Dependent Variable: Having a Guild							
	(1)	(2)	(3)	(4)	(5)	(6) drop if city if never guild	(7) drop if population < 10000
Log(Pop)	0.773 [31.07]***	4.205 [38.86]***	5.363 [40.91]***	3.481 [26.94]***	4.335 [27.21]***	5.209 [38.30]***	6.112 [28.11]***
Log(Pop)²		-0.524 [33.49]***	-0.666 [35.76]***	-0.412 [22.02]***	-0.508 [22.13]***	-0.655 [33.89]***	-0.766 [26.44]***
Constant	-1.294 [18.53]***	-6.503 [37.28]***	-8.663 [40.76]***	-4.456 [17.88]***	-5.919 [19.66]***	-8.374 [37.70]***	-9.851 [25.11]***
Half Century Effects	NO	NO	YES	NO	YES	YES	YES
State Effects	NO	NO	NO	YES	YES	NO	NO
Pseudo R²	0.0522	0.0869	0.2795	0.1597	0.3829	0.2851	0.2705
Observations	26987	26987	26987	26987	26987	25857	21833
Robust z statistics in brackets							
* significant at 10%; ** significant at 5%; *** significant at 1%							

Table 2: Benchmark Analysis

To explore the suggestive relation of Table 1 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 1864. Table 2 reports the results from the logit estimation. Column (1) reports the results for the full sample when only the log of city size is used as a regressor. Standard errors are reported in brackets. Column (1) shows that larger

cities were 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 our theory, the linear term continues to be positive whereas the quadratic term is negative. Using the results from Column (2) we can calculate the predicted probability of having at least one guild as a function of city-size. This is shown in Figure 1 by the solid curve. For comparison, we also plot in Figure 1 the share of cities of a given population size in the pooled data that had at least one guild. These points are indicated by triangles in the Figure.¹⁸ The inverted-U relation is readily apparent.

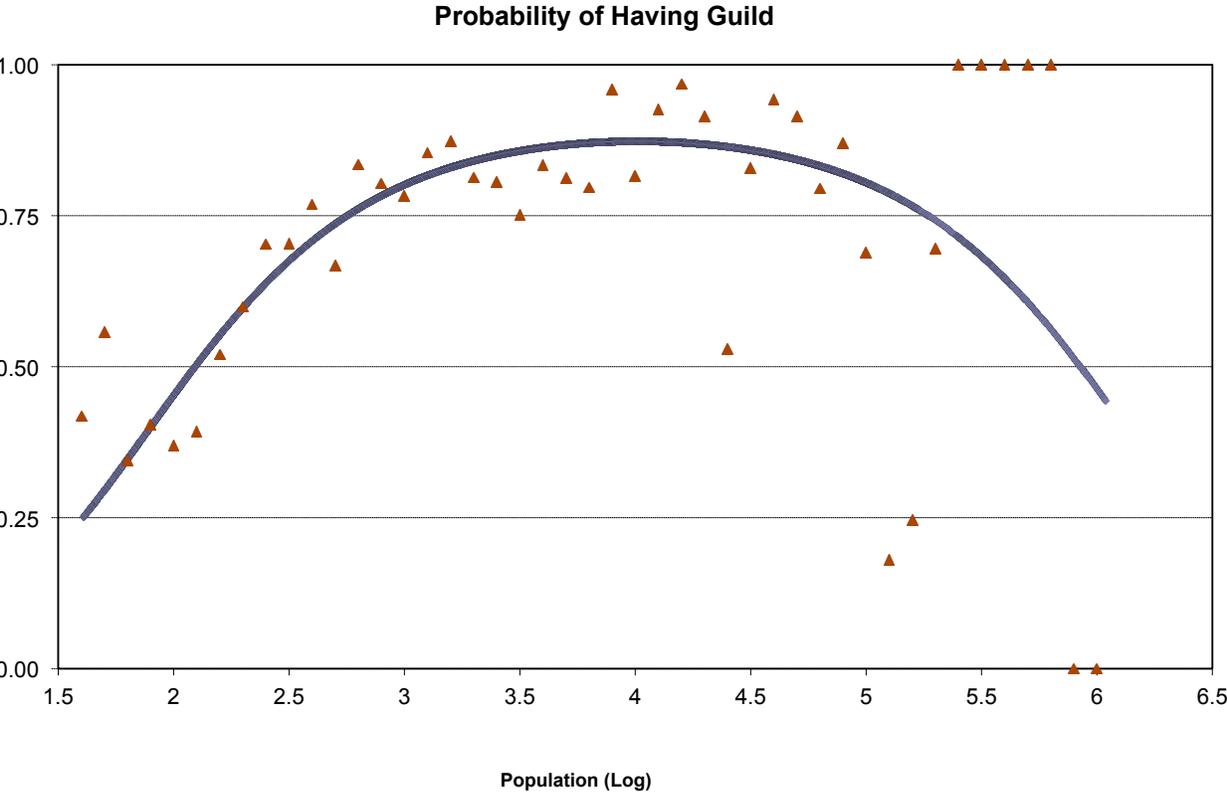


Figure 1: Probability of Having a Guild

How robust is this inverted-U relationship? To investigate the sensitivity of our results, we add 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. The results, which are reported in Columns (3)-(5), are not much changed by the inclusions.

¹⁸The seven most-rightward triangles, that go from 1 to 0, correspond to Naples. Dropping Naples from the regression does not change the qualitative result of an inverted-U relations.

One limitation of the *Corporazioni* database is that some cities have guilds for which no birth date is recorded. In the regressions whose results are reported in columns (1)-(5), we treated any guild without a birth date as being non-existent. As a robustness check, we rerun our preferred specification, but leave out cities for which we have no information on birth dates. The results, reported in column (6), hardly change. Thus, this limitation of our data set does not seem to be generating our results.

Another issue, mentioned before, is that our results may be biased because some of the very small cities may not have guilds, not because of the reasons in our theory, but because of the existence of setup costs. To see if set-up costs are possibly affecting the results, we rerun the regression excluding any city with a population of 10,000 or less. The results, which are shown in column (7), remain unchanged. From this, we conclude that set-up costs were not an important factor in explaining the birth and death of guilds.

Dependent Variable: Having a Guild				
	(1)	(2)	(3)	(4)
	all sectors	all sectors with guilds > 20 cities	tradeable sectors with guilds > 20 cities	nontradeable sectors with guilds > 20 cities
Log(Pop)	2.139 [65.84]***	3.223 [86.98]***	3.146 [69.47]***	3.287 [47.87]***
Log(Pop)^2	-0.154 [33.65]***	-0.319 [61.07]***	-0.308 [47.74]***	-0.326 [34.10]***
Constant	-0.527 [16.56]***	-7.721 [119.25]***	-8.173 [93.28]***	-8.6 [70.02]***
Half century dummies	YES	YES	YES	YES
Sectoral dummies	YES	YES	YES	YES
Pseudo R^2	0.2769	0.2346	0.2328	0.2146
Observations	512753	323844	188909	107948
Robust z statistics in brackets				
* significant at 10%; ** significant at 5%; *** significant at 1%				

Table 3: Sectoral Analysis

As a last check, we repeat the analysis but exploit the sectoral information reported in the database. Our model assumes that all differentiated goods are identical with respect to elasticity and cost of process innovation. In reality, both are likely to differ across sectors or industries. For this reason we examine whether our results are sensitive to sectoral differences. To do this, we exploit the sectoral information in the database that distinguishes 19 sectors. The logit results are reported in Table 3. As the unit of observation in these regressions is a city-year-sector rather than a city-year as in Table 2, the number of observations used in these regressions is far larger. Column (1) reports the logit results for the full sample. Consistent with the theory, the linear term

is positive and the quadratic term is negative, with both being statistically significant at the 1 percent level. Since some sectors have guilds only in a limited number of cities, column (2) reruns the same specification, but only for those sectors that at some point have guilds in at least 20 cities. The results are unchanged. Columns (3) and (4) report the results when sectors are divided into tradeable and non-tradeable sectors.¹⁹ As can be seen in columns (3) and (4), splitting the sectors into tradeable and nontradeable sectors makes little difference to the results. We conclude from this analysis that the regional specialization is not driving our results in an important way.

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 reduce workers' earnings. In our model guilds only appear if technology adoption benefits the firm, in the sense of generating positive profits, but hurts the original workers, in the sense of lowering wage earnings. The implication of our theory is that 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 workers with skills specialized in the original technology can be sufficiently compensated so as to not suffer a reduction in earnings, or 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 1400 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

¹⁹It is not entirely clear which criterion should be used to do so. Clearly, many goods that we would consider tradeable today may not have been so in the Middle Ages. The nontradeable sectors are taken to be personal services, construction, retail and restaurants, whereas tradeable sectors are taken to be clothing, food, metals, wood, leather and textile.

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 on the historical role of technology-blocking institutions, the pre-1700 era of stagnant living standards, and the post-1700 era of rising living standards.

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Appendix A: Proofs of Propositions

A.1: Proof of Proposition 1

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

Preliminary expressions We start by writing down a number of expressions for FMSE and for the deviating firm in FMSE. The profit expression (gross of fixed costs) of a firm under FMSE is:

$$\bar{\Pi}^* = (p^* - \frac{w_m^*}{A})Q^* = w_m^* \kappa \quad (26)$$

where

$$w_m^* = \frac{A_a(1-\mu)\alpha}{\mu(1-\alpha)} \quad (27)$$

The profit expression (gross of the fixed cost) of a firm that deviates from FMSE is:

$$\bar{\Pi}' = (p' - \frac{A_a}{A(1+\gamma)})Q' \quad (28)$$

The marginal cost of a firm in FMSE is

$$mc^* = \frac{w_m^*}{A} = \frac{A_a\alpha(1-\mu)}{A(1-\alpha)\mu} \quad (29)$$

The marginal cost of a firm that deviates from FMSE is

$$mc' = \frac{A_a}{A(1+\gamma)} \quad (30)$$

The marginal cost of a firm that deviates from FMSE relative to a firm that does not is

$$\delta = \frac{mc'}{mc} = \frac{(1-\alpha)\mu}{(1+\gamma)\alpha(1-\mu)} \quad (31)$$

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 FMSE is

$$p^* = \frac{\varepsilon^*}{\varepsilon^* - 1} \frac{A_a\alpha(1-\mu)}{A(1-\alpha)\mu} \quad (32)$$

whereas the price of a firm that deviates from FMSE is

$$p' = \frac{\varepsilon'}{\varepsilon' - 1} \frac{A_a}{A(1+\gamma)} \quad (33)$$

The price of a firm that deviates from FMSE relative to that of a firm that does not is

$$\frac{p'}{p^*} = \beta(N) = \frac{\varepsilon'}{\varepsilon' - 1} \frac{\varepsilon^* - 1}{\varepsilon^*} \delta \quad (34)$$

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:

$$\varepsilon = \sigma - (\sigma - 1) \frac{p^{1-\sigma}}{\sum_{j=1}^V p_j^{1-\sigma}} \quad (35)$$

where V is the number of firms. The elasticity of a firm that deviates from FMSE is then

$$\varepsilon' = \sigma - (\sigma - 1) \frac{p'^{(1-\sigma)}}{(V^* - 1)p^{*1-\sigma} + p'^{(1-\sigma)}} \quad (36)$$

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, equation (34) implies that the deviating firm lowers the price. However, this will make the elasticity change. From (36) it is easy to see that $\partial\varepsilon'/\partial p' > 0$. This, together with equation (34), then implies that

$$\frac{p'}{p^*} = \beta(N) > \delta \quad (37)$$

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 under FMSE is then:

$$\frac{\beta_1 p_i^* - \delta mc^*}{p_i^* - mc^*} \quad (38)$$

where p_i^* is the price under FMSE. The derivative of this expression with respect to p_i^* is negative. Given that $V_2^* > V_1^*$, we know that under FMSE $\varepsilon_2^* > \varepsilon_1^*$ 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,

$$p'_i - mc' = \zeta_i(p_i^* - mc^*) \quad (39)$$

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 $\beta_1 \leq \beta' \leq 1$, 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 (36) in economy i as:

$$\varepsilon'_i = \sigma - (\sigma - 1) \frac{(\beta' p_i^*)^{1-\sigma}}{(V_i^* - 1)p_i^{*1-\sigma} + (\beta' p_i^*)^{1-\sigma}} = \sigma - (\sigma - 1) \frac{\beta'^{(1-\sigma)}}{(V_i^* - 1) + \beta'^{(1-\sigma)}} \quad (40)$$

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

Step 4: The proportional increase in profits in economy 2 (relative to economy 1)

is greater than the ratio $\varepsilon_2^*/\varepsilon_1^*$. If a given proportional price drop would not change the elasticities, then the proportional increase in the quantity sold by the deviating firm in economy 2 relative to that by the deviating firm in economy 1 would be $\varepsilon_2^*/\varepsilon_1^*$, the ratio of the elasticities under FMSE. However, for a given relative price drop β' , the ratio $\varepsilon'_2/\varepsilon'_1$ can be written as

$$\frac{\varepsilon'_2}{\varepsilon'_1} = \frac{\sigma(V_2^* - 1)(V_1^* - 1) + (\sigma(V_2^* - 1) + (V_1^* - 1))\beta'^{(1-\sigma)} + \beta'^{(2-2\sigma)}}{\sigma(V_1^* - 1)(V_2^* - 1) + (\sigma(V_1^* - 1) + (V_2^* - 1))\beta'^{(1-\sigma)} + \beta'^{(2-2\sigma)}} \quad (41)$$

The derivative of this expression with respect to β is negative if $(V_2^* - 1)(V_1^* - 1)\sigma > \beta^{-2(\sigma-1)}$.²⁰ (If the number of firms is not too small and/or if the price drop is not huge, this condition holds). Supposing the condition holds for this derivative to be negative, it implies that $\varepsilon'_2/\varepsilon'_1 > \varepsilon_2^*/\varepsilon_1^*$ for any $\beta_1 \leq \beta' \leq 1$. This implies that the proportional increase in the quantity sold by the deviating firm in economy 2 relative to that by the deviating firm in economy 1 will be greater than $\varepsilon_2^*/\varepsilon_1^*$. Given that, in addition, the proportional increase in the profit margin in economy 2 is greater than in economy 1, then it must be that the proportional increase in profits is higher in economy 2 than in economy 1.

²⁰Given this condition, the formal statement of Proposition 1 should read: Consider two economies with $N_2 > N_1$ and their corresponding FMSEs. If $(V_2^* - 1)(V_1^* - 1)\sigma > \beta^{-2(\sigma-1)}$ then profits per original worker of the deviating firm in economy 2 are greater than profits per original worker of the deviating firm in economy 1.

Step 5: Profits per original worker of the deviating firm is greater in economy 2 than in economy 1. Under FMSE the number of workers per firm is $\kappa\varepsilon_i^*$. This, together with equation (26), implies that profits (gross of fixed costs) per worker under FMSE is:

$$\bar{\pi}_i^* = \frac{w_m^*}{\varepsilon_i^*} \quad (42)$$

where lower case $\bar{\pi}^*$ refers to profits gross of fixed costs per worker (whereas upper case $\bar{\Pi}^*$ refers to profits gross of fixed costs). In Step 4 we have shown that for a given proportional price decrease, the proportional increase in profits in economy 2 vs the proportional increase in profits in economy 1 is greater than $\varepsilon_2^*/\varepsilon_1^*$. Therefore

$$\frac{\bar{\Pi}'_2/\bar{\Pi}_2^*}{\bar{\Pi}'_1/\bar{\Pi}_1^*} = \frac{\bar{\Pi}'_2/\kappa w_m}{\bar{\Pi}'_1/\kappa w_m} = \frac{\bar{\Pi}'_2}{\bar{\Pi}'_1} > \frac{\varepsilon_2^*}{\varepsilon_1^*} \quad (43)$$

Therefore relative profits per worker of the deviating firm in economy 2 vs in economy 1 is

$$\frac{\bar{p}'_2}{\bar{\pi}'_1} = \frac{\bar{\Pi}'_2/\kappa\varepsilon_2}{\bar{\Pi}'_1/\kappa\varepsilon_1} = \frac{\bar{\Pi}'_2/\varepsilon_2}{\bar{\Pi}'_1/\varepsilon_1} \quad (44)$$

Since $\bar{\Pi}'_2/\bar{\Pi}'_1 > \varepsilon_2^*/\varepsilon_1^*$, it follows that

$$\frac{\bar{p}'_2}{\bar{\pi}'_1} > 1 \quad (45)$$

These are relative profits of the deviating firm per original worker gross of fixed costs. The profit expression of the deviating firm per original worker net of fixed cost is

$$\pi'_i = \bar{\pi}'_i - \frac{A_a e^{\phi\gamma}}{\varepsilon_i^*} \quad (46)$$

Given that $\pi'_2 > \pi'_1$ and that $\varepsilon_2^* > \varepsilon_1^*$, it follows that

$$\pi'_2 > \pi'_1 \quad (47)$$

□

A.2: Proof of Proposition 2

Using the notation from the Proof of Proposition 1, recall that $\Pi = \bar{\Pi} - A_a \kappa e^{\phi\gamma}$. From the Proof of Proposition 1 it follows that both Π' and π' are increasing in N , and that $\Pi' > \pi'$. The economy does not have a guild when either (i) $\Pi' < 0$ or (ii) $\Pi' > 0$ and $\pi' + A_a > (A_a(1-\mu)\alpha)/(\mu(1-\alpha))$. The economy has a guild when (iii) $\Pi' > 0$ and $\pi' + A_a < (A_a(1-\mu)\alpha)/(\mu(1-\alpha))$. From Proposition 1 it follows that to go from (i) to (iii) N must increase, and to go from (iii) to (ii) N must further increase. This implies an inverted-U shaped relation between N and guild existence. □