Spatial Competition, Innovation and Institutions: The Industrial Revolution and the Great Divergence*

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Abstract

This paper advances a theory in which the intensity of inter-city competition determines both the incentives of firms to adopt labor-saving technologies and the incentives of specialized workers to resist them. By providing historical evidence of the relation between spatial competition, guild resistance and innovation in England and China, it argues that the theory is plausible for understanding the timing of industrialization in both countries. Using data on inter-city competition, it shows that the theory calibrated to England in the pre-1600 era is consistent with an end of guild resistance and a start of industrialization in England by the beginning of the nineteenth century. The calibrated model also correctly predicts economic stagnation in China through the early twentieth century. The theory can therefore account for both the *Industrial Revolution* and the *Great Divergence*.

1 Introduction

Why did some countries industrialize earlier others? In particular, why was England the first country to attain sustained increases in per capita income and why did its take-off occur at the end of the eighteenth century? These questions have long occupied the efforts of both economic historians and growth theorists. One common answer emphasizes the growth in market size in the period leading up to the *Industrial Revolution*.[1] Although reasonable when comparing England to other countries in Europe, this answer becomes problematic when we bring China into the picture. Markets, whether measured in terms of total population, urban population or average city size, were much larger in China than in England. For this reason, many researchers reject a theory of the *Industrial Revolution* based on market size.

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[1] See, for example, Kremer (1993), Kelly (1997), Peretto (1998), and Desmet and Parente (2012).

This paper does not dismiss the idea that market size might have been important for the *Industrial Revolution*, but it argues that it only mattered to the extent that it affected the degree of spatial competition, which crucially depends on the prevalence of inter-city trade. The starting point of this paper is a largely overlooked fact in the literature: in the centuries leading up to the *Industrial Revolution* England experienced a dramatic increase in spatial competition. Between 1600 and 1800, the average distance of a city in England to its closest neighbor dropped from more than 60 km to less than 20 km. Over the same time period, the average city's access to population in other cities located in a 20 km radius increased from less than 1,000 to more than 70,000. In contrast, inter-city competition in China was much lower in the corresponding period and exhibited much smaller increases. At the beginning of the nineteenth century, the average city's access to population in other cities located in a 20 km radius in China was more than an order of magnitude smaller than in England.

To advance the hypothesis that the increase in inter-city competition might be key to understanding why England was the first nation to industrialize, this paper develops a theory where the degree of spatial competition affects both the incentives of firms to introduce more productive technology and the incentives of specialized factors of production to block this technology. The theory is illustrated in a simple spatial model consisting of two cities or regions, each with a continuum of monopolistically competitive industrial sectors and a perfectly competitive agricultural hinterland. For each industrial good, there are two production technologies: an artisanal technology and a modern technology. The modern technology has two important advantages relative to the artisanal one. First, it does not need skilled workers to operate, and second, output per production worker is greater. Initially, all firms use the artisanal technology, but each can choose to switch to the modern technology if it pays the fixed innovation cost. Additionally, firms must have the resources to overcome the potential resistance by skilled workers in their industry and city, who faced with the prospect of reduced earnings, have the ability to form a special interest group for the purpose of blocking the modern technology. At the risk of slightly abusing terminology, we refer to such a special interest group as a craft guild.[2]

We use this structure to examine how the degree of spatial competition affects when craft guilds form to block the introduction of the modern technology and when they give up their

[2]As we will discuss later, the role of craft guilds was not limited to dictating production processes.

resistance. The critical feature of our model is a preference construct in which the price elasticity of demand for each industrial good increases when inter-city competition intensifies. With the increased elasticity, mark-ups drop and firms become larger to break even (Helpman and Krugman, 1985; Hummels and Lugovskyy, 2009). This makes it more attractive for a single firm in a given city and industry to switch to the modern technology, because its larger size allows it to spread the fixed cost of innovation over a greater quantity of output. Distance between cities matters importantly for the profitability of innovation since the adopter in one city can capture market share at the expense of the neighboring city.

The model predicts three stages in an economy's development as the degree of spatial competition intensifies. Starting off in a situation where inter-city competition is weak, either because neighboring cities are small, transport costs are large, or distances between cities are great, no firm can pay the fixed innovation cost, making the modern technology unprofitable to use. In this case the equilibrium is characterized by all firms in all industries and cities using the artisanal technology and no technology-blocking guilds anywhere. As inter-city competition strengthens, a city-size threshold is reached where an individual firm in a given city and industry becomes large enough for its profits to cover the fixed innovation cost. In spite of this, the firm is not able to adopt the modern technology because the firm's skilled workers, faced with a loss in earnings, block its introduction. The firm's profits are too small to overcome workers' resistance, either by compensating them directly for reduced earnings or by defeating them through the judicial or political system. In this case, the equilibrium is characterized by all firms using the artisanal technology and guilds existing in all industries and cities. It is only when inter-city competition becomes sufficiently strong that profits from innovation are large enough to defeat guild resistance. At that point guilds disband, resistance to technological change ceases, firms innovate and the economy takes off.

A key result of the model is that an increase in market size *per se* is insufficient for the modern technology to be adopted. Rather, what matters is the interplay of city size and inter-city transport costs. To be more precise, in the absence of inter-city trade, an industry in a given city that introduces the modern technology is unable to increase its market share as it cannot gain customers at the expense of the other city, and therefore, will never have large enough profits to overcome guild resistance, regardless of how large its own city is. As an illustration, compare an economy with a single city of size x to another with two cities, each of size $x/2$. In the presence of prohibitely large inter-city transport costs, effective market size is larger in the first economy than in the second, yet the theory predicts innovation can only occur in the second economy. Critical for this result is the assumption that technology-blocking institutions are organized at the city-industry level. As such, the effective monopoly power of a craft guild is greater in the first economy than in the second. In our theory inter-city competition is thus at the basis of resistance to innovation breaking down and the economy taking off.

We assess the plausibility of our theory in a number of ways. First, we provide a historical account of the relation between guilds, spatial competition and innovation in England. We start by showing that the degree of spatial competition affected the intensity of resistance by guilds. We then provide empirical evidence suggesting that locations in England that were subject to stronger inter-city competition innovated more at the beginning of the *Industrial Revolution*. Second, we undertake a calibration exercise to examine if the theory is quantitatively consistent with England's development. More specifically, we use data on city sizes and inter-city distances between 1400 and 1600 to calibrate the model to the date when English guilds started blocking the introduction of labor-saving technologies. We then use the calibrated model to determine the date when resistance should have ended and the English economy should have taken off, given the data on city sizes and distances between cities from 1600 to 1850. We find that the model predicts well the timing of the *Industrial Revolution*.

To further assess its plausibility, we apply our theory to the *Great Divergence* between China and England. Until the eighteenth century, China was on par with England in terms of standard of living, but thereafter their paths diverged dramatically. To examine if differences in spatial competition could have contributed to the *Great Divergence*, we examine the predictions of our calibrated model for resistance to labor-saving technology in China. To that purpose, we solve the equilibria of our calibrated model using Chinese data on city sizes and inter-city distances between 1700 and 1900. Importantly, we show that the model predicts that technology-blocking guilds in China should have survived well into the twentieth century, thus generating a *Great Divergence* between the West and the East. To complete the application of our theory to China's development, we also provide historical evidence that shows how the emergence of European-style professional guilds in China coincided with the introduction of new labor-saving technologies from the West.

The literature that seeks to understand why the *Industrial Revolution* first happened in England is extensive. Diverse explanations abound, some of which are: proximity to a cheap energy source (Pomeranz, 2000), greater patience and stronger preferences for education (Galor and Moav 2002; Clark 2007), and institutions that better protect property rights (North, 1981; Mokyr, 1990).[3] Some of this literature, which includes Voigtländer and Voth (2006), Shiue and Keller (2007) and Desmet and Parente (2012), offers an explanation based on market integration. However, in these papers there is no suggestion that the degree of spatial competition and the geographic distribution of economic activity are critical. In particular, an increase in population or a decrease in trade costs have the same impact on innovation. That is not the case in our theory: an increase in market size in the absence of trade is never enough for resistance to end and take-off to occur.

This paper is related to at least two other strands in the literature. One strand is the literature on the importance of competition for innovation. Empirical evidence in favor of the positive effect of competition includes Nickell (1996), Galdón-Sánchez and Schmitz (2002) and Aghion et al. (2005). There are also a large number of theoretical papers that describe mechanisms whereby stronger competition leads to more innovation. Of particular note is the paper by Desmet and Parente (2010), which uses the Hotelling-Lancaster construct to show how an increase in market size leads to stronger competition between varieties. Although we borrow their basic setup, there are some key differences, the most important one being the endogenous formation of guilds that can block the introduction of more productive technology.

Another strand is the literature on technology-blocking institutions. The importance of resistance to the introduction of more productive technology by special interests in the context of the *Industrial Revolution* is a prominent theme in the work of Morison (1966) and Mokyr (1990). Important theoretical papers in this area include Krusell and Rios-Rull (1996), Parente and Prescott (1999) and Dinopoulos and Syropoulos (2007). The two most closely related papers are Holmes and Schmitz (1995) and Desmet and Parente (2014). In Holmes and Schmitz (1995), although trade is likewise shown to eliminate resistance, there is no role for market size and the theory remains silent on how an economy escapes an equilibrium where both regions block innovation. In Desmet and Parente (2014) workers form guilds or unions to block the introduction of a better production process until they can be bought off. However, that paper takes market size to be city size, thus ignoring spatial competition and geography.

[3]For a comprehensive list, see McCloskey (2007).

The rest of the paper is organized as follows. Section 2 provides historical and empirical evidence from England on the relation between spatial competition, guild resistance and innovation. Section 3 presents the model and analyzes the theoretical interaction between the spatial distribution of cities, the incentives for firms to innovate, and the incentives for guilds to resist. Section 4 applies the theory to the *Industrial Revolution*. Section 5 applies the theory to the *Great Divergence*. Section 6 concludes.

2 Spatial Competition, Guilds and Innovation in England

In this section we provide evidence that spatial competition was important to England's historical development, as it affected both the intensity of innovation and the resistance by craftsmen, threatened by new labor-saving technologies. We start by documenting the increase in spatial competition in England between 1400 and 1850 and by describing the history of the craft guilds. Using these measures and further historical evidence, we make the case that innovation and guild resistance depended importantly on the degree of spatial competition.

2.1 The Evolution of Spatial Competition

The main claim of this paper is that the increase in spatial competition was instrumental to England's take-off and industrial development. In this subsection we document the change in inter-city competition from the pre-modern period to the *Industrial Revolution* in England. To measure inter-city competition over time, we use historical data on city populations from Bairoch et al. (1988). The data set contains information on all cities that reached a population of at least 5,000 at some point between 800 and 1850. We restrict our analysis to the data covering the following years: 1400, 1600, 1700, 1750, 1800 and 1850.

Before turning to the construction of different measures of the degree of spatial competition, we report average city size over time. As can be seen in Panel A of Table 1, average city size did not change much between 1600 and 1800, hovering around 20,000. Only in the nineteenth century did city size start increasing dramatically, and by 1850 it had more than doubled. Although informative, average city size does not capture the degree of spatial competition that characterized the English economic landscape in this period, for the simple reason that it ignores the distance to other cities.

Table 1: Spatial Competition in England

Year	1400	1600	1700	1750	1800	1850
A. Average City Size (thousands)						
	11.2	19.1	25.1	28.0	21.2	50.8
B. Population access $\leq$ 20 km (S_1, thousands)						
	0.0	0.0	1.3	5.2	73.8	190.6
C. Population access, spatial decay $\gamma = 1.5$ (S_2, thousands)						
	0.0	0.2	0.6	0.8	4.1	11.6
D. Distance to reach same number of consumers (S_3, km)						
	93	70	44	44	21	21

Measures of Spatial Competition. When measuring the degree of spatial competition faced by a city, we aim to capture the ease by which an industry of that city can sell to customers of *other* cities. In that sense, we interpret spatial competition as inter-city competition, rather than as intra-city competition. As we will see later, this is the type of measure that will matter in our theory. Since there is no single accepted measure of inter-city competition, we construct three different indices. We start by introducing some notation. Denote by $\mathcal{R}$ the set of cities, with $r \in \mathcal{R}$ referring to a particular city, and denote by $\delta^{rr'}$ the distance between cities r and r'. Additionally, let L^r be the population size of city r.

The first measure of the spatial competition faced by city r is the total population of other cities located within a radius δ. This simple measure, which we denote by S_1^r, is defined as

$$S_1^r = \sum_{r' \in \mathcal{R}, r' \neq r, \delta^{rr'} < \delta} L^{r'}. \tag{1}$$

Since our theoretical results will depend on the capacity of selling to customers of other cities, we exclude the city's own population in (1). In light of the era we study, we set δ to 20 km, based on the idea that a 40 km roundtrip was close to the upper limit of travel in a single day. As can be seen in Panel B of Table 1, between 1700 and 1800 there was a dramatic increase in S_1^r, from around 1,000 to 74,000. This increase in the access to consumers outside the own city continued in the nineteenth century, with S_1^r reaching 191,000 in 1850.

An alternative way of measuring spatial competition is to use a distance-weighted measure of the access to consumers in other cities. As such, the second measure of the spatial competition faced by city r, referred to as S_2^r, is defined as

$$S_2^r = \sum_{r' \in \mathcal{R}, r' \neq r} L^r (\delta^{rr'})^{-\gamma}, \tag{2}$$

where $\gamma \geq 0$. The higher the value of γ, the smaller the weight given to distant populations. We find 1.5 to be a reasonable value for γ in pre-twentieth century England.[4] Panel C reports our estimates of S_2^r. Although the increase in inter-city competition associated with this measure is less stark compared to S_1^r, it is still large. In the eighteenth century alone, S_2^r experienced a seven-fold increase.

The last measure of spatial competition is the average distance for a city to reach a population equivalent to its own size. Of the three measures, this is the one that will directly come out of our theory to predict when guilds should end their resistance to labor-saving technologies. As such, it is also the measure of spatial competition that we will use in the calibration exercise. In constructing this measure, for each city r, define a vector of which the elements L_i^r represent the populations of all other cities, ordered by their distances to r. That is, L_1^r is the population of the closest city to r, L_2^r is the population of the second-closest city to r, and so on. Likewise, for each city r, define a second vector of which the elements δ_i^r represent the distances to the other cities, again ordered from the closest city to the most far away city. With these two vectors, we then can define

$$\begin{aligned} S_3^r &= \sum_{i=1}^{\bar{\iota}} \delta_i^r L_i^r / \sum_{i=1}^{\bar{\iota}} L_i^r \\ & \quad \text{where } \bar{\iota} = \text{argmin} \sum_{i=1}^{\bar{\iota}} L_i^r \\ & \quad \text{s.t. } \sum_{i=1}^{\bar{\iota}} L_i^r \geq L^r \\ & \quad \quad L_{\bar{\iota}}^r = L^r - \sum_{i=1}^{\bar{\iota}-1} L_i^r. \end{aligned} \tag{3}$$

As can be seen in Panel D of Table 1, this measure of inter-city competition also shows an important increase over time: in 1700, the average distance for a city to reach a population equivalent to its own size was 44 km; by 1800, this distance had dropped by more than half, to 21 km.

[4]Using data for many countries, Jacks et al. (2011) find a value of 1.2 for the time period 1870-1913. Given the dearth of historical evidence, an alternative strategy is to use present-day evidence from developing countries as a proxy. Daumal and Zignago (2010) estimate an elasticity of 1.9 for Brazil. As a midpoint between these two estimates, we use $\gamma = 1.5$.

Taken together, all three measures exhibit an increase in spatial competition in the era leading up to the *Industrial Revolution*. In contrast to the average city size, which only started to increase in the nineteenth century, this intensification of inter-city competition was well under way in the pre-industrial period. Though the *Industrial Revolution* may of course have further strengthened spatial competition, this timing suggests that the initial increase in inter-city competition was not caused by industrialization. In addition, the reported rise in spatial competition during the eighteenth century in Table 1 likely constitutes a lower bound because it ignores the decline in transport costs that came about with the major expansion of turnpikes and canals during that same time period (Szostak, 1991; Bogart, 2005).

2.2 The Rise and Decline of Guilds and their Attitude towards Innovation

In this subsection we describe the history of guilds in England, focusing on their rise, their decline and their attitude towards innovation. We aim to make the point that craft guilds, though originally not created as organizations bent on resisting innovation, over time turned against the introduction of more productive technologies, especially when labor-saving in nature.

Rise and decline of guilds. Guilds emerged in Europe in the Medieval period in response to the institutional vacuum that prevailed between the ninth and eleventh centuries, with states being unable to provide local public goods in a satisfactory manner. To fill this void, European society created different types of organizations, or corporations in the medieval sense of the term, such as guilds, communes, city-states, monasteries and military orders. In the words of Greif (2006), a guild (gild, Hansa, company, livery, or mystery) was an "intentionally created, voluntary, interest-based, and self-governed permanent association". The emergence of guilds and other types of corporations was also a manifestation of the broader social and political process through which European society became increasingly organized around local or professional interests, rather than around state or kinship interests.

There were two main types of guilds: merchant guilds, which had rights over some form of exchange (e.g., retail, wholesale, export, staples, etc.), and craft guilds, which had regulatory rights over some craft or product (e.g., tanning, dying, wool, cloth, etc.). Merchant guilds started losing power as early as the fourteenth century, and were largely irrelevant by the end of the fifteenth century (Seligman, 1887), well before the advent of the many labor-saving technologies that fueled the *Industrial Revolution.* In contrast, craft guilds became more numerous in the fourteenth century as local authorities increasingly delegated regulatory powers to them. Craft guilds were more common in large cities than in small towns (De Munck et al. 2006; Desmet and Parente, 2014). Membership tended to be widespread. For example, according to Gadd and Wallis (2002), perhaps as many as three-quarters of the male population in London in the mid-sixteenth century belonged to a guild.

Having such a large representation in the urban centers, guilds were an important part of the European urban landscape up until the early nineteenth century, when their influence began to wane (Gadd and Wallis, 2002; Britnell, 2008). Officially, guilds were not outlawed in England until the *Municipal Corporations Act of 1835*, which stated that "every person in any borough may keep any shop for the sale of all lawful wares and merchandises by wholesale or retail, and use every lawful trade, occupation...".[5] But before 1835, many guilds had already started to disband of their own accord (Epstein, 2008; Gadd and Wallis, 2002). In that sense, it is more appropriate to treat their decline as an endogenous response to a changing economic landscape. More to the point, it is unlikely that the government would have been able to abolish the guilds in 1835 had they not already been weakened in the preceding decades.

Attitude towards innovation. Although initially craft guilds functioned primarily as social institutions providing mutual support, by the seventeenth century they were in a process of transformation. According to Hibbert (1891, p. 103), "The old Gilds [sic], which had lived through the shocks of the Reformation, and the Elizabethan changes, had quite altered their character. The new ones which had arisen differed widely from the old fraternities. Instead of being brotherhoods of craftsmen desirous of advancing the public weal, they were now mere societies of capitalists, intent only on private and personal advantage... There is a constant endeavor to restrict the companies to favored individuals. Every 'foreigner' is subjected to a heavy fine, which grows larger in amount as the companies feel the trade slipping from their hands in spite of their desperate endeavors to restrict it." It is this transformation that Adam Smith (1774) emphasized in the *Wealth of Nations* when he described the craft guilds as rent-seeking organizations that limited entry through

[5]Gross (1890), p. 165.

an excessively lengthy seven-year apprenticeship system.[6]

This is not to say that the apprenticeship system, as enshrined in the *Statute of Artificers of 1563*, did not have its virtues. As emphasized by Epstein (1998), it played an important role in the training and transmission of human capital, which was key to upholding the quality of locally produced goods. Although initially this had a positive effect on productivity, over time the apprenticeship system acted as a brake on progress for the simple reason that its stipulations, intended to ensure the quality of a product, ended up curtailing experimentation and innovation (Mokyr, 1998). That is, the apprenticeship system was good at transmitting existing knowledge but not at creating new knowledge. This technological inertia was exacerbated by the barriers to entry imposed on craftsmen who were trained elsewhere, as this entry ban limited the spatial diffusion of knowledge.

Of course, technology was not completely stagnant under the guild system. As Epstein (1998) documents, the craft guilds were not opposed to all types of technological advances. Innovation aimed at saving capital or enhancing skills was generally not frowned upon. It was a different matter with labor-saving technologies, however. An analysis of patents and legal cases during the late sixteenth and early seventeenth century in England reveals great concern about the impact of patents and innovations on employment (Dent, 2007). In particular, he noted that "the legal decisions of the period confirm that the maximization of employment was a priority of the elites. As a result of the legal writings of the time, Letwin [1954] has argued that there was, at the time, a 'common law right to work predicated on an economic system that would protect the established trades from competition, whether from foreign workmen, improperly qualified English workmen [or] overly aggressive guilds'." Riots were common following attempts to introduce technologies that threatened jobs. Attempts to block the adoption of labor-saving technologies became increasingly frequent in the seventeenth, and especially in the eighteenth and early nineteenth, century. In England, these culminated in the Luddite riots of 1811 to 1816.

The increase in resistance by craft guilds in the period leading up to the *Industrial Revolution* is consistent with the patent records that show a rise in the fraction of discoveries that were labor-saving in nature. Analyzing British patents from 1662 to 1800, MacLeod (1998, p. 160)

[6]This same negative perception is echoed by Pirenne (1936, p. 185-186) who argued that the main aim of the craft guilds was to "protect the artisan, not just from external competition, but also from the competition of his fellow-members".

summarizes the beliefs patentees held about the impact their invention would have. Over this time period he finds a significant increase in the fraction of patents intended to reduce the labor requirements for production. More specifically, of the 505 patent applications from 1662 to 1750 for which patentees stated the expected impact, only 2% declared that the invention would save labor, whereas 45% claimed the invention would be labor-augmenting, 37% claimed it would be capital-saving, and 11% believed it would increase government revenue. For the last fifty years of the study, the number of labor-saving responses increased fourfold, representing 8% of the total. Many of these patents were at the heart of worker resistance.

Although there is some disagreement over the general attitude of guilds towards technology,[7] the above discussion suggests that there is a broad consensus on a number of points. First, although craft guilds were initially not created as anti-competitive organizations set on resisting technological change, they increasingly took on that role in the later stages of their existence. In the words of Mokyr (1997, p. 31), "most authorities are in agreement that eventually much of the guild system was overtaken by technologically reactionary forces which instead of protecting innovators threatened them". Second, although there was a certain amount of innovation that occurred within the guild structure, it was not of the labor-saving type. Lastly, but not surprisingly, when in the seventeenth and eighteenth centuries workers were faced with the threat of reduced earnings following the introduction of labor-saving technology, the craft guilds did their best to prevent this, often through riots and violence.

2.3 Spatial Competition and Innovation

How did the intensity of spatial competition factor into guild resistance and innovation? This question is fundamental to the theory put forth in this paper. In this subsection we aim to establish two facts. First, greater spatial competition was accompanied by less effective resistance by guilds. Second, more intense spatial competition was associated with more innovative activity. Of course, the second fact is not unrelated to the first: if attempts to block labor-saving technology declined, the capacity to innovate was bound to improve.

Several case studies suggest a causal link between greater spatial competition and less effective resistance. For example, 't Hart (1993) and Mokyr (1998) describe how in 1604 the city

[7] The positivists claim that guilds fostered the diffusion of knowledge (Hickson and Thompson, 1991; Epstein, 1998, 2008; Richardson, 2004), whereas the negativists argue that guilds blocked technological progress (Ogilvie, 2008).

government of Leiden in the Netherlands refused to support the craft guilds' pleas to ban a newly invented ribbon loom because it worried the industry would move to the nearby city of Delft, 20 km away. In the same vein, Ogilvie (2004) gives the example of Lille, a town in Northern France, where the textile industry relaxed guild regulations in the late seventeenth century because of greater competition from rural weavers.

Likewise in England, if one location did not adopt a new technology, often the neighboring location would. In tracing the shearers' attempt to block the introduction of the gig mill in the West of England, Randall (1991) argues that the end of resistance coincided with its use in other parts of the country. If guilds could have controlled multiple cities, things might have turned out differently. But craft guilds were local, and their authority did typically not extend beyond the own city. In England, their monopoly power was further reduced by the growth of new townships such as Birmingham and Manchester in previously rural areas. Such towns were free from guild regulations and became attractive locations for industrialization. According to Hibbert (1891, p. 129), "Most of the new industries did not come under the Apprenticeship Act [Statute of Artificers], and were consequently free and unshackled. Such formidable rivals drew away trade from the old privileged boroughs. The companies were quite unable to retain their monopolies."

The importance of spatial competition for effective resistance is also apparent in several episodes where the inter-city competition was international in nature. Randall (1991), for example, shows that resistance to the scribbling machine in the West of England textile industry ended in 1795 following a trade boom.[8] Binfield (2004) argues that the Luddite riots were a response to changes in trade 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.[9]

If resistance to new technologies broke down when spatial competition became strong enough, we should see more innovative activity in areas where such competition was more intense. To provide evidence of this, we examine whether English counties that were subject to greater inter-city competition were also more likely to adopt new technologies at the beginning of

[8]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).

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

the *Industrial Revolution*. To measure the degree of spatial competition, we use S_1^r, i.e., the population within a radius of 20 km of city r. As an alternative measure, we also compute the number of cities in a radius of 20 km. We then take the county-level population-weighted average of these two measures. For counties with no cities, we set our spatial competition measures to zero.[10]

To measure innovation, we rely on British county-level patent data between 1796 and 1820 from the Royal Society of Arts (1784-1845). In particular, we use the number of patents per capita in a county as a proxy for that county's propensity to adopt new technologies. If inventions can happen anywhere in the county, it would be reasonable to measure this patent-intensity as the number of patents divided by the total population of the county. If, instead, inventions only occur in cities, then a more meaningful measure would divide the number of patents by the county's urban population. In our analysis we experiment with both measures. Another potential issue is that our patent data give the location of the invention, rather than the location of the adoption. As already discussed, there are many instances of technologies being developed in one place and being adopted in another. This is not a problem if both locations are in the same county. If they are not in the same county, then for our analysis to be meaningful, it must be that there is a positive correlation between the patent intensity of a location and its propensity to adopt new technologies.

Table 2: Correlation Patents per Capita with Different Measures of Spatial Competition

	Patents per total population		Patents per urban population	
	(1)	(2)	(3)	(4)
	All counties	Urban counties	All counties	Urban counties
Market access < 20 km	0.3127**	0.2938*	0.8781***	0.8757***
Number of cities < 20 km	0.6600***	0.6453***	0.3847**	0.3635**

* Statistically significant at 10%, ** at 5% and *** at 1%

Table 2 reports the correlations between patent intensity and different measures of spatial competition. The positive correlations imply that innovation is stronger in counties where cities are subject to greater spatial competition. Columns (1) and (2) use the number of patents in a county divided by the total population of the county as its measure of innovation. Column (1) uses all counties, whereas Column (2) only focuses on counties that have a positive urban population. Consistent with the theory, the correlations are always positive, and in all cases the correlations

[10] Alternatively, we could drop those counties. As we will see, this does not change the results.

are statistically significant at the 1%, 5% or 10% level. Columns (3) and (4) report the same correlations, but now we measure innovation as the number of patents in a county divided by the urban population of the county. The correlations continue to be positive, and their statistical significance is stronger, between 1% and 5%. This allows us to conclude that spatial competition was positively associated with innovation intensity.

The evidence above suggests that areas with stronger inter-city competition suffered from less resistance and benefitted from more innovation. At the more aggregate level, Table 1 reports a significant strengthening of inter-city competition between 1700 and 1850. Consistent with the above evidence, we would therefore expect to see an overall weakening of guilds over that time period. This is indeed what occurred: with guilds becoming less effective in blocking the adoption of labor-saving technology, England eventually took off and industrialized.

This is not to say that no other factors facilitated the disappearance of guilds. One of these was the expansion of poor relief. Although the poor laws were originally motivated by other considerations such as civic humanism (Slack, 1999), by the late eighteenth century contemporaries recognized that they had a role to play in maintaining social order in the face of the introduction of new labor-saving technology. Sir F. M. Eden, a prominent social scientist of the time, noted in his 1797 seminal book on poverty that "machines or contrivances calculated to lessen labour ... throw many industrious individuals out of work; and thus create distresses that are sometimes exceedingly calamitous. Still, however, [the policy response to labor-saving inventions should] ... consider how far they [the inventions] actually do or do not promote the general wealth, by raising the largest quantity of provisions, or materials for manufacture, at the least cost, their inconvenience to individuals will be soften and mitigated, indeed, as far as it is practical" (Eden, 1797, vol. 1, p. xiv, cited in Greif and Iyigun, 2013, p. 534). This more comprehensive approach to poor relief was particularly pronounced in the newly industrialized areas in the North and West (King, 2000). At the same time that the system expanded, it also became more predictable and better financed than before (Solar, 1995). Paid for by local taxes, the newly-generated wealth from industrialization allowed for a continued increase in social spending. In doing so, it made it easier for society to compensate individuals who became redundant following the introduction of these technologies.

2.4 Summary

There are at least four stylized facts to take away from the empirical and historical evidence presented in the preceding subsections. First, there was an important increase in the degree of spatial competition in the time period leading up to the *Industrial Revolution*. Second, the attempt of guilds to block the adoption of labor-saving technologies roughly coincided with that same time period. Third, the guilds' success in resisting innovation became increasingly limited by the intensification of spatial competition. Fourth, compensating the losers from industrialization contributed to maintaining social order, thus facilitating England's take-off.

3 The Model

Motivated by these stylized facts, we proceed to illustrate our theory in a model in which resistance to process innovation depends on the economy's spatial organization. The basic setup of the model borrows from Desmet and Parente (2010), with two important differences. First, we allow for the existence of city-industry guilds that can dictate technology use in their city and industry. Second, we allow for a continuum of industries, rather than for just one industry. This implies that any given guild has power over only a specific industry in a city, rather than over a city's entire economy.

We proceed in three steps. First, we describe the model economy and characterize the equilibrium conditions when the only technology available is an artisanal one that requires skilled labor. Second, we introduce a modern technology that does not require the skilled labor input of the artisanal technology. We characterize the equilibrium conditions for which guilds — organizations of skilled workers in an industry and city — form to block the use of the modern technology. Third, we show analytically that if trade is prohibitively costly between cities, guilds always resist and the artisanal technology is used forever. An important corollary of this result is that inter-city trade is necessary for the modern technology to be adopted.

3.1 Artisanal Technology Only

The model consists of two identical city-regions, referred to as the East (E) and the West (W) and indexed by the superscript $r \in \{W, E\}$. Each city-region is populated by a continuum of measure L of one-period lived households, of which measure $(1-\mu)L$ are skilled and measure μL are unskilled. We denote a household's type by the superscript $h \in \{u, s\}$, where u refers to unskilled and s to skilled. Households of each type and each city-region are uniformly distributed around the unit circle. Each household inelastically supplies one unit of labor to the region in which it resides. There is no household migration between city-regions.

3.1.1 Preferences and Utility Maximization

Preferences. Household preferences are defined over an agricultural good and a continuum of industrial goods. We use the letter $i \in [0,1]$ to denote a particular industrial good, the letter v_i to denote a particular variety of that good i, the letter V_i to denote the set of varieties of good i produced in the entire economy, and the letter V_i^r to denote the set of varieties of good i produced in city-region r. Goods can be thought of as textiles, furniture, wines, etc., whereas varieties correspond to different colors, flavors or textures of these goods.

Preferences over each industrial good is of the Hotelling-Lancaster type, meaning that a household's location on the unit circle identifies the particular variety of each good that it prefers over all others. We assume that each household's ideal variety is the same for the continuum of industrial goods. Let $d_{v_i\tilde{v}}$ denote the shortest arc distance between variety v_i and the household's ideal variety $\tilde{v}$ for a given good i.[11] The utility that a household of type u, residing in city-region r and located at point $\tilde{v}$ on the unit circle derives from consuming c_a^{rh} units of the agricultural good and $c_{v_i}^{rh}$ units of variety v of good i is given by

$$(1-\alpha)\log c_a^{rh} + \alpha \int_0^1 \log f(c_{v_i}^{rh} | v_i \in V_i) di, \tag{4}$$

where, following Hummels and Lugovskyy (2009),

$$f(c_{v_i}^{rh} | v_i \in V_i) = \max_{v_i \in V_i} \left(\frac{c_{v_i}^{rh}}{1 + d_{v_i\tilde{v}}^{\beta}} \right). \tag{5}$$

In expression (5), the denominator $1 + d_{v_i\tilde{v}}^{\beta}$, where $\beta > 0$, is the quantity of variety v_i that gives the household the same utility as one unit of its ideal variety $\tilde{v}$. In the literature, this term is referred to as the Lancaster compensation function.

Utility maximization. The utility function (5) implies that a household residing in city-region r buys a single variety $\hat{v}_i^r$ that minimizes the cost of the quantity equivalent to one unit of its ideal variety, $\tilde{v}$:

$$\hat{v}_i^r = \operatorname{argmin}[p_{v_i}^r (1 + d_{v_i\tilde{v}}^{\beta}) | v_i \in V_i], \tag{6}$$

[11] Since a household's ideal variety depends on its location on the unit circle, $\tilde{v}$ does not require a subscript i.

where $p^r_{v_i}$ is the price of variety v_i in city-region r. Let y^{rh} be the income of a household of type h residing in city-region r. The household's budget constraint is then

$$p^r_a c^{rh}_a + \int_0^1 \left(\sum_{v_i \in V_i} p^r_{v_i} c^{rh}_{v_i} \right) di \leq y^{rh}. \tag{7}$$

Maximizing (4) subject to (7) implies that a household of type h residing in r with ideal variety $\tilde{v}$ consumes

$$p^r_a c^{rh}_a = (1-\alpha) y^{rh} \tag{8}$$

and

$$p^r_{\hat{v}^r_i} c^{rh}_{\hat{v}^r_i} = \alpha y^{rh}. \tag{9}$$

3.1.2 Technologies and Profit Maximization

Farms. The farm sector produces a homogeneous good according to a linear technology that uses unskilled labor only. Without loss of generality, we assume the farm good is non-tradeable. Let Q^r_a denote farm output in city-region r. Then

$$Q^r_a = \Gamma_a L^r_a, \tag{10}$$

where Γ_a is farm-sector TFP and L^r_a is farm-sector employment in city-region r.

The farm sector is perfectly competitive. As we assume the same farm TFP in both city-regions, we can normalize the agricultural price to 1 in both regions,

$$p_a = 1. \tag{11}$$

Profit maximization then implies a common agricultural wage rate across regions given by

$$w_a = \Gamma_a. \tag{12}$$

Industries. Each industry, of which there is a continuum of measure one in each region, produces a set of differentiated varieties, which are tradeable across regions. Trade is subject to iceberg transport costs: to deliver one unit of a variety produced in one city-region to the other city-region, $\tau > 1$ units must be shipped.

The market structure in any given industry is monopolistically competitive due to the existence of a fixed operating cost. Output is generated using an artisanal production technology, the key property of which is that it requires skilled labor to operate.[12] Let $Q^r_{v_i}$ denote the output of a firm in city-region r that produces variety v_i. Then, the artisanal technology is

$$Q^r_{v_i} = \Gamma_v[L^r_{v_i} - \kappa], \tag{13}$$

where κ is the fixed operating cost in units of labor and Γ_v is the marginal product.

When maximizing profits, each monopolist takes the choices of other firms as given. For reasons of space, we only present the profit maximization problem facing a firm located in the East; expressions for Western firms can be derived analogously. To distinguish between the production and the consumption locations, we use a double superscript, where the first superscript refers to the production location and the second refers to the consumption location.

Using the production function (13), together with the fact that the Eastern firm's production meets consumption of Eastern and Western consumers, namely,

$$Q^E_{v_i} = C^{EE}_{v_i} + \tau C^{EW}_{v_i}, \tag{14}$$

we can write an Eastern firm's profits, $\Pi^E_{v_i}$ as

$$\Pi^E_{v_i} = p^{EE}_{v_i} C^{EE}_{v_i} + p^{EW}_{v_i} C^{EW}_{v_i} - w^E_x[\kappa + \frac{C^{EE}_{v_i} + \tau C^{EW}_{v_i}}{\Gamma_v}], \tag{15}$$

where $p^{EE}_{v_i}$, $p^{EW}_{v_i}$, $C^{EE}_{v_i}$ and $C^{EW}_{v_i}$ are the prices and consumption levels of an Eastern-produced variety in the Eastern and the Western markets, and w^E_x is the Eastern wage rate in the industrial sector.

An Eastern firm producing variety v_i chooses the price in the East, $p^{EE}_{v_i}$, and the price in the West, $p^{EW}_{v_i}$, to maximize (15), subject to demand in the East and demand in the West, taking the wage rate in the industrial sector, w^E_x, as given. The profit-maximizing price in each market is a mark-up over the marginal unit cost, so that

$$p^{EE}_{v_i} = \frac{w^E_x}{\Gamma_v} \frac{\varepsilon^{EE}_{v_i}}{\varepsilon^{EE}_{v_i} - 1} \tag{16}$$

and

$$\frac{p^{EW}_{v_i}}{\tau} = \frac{w^E_x}{\Gamma_v} \frac{\varepsilon^{EW}_{v_i}}{\varepsilon^{EW}_{v_i} - 1}, \tag{17}$$

where $\varepsilon^{EE}_{v_i}$ and $\varepsilon^{EW}_{v_i}$ are the price elasticities of demand for variety v_i in the East and the West. Namely,

$$\varepsilon^{EE}_{v_i} = -\frac{\partial C^{EE}_{v_i}}{\partial p^{EE}_{v_i}} \frac{p^{EE}_{v_i}}{C^{EE}_{v_i}}$$

[12] We use the adjective "artisanal" because we will later introduce a "modern" technology.

and

$$\varepsilon_{v_i}^{EW} = -\frac{\partial C_{v_i}^{EW}}{\partial p_{v_i}^{EW}} \frac{p_{v_i}^{EW}}{C_{v_i}^{EW}}.$$

3.1.3 Aggregate Demands

We now derive the aggregate demands for the agricultural good and for each differentiated industrial good. Our analysis focuses exclusively on the properties of the model's symmetric Nash equilibria. As such, in our analysis all firms are equally spaced around the unit circle, with each variety of one city-region having two varieties of the other city-region as its closest neighbors.

Agricultural good. Assuming symmetry, there is no reason to trade the agricultural good across city-regions. Since each household spends a fraction $1-\alpha$ of its income on the agricultural good, the aggregate demand in city-region r is simply

$$C_a^r = (1-\alpha)((1-\mu)w_x^r + \mu w_a^r)L. \tag{18}$$

Differentiated industrial goods. We have established that each household buys a single variety of each industrial good, spending a fraction α of their income on it. To determine the aggregate demands, we therefore need only determine the measure of households in each region that buy a given variety i. Because all varieties are equally spaced around the unit circle, aggregate demand for an Eastern firm producing variety v^E depends on the locations and the prices of its closest neighbors to its right and its left on the unit circle, which are both Western firms.[13] Since these two Western-produced neighboring varieties are each located at the same distance d from the Eastern-produced variety in a symmetric equilibrium, we do not need to differentiate between them, and therefore denote each by v^W. The Eastern household who is indifferent between buying varieties v^E and v^W is the one located at distance d^{EE} from v^E, where d^{EE} satisfies

$$p^{WE}[1 + (d - d^{EE})^\beta] = p^{EE}[1 + (d^{EE})^\beta]. \tag{19}$$

Given this indifference condition applies to households both to the right and to the left of v^E, a share $2d^{EE}$ of Eastern households consumes variety v^E. As both skilled and unskilled Eastern

[13]Depending on the parameter values, aggregate demand could in principle also depend on the locations and the prices of varieties that are farther away on the unit circle. However, in the numerical section parameter values are such that only the closest neighbors matter, so we write down our theory for this simple case.

households are uniformly distributed along the unit circle and each household spends a share α of its wage earnings on a single variety in any given industry, the East's demand for v^E is

$$C^{EE} = \frac{2d^{EE}\alpha[(1-\mu)w_x^E \ \ + \mu w_a^E]L}{p^{EE}}. \tag{20}$$

By analogy we can derive the West's demand for v^E,

$$C^{EW} = \frac{2d^{EW}\alpha[(1-\mu)w_x^W + \mu w_a^W]L}{p^{EW}}, \tag{21}$$

where d^{EW} gives the distance from v^E at which a Western household is indifferent between consuming v^E or v^W, so that

$$p^{WW}[1 + (d - d^{EW})^\beta] = p^{EW}[1 + (d^{EW})^\beta]. \tag{22}$$

Price elasticity. With these demand equations in hand, we can solve for the price elasticities of demand that determine the mark-ups in the firm's optimal pricing decisions (16) and (17). The East's demand (20) implies that

$$-\frac{\partial C^{EE}}{\partial p^{EE}}\frac{p^{EE}}{C^{EE}} = 1 - \frac{\partial d^{EE}}{\partial p^{EE}}\frac{p^{EE}}{d^{EE}}. \tag{23}$$

After solving for the partial derivative, $\partial d^{EE}/\partial p^{EE}$, by taking the total derivative of the indifference equation (19) with respect to p^{EE}, we obtain

$$\varepsilon^{EE} = 1 + \frac{[1 + (d^{EE})^\beta]p^{EE}}{[p^{EE}\beta(d^{EE})^{\beta-1} + p^{WE}\beta(d - d^{EE})^{\beta-1}]d^{EE}}. \tag{24}$$

By analogy, the elasticity faced by an Eastern firm in the West is

$$\varepsilon^{EW} = 1 + \frac{[1 + (d^{EW})^\beta]p^{EW}}{[p^{EW}\beta(d^{EW})^{\beta-1} + p^{WW}\beta(d - d^{EW})^{\beta-1})d^{EW}}. \tag{25}$$

3.1.4 Equilibrium Conditions

Having derived the aggregate demands, we proceed to define the competitive symmetric Nash equilibrium. Apart from utility maximization and profit maximization, all markets must clear in equilibrium. Additionally, profits in each industry must be zero. This follows from free entry.

Goods and labor market clearing. The market clearing condition for any industrial good is (14). The corresponding condition for the agricultural market is

$$\Gamma_a L_a^r = C_a^r. \tag{26}$$

The labor markets must also clear in each region. As only skilled labor is used in the artisanal technology, and only unskilled labor in farming, there are two labor markets in each region. We start by deriving the demand for skilled labor. As d is the shortest-arc distance between any two varieties on the unit circle, it follows that the number of varieties of each industrial good produced in the economy is $1/d$. Because there is measure one of industrial goods, symmetry implies that each city-region produces $1/(2d)$ varieties of each industrial good. Given the production function (13), each Eastern firm employs $\kappa + \frac{C^{EE}+\tau C^{EW}}{\Gamma}$ units of skilled labor. The labor market clearing conditions are then:

$$\begin{aligned} (1-\mu)L &= \frac{1}{2d}[\kappa + \frac{C^{EE}+\tau C^{EW}}{\Gamma_v}] \\ \mu L &= \frac{C_a^E}{\Gamma_a}. \end{aligned} \tag{27}$$

Zero profit condition. Because of free entry and exit, all firms make zero profits. For Eastern firms in any given industry i this implies

$$p^{EE}C^{EE} + p^{EW}C^{EW} - w_x^E[\kappa + \frac{C^{EE} \ + \tau C^{EW}}{\Gamma}] = 0. \tag{28}$$

The zero profit condition in each industry determines the number of varieties produced in the East. We are now ready to define a symmetric equilibrium.

Definition of Symmetric Artisanal Equilibrium. *An Artisanal Technology Symmetric Equilibrium (ARTSE) is a vector of elements* (p^{ii*}, ε^{ii*},p^{ij*}, ε^{ij*}, w_x^{i*}, w_a^{i*} ,d^*, d^{ii*}, d^{ij*}, Q^{i*}, Q_a^{i*}, C^{ii*}, C^{ij*}, C_a^{i*}, V^{i*})*, where* $i,j \in \{E,W\}$, $i \neq j$, *and* $x^{ii*} = x^{jj*}$, $x^{ij*} = x^{ji*}$ *and* $x^{i*} = x^{j*}$ *for any variable* x^*, *that satisfies conditions (10), (12), (14), (16), (17), (18), (19), (20), (21), (22), (24), (25), (26), (27) and (28), as well as the corresponding conditions for Western industrial firms.*

3.2 Innovation, Guilds and Spatial Competition

Starting off in a symmetric equilibrium where all firms use the artisanal technology, we assume that a modern technology becomes available. We study the incentives of firms to adopt the modern technology, and the incentives of skilled workers in a given industry and city-region to resist its adoption. Compared to the artisanal technology, the modern technology has the advantage of a higher marginal productivity, but the drawback of a higher fixed cost. In addition, the modern technology can indistinctly use skilled and unskilled workers. As a result, the skilled in an industry may lose because of low-wage competition from the unskilled if a firm decides to switch to the modern technology.

We proceed in steps. First, we analyze whether it is profitable for an individual firm in a given city-region to adopt the modern technology. We then describe conditions for skilled workers of the industry and city-region of the adopting firm to form a guild to prevent the switch to the modern technology. Finally, we establish conditions for an industry in a city-region to buy out guild members so they stop blocking adoption. Our main interest is to analyze the relation between the degree of spatial competition and the existence of technology-blocking institutions.

3.2.1 Incentive to Adopt Modern Technology

We start by studying the problem of an individual firm that switches to the modern technology. By switching, the output of a firm in city-region r that produces variety v_i becomes

$$Q^r_{v_i} = \Gamma^r_v(1+\gamma)[L^r_{v_i} - \kappa - \phi], \tag{29}$$

where $\phi > 0$ is the increase in the fixed operating cost and γ is the proportional improvement in the marginal productivity, compared to the artisanal technology.

In establishing the condition for a firm to adopt the modern technology, we assume that all other firms still use the artisanal technology. In this sense, we are analyzing the incentives of a firm to deviate from the *ARTSE*. To facilitate interpretation, we use the prime symbol ($'$) to denote variables that pertain to deviations from the *ARTSE*. Let $\Pi^{E\prime}$ denote the profit of a single firm deviating from the artisanal technology. We can then write the condition for a firm to find it profitable to switch to the modern technology as

$$\begin{aligned}
\Pi^{E\prime} > 0, \qquad & \text{where} \\
& \Pi^{E\prime} = \max_{p^{EE\prime}, p^{EW\prime}} \{p^{EE\prime}C^{EE\prime} + p^{EW\prime}C^{EW\prime} - w_a[\kappa + \phi + \frac{C^{EE\prime} + \tau C^{EW\prime}}{\Gamma_v(1+\gamma)}]\} \\
\text{s.t.} \quad & C^{EE\prime} = \frac{2d^{EE\prime}\alpha[(1-\mu)w^E_x + \mu w^E_a]L}{p^{EE\prime}} \\
& C^{EW\prime} = \frac{2d^{EW\prime}\alpha[(1-\mu)w^W_x + \mu w^W_a]L}{p^{EW\prime}}.
\end{aligned} \tag{30}$$

Because a firm can hire any workers when it uses the modern technology, the wage rate is w_a. Implicitly, we assume parameters such that $w_a < w^r_x$ in the *ARTSE*.

Computing the deviating profits $\Pi^{E\prime}$ requires re-writing (19) and (22), the two conditions that determine the Eastern household and the Western household that are indifferent between the deviating firm's variety and its neighbors' varieties to the left and to the right,

$$p^{WE}[1 + (d - d^{EE\prime})^{\beta}] = p^{EE\prime}[1 + (d^{EE\prime})^{\beta}] \tag{31}$$

and

$$p^{WW}[1 + (d - d^{EW\prime})^{\beta}] = p^{EW\prime}[1 + (d^{EW\prime})^{\beta}], \tag{32}$$

as well as the expressions (24) and (25) that represent the price elasticities faced by the deviating firm in both markets,

$$\varepsilon^{EE\prime} = 1 + \frac{[1 + (d^{EE\prime})^{\beta}]p^{EE\prime}}{[p^{EE\prime}\beta(d^{EE\prime})^{\beta-1} + p^{WE}\beta(d - d^{EE\prime})^{\beta-1}]d^{EE\prime}} \tag{33}$$

and

$$\varepsilon^{EW\prime} = 1 + \frac{[1 + (d^{EW\prime})^{\beta}]p^{EW\prime}}{[p^{EW\prime}\beta(d^{EW\prime})^{\beta-1} + p^{WW}\beta(d - d^{EW\prime})^{\beta-1})d^{EW\prime}}. \tag{34}$$

For the subsequent analysis it is important to point out that the deviation condition (30) is the same whether we consider one firm in a particular industry and city-region deviating or all firms in that industry and city-region deviating. One reason is that the incentive for an Eastern firm to deviate only depends on its two Western-produced neighboring varieties. Another reason is that each industry is measure zero, so that even if all firms in a given industry and city-region deviate, this has no effect on aggregate income.

When are firms more likely to deviate and adopt the modern technology? The following claim states that larger markets, lower transport costs and shorter inter-city distances increase the profitability of deviating.

Claim 1. *Starting off in an equilibrium where all firms use the artisanal technology, an increase in population, a drop in transport costs and a reduction in inter-city distances all increase the incentives of an individual firm to switch to the modern technology.*

We here limit ourselves to providing some intuition for this claim, which we will further explore in the numerical section of the paper. In a similar model, Desmet and Parente (2010) show that bigger markets and lower transport costs increase the incentives to deviate. To see the rationale for this claim, we start by focusing on the importance of market size, and later discuss the role of transport costs and distance. The key insight is that as the population increases, Hotelling-Lancaster preferences imply a less-than-proportional increase in the number of varieties, in contrast to what occurs when preferences are of the Spence-Dixit-Stiglitz type, where the number of varieties increases proportionally with population. The implied positive relation between market size and firm size emerges because as more varieties enter the market, neighboring varieties become more substitutable, leading to an increase in the price elasticity of demand. The result is a drop in mark-ups, so that each differentiated good producer must become larger to break even. This increase in firm size favors adoption, since a firm can now spread the fixed adoption cost of the modern technology, ϕ, over more units. The deviation condition (30) is thus more likely to be satisfied for larger city-regions.

A drop in transport costs has a similar effect on the incentives to adopt the modern technology because it leads to greater competition between neighboring varieties, and thus to lower mark-ups and larger firms. It is important to note that decreasing the geographic distance between city-regions is equivalent to lowering transport costs. Hence, having city-regions more closely spaced also increases the incentive for firms to switch to the modern technology.

3.2.2 Guilds

We now analyze whether skilled workers in a given industry and city-region have an incentive to form a professional guild, with the purpose of blocking the introduction of the modern technology in their city and industry. As we already discussed, there are of course many other reasons why in reality guilds might have formed. We can therefore rephrase the objective of our theoretical analysis of guilds as follows: if skilled workers in a given industry and city-region did not form a guild before for some other reason, do they have an incentive to do so with the objective of resisting the adoption of the modern technology? Equivalently, if skilled workers already formed a guild for some other purpose, when does that guild turn anti-technology?

A guild, should it form, is industry- and city-specific. By this we mean that all firms in a given industry and city-region must abide by the guild's directives prohibiting the use of the modern technology. An important implication is that an industry guild in the East has no power over the action of firms in the same industry in the West. Faced with a guild, an industry in a city-region can only switch to the modern technology if it breaks guild resistance. As a practical matter, resistance could be overcome in a variety of ways, some of which involve the polity and the judiciary. To keep things simple, we assume that resistance is overcome only if the industry can pay off the guild members by maintaining their original wages. If workers can be sufficiently compensated, the modern technology gets adopted, the guild no longer has a reason to exist, and it disbands.

The starting point for our analysis is, again, the symmetric equilibrium where only the artisanal technology is available. Specifically, we find the prices and allocations that satisfy all the conditions in the definition of the *ARTSE*. In this equilibrium, the skilled workers in a given industry and city-region constitute the set of potential guild members and the number of varieties constitute the set of firms that are subject to the guild's rules. As there is measure L of workers in each region, of which $1-\mu$ are skilled, and measure one of industries in each region, then the size of a guild that forms in industry i and city r is $(1-\mu)L$. We denote this guild size by G_i^r.

A group of skilled workers in a given industry and city-region will form a guild if at least one firm finds it profitable to use the modern technology and if the industry profits if all firms were to adopt are too small to compensate skilled workers for lost wages.[14] The first condition is simply the deviation condition (30). Clearly, if the first condition is not met, then no industry would have a guild for the simple reason that skilled workers are not at risk of earning lower wages. As such, they have nothing to gain from forming a guild. As a result, no guild forms and the artisanal technology prevails. The second condition says that the profits from adoption are not enough to compensate the skilled workers, so that

$$\frac{V_i^{E*}\Pi_i^{E'}}{G_i^{E*}} + w_a^{E*} \leq w_x^{E*}. \tag{35}$$

Notice that (35) makes two implicit assumptions about how losers are compensated. First, the transfers to the skilled workers are financed by the profits of the industry that switches to the modern technology. This compensation mechanism could be interpreted as being the outcome of either a bargaining process between the industry and the guild or a tax on industry profits. The latter interpretation is not unlike the poor laws which were financed locally by taxes on the wealthy.[15] Second, there are no labor market frictions, so that displaced skilled workers can immediately find employment as unskilled workers in the economy. If we were to allow for the possibility of unemployment, the existence of poor relief would become even more important, as the expected income of the skilled workers would fall below that of the unskilled.

When profits from innovating are positive but too small to fully compensate the losers, the symmetric equilibrium is characterized by each industry in each region having a guild and operating

[14] From our discussion before, recall that the condition for one firm deviating or all firms deviating is the same.

[15] Strictly speaking, in our model the deviating industry would be the only one making profits, so that the limit on tax revenues from profits would be total profits, as in (35).

the artisanal technology. We refer to this equilibrium as a *Symmetric Artisanal Equilibrium with Guilds (GARTSE)*. Formally,

Definition of Symmetric Artisanal Equilibrium with Guilds. *A Symmetric Artisanal Equilibrium with Guilds (GARTSE) satisfies the same conditions as ARTSE, with two differences: (i) the deviation condition (30) is satisfied, and (ii) the profits of a deviating industry in a city-region are not enough to pay off their skilled workers, i.e., (35) is satisfied.*

Importantly, the prices and allocations in the *GARTSE* coincide with those in the *ARTSE*. In effect, the set of skilled workers, by forming a guild, are able to sustain the same equilibrium allocations and prices as before.

In light of Claim 1, one would expect guilds to form when market size/population reaches a certain threshold and disband when it reaches a second higher threshold. The latter part of this statement is not exactly correct, however. As we now show, an increase in market size *by itself* is not enough for guilds to disappear. What is critical is the spatial distribution of city-regions: only with sufficient inter-city competition will the guilds disband.

3.3 Market Size, Spatial Competition and the Demise of Guilds

In this section we show that the degree of spatial competition determines the point at which the skilled workers end their resistance to the modern technology so that the economy can take off. Importantly, we show that in the absence of trade between cities, an increase in market size is never enough to lead to the demise of guilds, although it is enough to bring about their formation. Trade between cities is hence essential for an economy's take-off. The intuition for this result is as follows. Suppose the economy is in a symmetric artisanal equilibrium with guilds *(GARTSE)*. For the guilds to disappear, the industry's profits from deviating must be enough to compensate the industry's original skilled workers. These profits come from increasing market share at the expense of other firms in the industry. When there is trade, the industry in one city-region can increase its market share at the expense of the other city-region; however, in the absence of trade, this is not possible, so that deviating never leads to an increase in profits. We now formally state and prove this proposition.

Proposition 1. *For an economy in GARTSE that faces prohibitive trade costs, an increase in population will never lead to the violation of (35), so that guilds will never disband.*

Proof. Start from an equilibrium where all firms use the artisanal technology. Firms make zero profits and all the firms' earnings are paid out to the industry's (skilled) workers. Now suppose all those firms switch to the modern technology. Because each industry is measure zero and household preferences are Cobb-Douglas across industries, the total income spent on a given industry's varieties is independent of the technology it uses. Since there is no trade, all the income is spent on the local industry, both before and after the adoption of the modern technology. Hence, switching technologies does not affect an industry's total earnings. Since all earnings before the technology switch were going to the industry's original workers, it is impossible to make all those original workers better off when adopting the modern technology. Hence, (35) is never violated, and guilds never disband. □

As stated in the following corrollary and subsequently clarified in our numerical simulations, the same argument does not hold once trade costs between city-regions are no longer prohibitive.

Corrollary. *For an economy in GARTSE that faces non-prohibitive trade costs, an increase in population or a decrease in inter-city transport costs may lead to the violation of (35), so that guilds disband.*

Proposition 1 implies that the role of market size on innovation is subtle. In a world where cities are geographically too isolated to trade with each other, increasing population size never leads to industries switching to the modern technology. In contrast, if there is trade across cities, then increasing population size or decreasing trade costs makes it more likely for innovation to occur. Hence, having a sufficiently large market is never a sufficient condition for countries to industrialize. Instead, it is a favorable spatial organization of economic activity, with cities located fairly close to each other, together with those cities being large, that provides the adequate conditions for guilds to weaken and industrialization to take off.

The assumption that guilds operate at the city-region level rather than at the national level is the key to understanding the role of trade. Consistent with historical evidence, in the model a guild's power does not transcend the boundaries of its own city-region. As a result, in a multi-city model, when an industry in a given city switches to the new technology, it only needs to compensate its skilled workers in its own city. It can do so by capturing market share from firms in the other city. This possibility of capturing market share between cities is greater when either the market size increases or transport costs between cities drop. In the absence of trade, this capacity of gaining profits at the expense of the other city disappears.[16]

4 Calibration Exercise

To assess the plausibility of our theory we calibrate the model economy to the evolution of spatial competition in England between 1400 and 1600 and derive the model's predictions for England's take-off taking into account the post-1600 evolution of spatial competition in England. The first model period, without loss of generality, is associated with the year 1400, and the model period in which skilled artisans first organize for the purpose of blocking the modern technology is associated with the year 1600.[17] As discussed in Section 2, although guilds appeared much earlier in Europe, it is not until the seventeenth and eighteenth centuries that they regularly exhibited resistance to labor-saving technology. Since in our theory craft guilds have the single function of blocking the introduction of labor-saving technology, the relevant starting date is when guilds began resisting, not when they first appeared. This explains our choice of 1600.

The calibration exercise is done assuming that the modern technology is already available in 1400. This is a slight and inconsequential modification from the analytical analysis above, which assumes that only the artisanal technology is available originally.[18] Given the evolution of spatial competition in England between 1400 and 1600, the parameter values are assigned so that the profits of a firm in any industry and city that introduces the modern technology are (i) negative prior to 1600 and (ii) positive but insufficient to compensate skilled workers for lost earnings in 1600. In terms of the equilibrium concepts, this means that between 1400 and 1600, the $ARTSE$ prevails and in 1600 the $GARTSE$ exists.

The test of the theory then involves determining the first date when the $GARTSE$ fails to exist. At this date industry profits in a given city are large enough to compensate the skilled workers in that industry for their reduced earnings. Therefore, at this date guilds stop resisting, and the economy takes off. To determine this date, we feed data on English city sizes and inter-city

[16]Note that in a setup where industries are large or where the elasticity of substitution between industries is greater than one, there would not be such a sharp distinction between a situation with trade and one without trade, although the qualitative insights would not change.

[17]Although the general strategy underlying the calibration refers to specific dates, they are actually irrelevant when it comes to the actual assignment of parameters. More to the point, it is the degree of spatial competition at various dates that matters in restricting the parameter values.

[18]Since we assume that the modern technology is always available, the definition of the $ARTSE$ now requires the additional condition that no firm in no industry has an incentive to adopt the modern technology, i.e., $\Pi^{E\prime} \leq 0$.

distances in the post-1600 period into the calibrated model. We find that the calibrated model predicts fairly closely the date at which guilds ended their resistance to labor-saving technology in England.

4.1 Parametrization

Table 3: Parameter Values

Parameter	Target/Comment
1. Endowments	
$L_{1400} = 210$	Average firm size of in 1600 of 2.0
$\mu = 0.925$	Fraction of non-urban population in 1600
2. Transport costs	
$\tau_{1400} = 0.09$	Willan (1976), Masschaele (1993) and Munro (1997)
$\tau_{1600} = 0.07$	Drop in average distance between same-size cities (Table 1)
$\tau_{1800-1850} = 0.02$	Drop in average distance between same-size cities (Table 1)
3. Preferences	
$\alpha = 0.097$	Urban-rural real wage premium of 33% between 1400 and 1600 (Clark, 2001)
$\beta = 0.50$	Ratio of average city size between 1400 and 1600 (Table 1)
4. Technologies	
$\Gamma_a = 1.0$	Normalization
$\Gamma_v = 1.0$	Normalization
$\gamma = 1.5$	Productivity gains in textile (Randall, 1991)
$\kappa = 0.25$	10% to 15% Share of time on non-production activities in 1600
$\phi = 3.50$	20% rate of return earned by Bean Ing Mill in 1792-99 (Hudson, 1986)

The parameter values are shown in Table 3. As the model structure is not commonly used in the growth literature, we explain in detail how each parameter value was chosen. Starting with the parameter values listed under the endowment category, we set the average city size in 1400 in the model so as to generate an average firm size of 2.0 workers in 1600. This firm size is based on work by Minns and Wallis (2012) that documents the average number of apprentices present in the households of masters in several English cities in this period. For example, in Bristol in the seventeenth century the average master employed 1.0 apprentice whereas in London, this average was larger at 1.6.[19] The second endowment parameter, μ, requires far less explanation. As it represents the fraction of the population that is unskilled, its value is set to the fraction of the rural

[19] An obvious question is why we did not set the population to reflect the actual 1400 average city population in England. The short answer is that theoretically city size only matters to the extent that it affects firm size, so the relevant target is the firm size. Had we wanted, we could have set L_{1400} to the actual 1400 average city size. Matching firm size would then require adjusting the circumference of the circle. This would not change anything, but it would come at the cost of introducing one more parameter, so we refrain from doing so.

population in England in 1600.

Turning to the iceberg transport costs, its values are based on several studies that provide estimates of transport costs as a fraction of total costs in pre-industrial Europe. Taking an average over a variety of goods, we obtain a cost of 0.1% per km.[20] To obtain a measure of inter-city transport costs, we need to multiply this number by the average distance between cities. In the context of our model, the appropriate distance measure is S_3, the average distance for a city to reach the same number of consumers as its own city. As reported in Table 1, in 1400 that average distance was 93 km, so we set $\tau_{1400} = 1.09$. The 1600 and 1800-1850 values are then chosen based on the decline in the average distance to same-sized cities. From Table 1 we know that S_3 dropped to 70 km in 1600 and to 21 km between 1800 and 1850, so that $\tau_{1600} = 1.07$ and $\tau_{1800-50} = 1.02$.

Moving on to the preference parameters, the assignment of the expenditure share on the industrial goods in the household utility function, α, is straightforward. Given the fraction of unskilled households, the expenditure share parameter is set so that the wage differential for skilled to unskilled workers in the *ARTSE* matches the urban-rural wage premium in England between 1400 and 1600 reported by Clark (2001).[21] The assignment of the curvature parameter of the Lancaster compensation function, β, requires greater explanation as it is one of the parameters specific to our preference structure. To calibrate it, we exploit the fact that the curvature parameter is critical for determining the city size threshold at which resistance starts.[22] As such, we set β so that the *GARTSE* first exists when the average city size in the model exhibits the same increase as that experienced by England between 1400 and 1600, using the calibrated iceberg costs in those two years.

The last set of parameters are technology related. Because of the Cobb-Douglas nature of

[20]We base our estimate on information on four different goods: grain, wine, luxury woolens and semi-worsted woolens. Masschaele (1993) finds that transporting grain in 14th century England added around 0.25% per km to the price. Based on data from the end of the 16th century, transporting wine from Chester to Smithills increased the price by 0.17% per km (Willan, 1976). As for woolen products, Munro (1997) cites different studies. One is based on the writings of a Flemish merchant who exported luxury woolen from Bruges to Barcelona in the late 14th century at a cost of 0.02% per km. Another study reports a cost of around 0.01% per km for semi-worsted woolen products exported from Caen to Florence in the early 14th century. Taking these four numbers, the average transport costs was around 0.1% per km.

[21]Clark (2001) reports wages for urban craftsmen, urban laborers and farm laborers. We estimate the urban wage to be the average of the wages of the urban craftsmen and the urban laborers. We then define the urban-rural wage premium as the ratio of urban to rural wages. We adjust this ratio for the cost of living differences between urban and rural area by using the relative wage of laborers in both places.

[22]A decrease in the value of β, i.e., more curvature, makes it harder for an innovating firm to steal away consumers who are closely located to their nearest neighbors on the variety circle. This implies that firms have less of an incentive to introduce the modern technology, thus increasing the threshold for when resistance starts.

preferences between the agricultural good and the industrial goods, any change in relative productivities translates into changes in relative prices, leaving expenditure shares unchanged. From that point of view, the TFP parameters do not affect the market size of the industrial sector. For this reason, the TFP parameters in agriculture, Γ_a, and in industry, Γ_v, are both normalized to one. For the parameter γ, which governs how much more productive the modern technology is relative to the artisanal technology, we set its value to 1.5, consistent with the reduction in the time input of men making woolen cloth between 1781 and 1796, as summarized by Randall (1991).[23] The fixed operating cost parameter, κ, is targeted so that skilled workers spend between 10% and 15% of their working time on non-production activities in the *ARTSE*. We are not aware of any historical study documenting the amount of time industrial workers spent in the fifteenth and sixteenth centuries on non-production activities. Absent such evidence, we thought that a time allocation between 10% and 15% to non-productive activities is reasonable.

This leaves the assignment of the fixed innovation cost parameter, ϕ. Because the calibration is done so that no firm would introduce the modern technology before 1600, we cannot use observations from this period to tie down its value. What is needed is an observation associated with an actual deviation, where a firm first introduces the modern technology. A good empirical counterpart would be the observed profits or rates of return on a textile mill established in the early phases of the *Industrial Revolution*. Hudson (1986) provides such an observation. He reports rates of return earned by a number of textile mill owners in the late eighteenth century, with John Gott and his Bean Ing mill being the earliest listed. We take the 1792-99 reported returns in Table 8 of Hudson (1986) for John Gott's mill, assigning a value for ϕ so that the implicit rate of return on fixed cost expenditures in our model, defined as $\Pi^{E\prime}/[w_a(\phi+\kappa)]$, matches this value. This completes the calibration of the model.

4.2 Test of the Theory

Having calibrated the model to England between 1400 and 1600, we analyze its predictions for when resistance should have broken down. Specifically, we set the iceberg cost to its 1800-1850 value, $\tau_{1800-50} = 1.02$, and determine the smallest average city size for which the *GARTSE* fails to exist. The calibrated model predicts that resistance ceases when the average city reaches a size

[23] See Randall (1991, p. 52.-55) for estimates of the labor requirements for making a piece of superfine broadcloth between 1781 and 1828.

2.7 times greater than its 1400 level. How does this match up with England's historical record? Going back to Table 1 and assuming a constant exponential growth rate of city size between 1800 and 1850, the average city size was 2.7 times greater than its 1400 level in 1820. Thus, the model predicts that guilds should have stopped blocking labor-saving technology in England in 1820. This is within the main period when guilds ended their resistance to labor-saving technologies.

To provide some additional perspective on how important the increase in spatial competition was for England's industrialization, we perform the following counterfactual experiment. We determine the city size that would have been needed for guilds to form and for resistance to break down if we kept the iceberg cost parameter τ at its 1400 value of 1.09. What the counterfactual reveals is that in the absence of a decline in inter-city distances, guilds would have formed when the city size reached $21,200$ and guilds would have disappeared when the city size reached $38,600$. Recall that the model predicts that guilds would have started to form when city size reached a population of $19,300$ and they would have ended their resistance when city size reached a population of $30,300$.

The counterfactual therefore suggests that industrialization would have required a city size 26% greater had inter-city distance remained at its 1400 level. While this difference is substantial, the high growth rate in city size between 1800 and 1850 implies that this would have delayed industrialization by a mere 15 years. Though this seems to suggest that the increase in spatial competition may have been quantitatively unimportant for the timing of take-off, such as conclusion would be premature for two reasons. First, much of the average city size increase experienced by England in the first half of the nineteenth century was surely a response to the *Industrial Revolution*. Second, the degree of spatial competition in England in 1400 was already quite high, compared to other countries, such as China. As we will show next, the model predicts that China's much greater inter-city distances implies a delay in its take-off until the twentieth century.

5 Spatial Competition and the Great Divergence

Having demonstrated that the theory is able to account for the timing of the breakdown of resistance in England, we next explore whether the model offers a plausible explanation for the *Great Divergence*. We do this in three steps. First, we document the degree of spatial competition in China, showing that it was far less intense compared to England. Second, we provide a history of the guilds in China, paying particular attention to the period when new labor-saving technology became available. Finally, we feed the data on city sizes and inter-city distances in China into our calibrated model and determine when guilds in China should have started to block labor-saving technology and when they should have given up.

5.1 Spatial Competition in China

In this section we document the important disparity in the degree of inter-city competition between China and England.

5.1.1 Data

The most detailed historical data on city populations in China come from Yue et al. (2007). The data is for a single year, 1893, and includes all 2403 cities that served as administrative capitals of prefectures or counties during the period 1820-1893. Rather than providing the exact population of each city, cities are identified by size classes, of which there are 11. Starting with populations of less than 500 for the lowest size class, the upper limit of each size class is defined to be twice its lower limit, until reaching 512,000. That is, classes consist of: less than 500; 500 to 1,000; 1,000 to 2,000; 2,000 to 4,000; . . . ; 256,000 to 512,000; and more than 512,000. Except for the highest class, we use the mid-value of each class to define the size of a city's population. For the highest class, we use city population data of 1900 from Eggimann (1999) to assign populations.[24]

To check the consistency of these population data, we compare China's implied urbanization rate in 1893 to other estimates in the literature. To make our calculation comparable to existing estimates, we focus exclusively on cities with a population of more than 10,000. Taking the total population of China to be 386 million in 1893 (Maddison, 2001), this yields an urbanization ratio of 7.5 percent. This is much higher than the 4.4 percent consensus figure, dating back to Rozman (1973) and widely used in the literature (Broadberry and Gupta, 2006; Maddison, 2001). One reason for this discrepancy is that many of the administrative capitals of counties (rather than prefectures) are not cities in any real sense. If we restrict our attention to prefecture-level cities that appear in Cao (2000), rather than to the larger set of locations in Yue, Skinner and Henderson (2007), we get an urbanization ratio of 4.7 percent, in line with the estimates of Rozman (1973). We therefore use this subset of cities as our benchmark. However, we will conduct robustness analysis

[24]Note that we cannot use Eggimann (1999) as an alternative source for our overall study of urbanization in China because of the high number of missing data: for 1850 Eggimann (1999) only has data on 62 Chinese cities, and by 1900 that number has only increased to 85.

with the broader set of cities in Yue, Skinner and Henderson (2007) to ensure that our results are not driven by this more restrictive definition of what constitutes a city. Furthermore, to make our analysis for China comparable to that for England, we also include cities with a population between 5,000 and 10,000.

For years before 1893, there are no detailed and comprehensive data on Chinese city sizes. There are prefecture-level data collected by Cao (2000) for 1776, 1820, 1851, 1880 and 1910. However, these population data refer to the entire prefectures, and not just to the urban centers. To estimate the population of the urban centers in these other years, we proceed as follows. We calculate the growth rate of the prefecture populations for the dates given in Cao (2000). Between any two dates in Cao (2000), we assume growth rates of prefectures to be constant. Next, we assume that cities in a given prefecture grow at the same rate as the entire prefecture. With these growth rates and the 1893 data, we impute the city population levels in 1776 and 1820. Lastly, we scale all the city populations in a given year to match the overall urbanization rates as reported by Rozman (1973). Using this methodology, we get estimates for Chinese cities with a population of more than 5,000 in 1776 and 1820. To also obtain estimates of city sizes in 1700, we exploit the fact that the urbanization rate in China did not change between 1700 and 1820 (Maddison, 2001). Therefore we impute the 1700 city size assuming that cities in China grew at the same rate as the overall population between 1700 and 1820. Of course, these estimates should be interpreted with some caution, but they provide a rough idea of China's urban structure at the beginning of the century that saw the start of the *Industrial Revolution*.

Market size and city size. Before calculating the measures of spatial competition developed in Section 2 for China, we present some descriptive statistics that relate to market size and city size. These are shown in Panels (A)-(C) in Table 4. To facilitate comparison, we include the corresponding statistics for England, although some of them were already reported in Table 1.[25] Not surprisingly, Panel A shows that China was huge compared to England in terms of total population. Although population growth was much higher in England, the difference in levels was still very large in 1850. If, instead, we focus on the urban population as the relevant measure of

[25] In order to compare China and England, note that for England we have imputed population values for 1776 and 1820, assuming that city-specific growth rates between two consecutive years in the Bairoch et al. (1988) dataset were constant.

Table 4: Spatial Competition: England and Northwest Europe vs China

Year	1600	1700	1776	1800	1820	1850	1893
A. Total Population (millions)							
England	4	5		8	10	15	24
China	160	138		381	412	386	
B. Urban Population (millions)							
England	0.3	0.9	1.5	2.6	3.8	7.0	
China		5	11.3		14.4		18.4
C. Average City Size (thousands)							
England	19.1	25.1	30.5	21.2	30.3	50.8	
China		33.7	57.2		66.1		77.0
D. Population access $\leq$ 20 km (S_1, thousands)							
England	0.0	1.3	26.6	73.8	107.2	190.6	
China		2.9	5.2		6.1		5.7
E. Population access, spatial decay $\delta = 1.5$ (S_2, thousands)							
England	0.2	0.6	1.5	4.1	6.1	11.6	
China		0.9	1.8		2.2		2.7
F. Distance to reach same number of consumers (S_3, km)							
England	70	44	37	21	21	21	
China		181	173		164		157

market size, Panel B shows China was still much bigger than England.[26] Panel C reports average city sizes in England and China. Whereas average city size increased over time in both countries, at any point in time it was greater in China than in England. For example, in 1700 the average Chinese city had a population of 33,700, around 35% larger than the average English city. This difference increased over time, with Chinese cities becoming more than twice the size of English cities. Given that England and China had very similar income per capita around 1600, these different measures suggest that market size alone is an unlikely explanation for why England industrialized first.

5.1.2 Measures of Spatial Competition

Of course, our theory does not identify market size/city size as the key factor in determining an economy's take-off. Instead, the degree of spatial competition is what matters. We now compare the different measures of spatial competition in the two countries. Panel D reports the population access in a radius of 20 km, what we referred to as measure S_1^r. In 1776, around the time of Adam

[26]Rather than comparing China to England, we could focus on Northwest Europe, the broader region to first industrialize, as the relevant counterpart of China. If we take Northwest Europe to be Great Britain, France, Belgium, Netherlands and Germany, the differences become obviously smaller, though China continued to be larger in terms of both its total population and its urban population.

Smith's scything critique of the English craft guilds, market access of the average English city was about five times that of the average Chinese city. By 1820, when English craft guilds were severely weakened and about to be abolished, that advantage had risen to an 18-fold difference. At the end of the nineteenth century, market access of the average Chinese city was similar to that of the average English city 150 years earlier.

The same pattern emerges using our other two measures of spatial competition. Panel E reports S_2^r, the distance-weighted access to population with a spatial decay parameter γ of 1.5. The difference between England and China is less stark with this measure. Nevertheless, in the early nineteenth century, when resistance to innovation broke down in England, market access was between two and three times larger in England. Lastly, Panel D, which is our preferred measure of spatial competition, shows that the average distance to reach the same number of consumers started off being about four times larger in China compared to England. Whereas this distance declined in England, it changed very little in China over the period. Moreover, when we do the same calculation including the broader set of cities in Yue, Skinner and Henderson (2007), these distances are hardly changed. This implies that our findings do not depend on our focus on prefecture-level cities.

These different measures show that whereas the degree of inter-city competition increased dramatically in England, it only slightly increased in China. Furthermore, they show that the level of inter-city competition was a lot lower in China than in England over the entire period. This suggests that the capacity of the average English city to capture market share at the expense of its close-by neighbors was much stronger than that of the average Chinese city.

5.2 Guilds in China

Fifteenth century China and England differed much in terms of their political and social structures. Although politically unified, China was an empire consisting of socially and culturally distinct areas. Yet, travel to far-away administrative and commercial centers was often necessary and rewarding. Those who traveled organized themselves according to their place of origin to help each other during their stay. These native-place organizations that served to mutually assist its members were called *huiguan, hui-kuan* or *tung-hsiang-hui* (meaning "assembly" or "club-houses"). Although many of the names of the *huiguan* referred to some province, membership was usually confined to a smaller area, such as a county, a city, or a few villages.

The relevant point for our theory is that although the *huiguan* often catered to the economic interests of their members, they did not monopolize specific sectors, and therefore are different from what we call guilds in our model. In a city such as Beijing, for example, there would not have been *one* cloth guild controlling the entire industry, but rather many different *huiguan*, representing different regions in China, many of which might have had some presence in the cloth industry. Consistent with this, in their heyday, there were up to 400 *huiguan* in Beijing alone (Rozman, 1973). In that sense the *huiguan* did not impede within-sector competition in Chinese cities. If anything, in their early days the *huiguan* enhanced competition by counteracting the monopolistic power of the government-appointed headmen (*hangtou* or *hanglao*) who set prices in different crafts and trades. These *huiguan* also increased competition by facilitating long-distance inter-regional trade, and in this sense were similar to merchant guilds in Europe.[27]

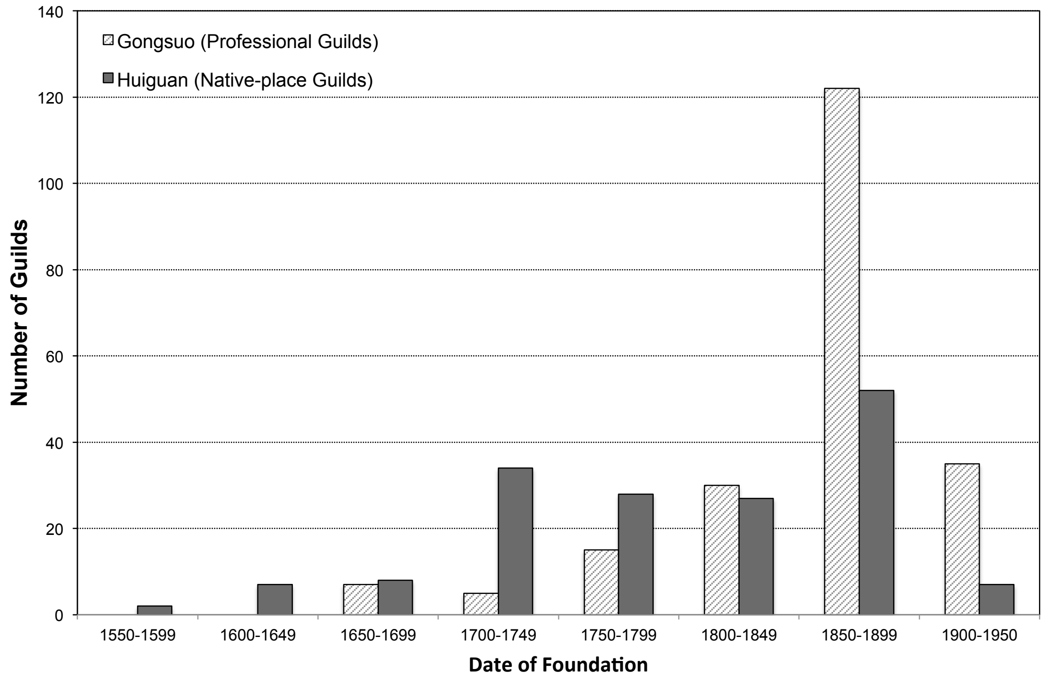
Similar to the European merchant guilds, the prevalence of the *huiguan* diminished over time. The transition began in the late seventeenth century, evolving into a system in which European-style, occupation-based local craft guilds dominated. Those occupation-based guilds were referred to as *gongsuo*, literally meaning "public hall" or "meeting place" (Moll-Murata, 2008). There is no simple way of dividing Chinese guild history into a *huiguan* and a *gongsuo* period. Using data from Moll-Murata (2008), Figure 1 shows the relative evolution of *huiguan* and *gongsuo* by their founding period.[28] As can be seen, the big push towards *gongsuo* is associated with the second half of the nineteenth century. This coincides with a growing European presence in the region following the Opium Wars, and an increasing availability of imported European labor-saving technologies. In terms of our theory, the emergence of guilds in China should thus be situated in that time period.

Similar to the Europe craft guilds, the *gongsuo* emerged earliest in the largest cities. Between 1650 and 1700 the first *gongsuo* appeared in cities such as Beijing, the country's capital, and Suzhou, an important inland port city in Jiangsu province. Between 1780 and 1850, a total of twelve *gongsuo* were established in Suzhou, including those of tailors, hatters, cabinet-makers, tanners and butchers. The Chinese *gongsuo* pursued policies similar to the European crafts guilds

[27] For China see, e.g., Shiue and Keller (2007) and Moll-Murata (2008); for Europe see, e.g., Gelderblom and Grafe (2010).

[28] The database contains 516 named pre-1900 guilds of which 347 can be classified as either *huiguan* or *gongsuo*.

Figure 1: Native-place *(huiguan)* vs Professional *(gongsuo)* Guilds by Date of Foundation in China



prior to the latter's decline.[29] The *gongsuo* provided public goods, collected tax for the authorities, and regulated production, prices and trade. Although early on the *gongsuo* did not acquire the same judicial authority over their trade as European craft guilds did, they were *de facto* very effective in monopolizing professions. The evidence reveals that they "establish rules and compel obedience to them; they fix prices and enforce adhesion; they settle or modify trade customs and obtain instant acquiescence; they impose their will on traders in and out of the gilds [sic], and may even, through the measure known as the 'cessation of all business' cause the government to modify or withdraw its orders; and their end, that of having the absolute control of their craft, is obtained by methods of which some are indicated above" (Morse, 1909, p. 31).

The *gongsuo* thus obtained "an enormous and almost unrestrained control over their respective trades" (Morse, 1909, p. 21). If anything, they might have been more powerful than their European counterparts. Certainly, they were were far more successful at restricting trade. One observer of China remarked, for example, that "it is not too positive to write, that it is within

[29]The Great Guild of Newchwang, for example, was composed of all the merchants and bankers in this city port. It regulated quality and prices and punished any member who cut rates. Only members and those whom they invited were allowed to be active in the money markets. The guild regulations stated that "visitors, however, shall not be allowed to bid in the market, and all their business must be transacted through a member" (Morse, 1909, p. 51). Other guilds in that city controlled the grain, fuel, and straw markets.

the power of the guilds to interfere with commercial intercourse in China, to seriously impair the commercial relations of Western nations with China, and to comparatively drive from the trade markets of the Empire the foreign products now sold in those markets, or to make the demand for them so unremunerative as to partially destroy importation, while the Central Government, if it had the inclination or the means, would scarcely have the courage to remove the organized obstruction or to punish the obstructors" (Jernigan, 1904, p. 103).

The strict control that the *gongsuo* imposed on their members could not but hinder innovation. The guilds were particularly active in preventing competition from introducing new, labor-saving innovations, as noted, for example, in a first-hand account by MacGowan (1886):

> Native merchants imported from Birmingham a quantity of thin sheet-brass for manufacturers of brass utensils at Fatshan, throwing out of employment a class of coppersmiths whose business consisted in hammering out the sheets heretofore imported in a thick form; but the trade struck to a man, would have none of the unclean thing, and to prevent a riot among the rowdiest class of the rowdiest city in the empire, the offending metal was returned to Hongkong. Further, a Chinese from America the other day imported thence some powerful sewing machines for sewing the felt soles of Chinese shoes to the uppers, but the native sons of St. Crispin destroyed the machines, preferring to go on as their fathers did, while the enterprising Chinaman returned to Hongkong, a poorer and sadder man. Again, some years ago a progressive Chinaman set up a steam-power cotton mill, only to be made useless by the very simple plan of the growers refusing to send in a pound of cotton. Filatures from France, effecting not only a wonderful saving in time and money but improving the quantity and quality of the output of silk, succeeded at Canton for a while, and were introduced latterly by Chinese capitalists into the silk-rearing districts, only to be destroyed and wrecked by the country-folk" (p. 183).

The evidence reveals that adoption of labor-saving machinery was often hindered by the threat of social disorder due to the job loss. Consider, for example, a report sent from China to the Foreign Office in London, concerning the mechanization of cotton cloth production in Shanghai in 1876:

> During the past year [1876] an attempt was made to launch a Steam Cotton-Mill Com-

pany at this port [Shanghai], for the purpose of manufacturing cotton piece-goods from native-grown cotton ... similar . . . to the goods at present made by Chinese . . . but with the advantages of English machinery and steam-power, . . . When the enterprise came to be generally known to the Chinese newspapers, the attitude of the Cotton Cloth guild became so alarming that the native supporters [of the project] drew back. An idea was unfortunately circulated among the natives, and more particularly amongst the workers of native hand-made cloth, that the trade would be immediately put an end to if such a scheme were put into operation, whereupon the guild passed a resolution to the effect that no clothes made by machinery should be permitted to be purchased. . . The local officials refused their support or countenance the scheme through fear of causing riots amongst the people. . . " (Great Britain. Foreign Office. 1875-8. pp. 17-18 in the report for 1877).

The report makes clear that guilds had the power to block new technologies. Attempts to mechanize other industries faced similar barriers. In 1868 for example, the "fiercest resistance" to mechanizing the silk industry "came from the organized silk handicraft and commercial guilds" (Ma, 2005, p. 201).

Importantly, the fear of riots suggests that the poor relief measures that prevailed under the Qing period were inadequate to mitigate the threat to social order associated with the introduction of labor-saving machinery. A few such measures did exist, but they were insufficient. One was the granary system, run mainly by the state and aimed at alleviating food shortages. Another was the "clan trust", the use of common property by the kin group to assist clan members in need.[30] These measures were not well-equiped to face the challenges of industrialization. The granary system, which was in decline, was not designed to assist the poor, but rather to dampen high grain prices when harvests failed. The clan trust did help the poor, but it was confined to clan members, and hence limited to clans with sufficient resources. The inadequacy of the Chinese poor relief system is an important difference compared to England.

Despite the threat of social disorder, by the end of the nineteenth century increasing competition from Western goods that were either cheaper or better than the equivalent local goods started to reduce the ability of the *gongsuo* to maintain the status quo. In terms of our analysis,

[30] For an in-depth description of these poor relief policies, see Bradstock (1984), Greif, Iyigun and Sasson (2012), Greif and Iyigun (2013) and Will and Wong (1991).

spatial competition between Chinese firms in different cities and between Chinese producers and Western importers had risen. For example, the introduction of Western-style hats reduced the demand for traditional-style hats, and the local makers of the traditional brass-wash basins found it difficult to compete with the lighter and cheaper imported enameled basins (Bradstock, 1984, p. 228). The increase in spatial competition on the one hand and the technological stagnation on the other were increasingly undermining Chinese industry by the late nineteenth century.[31] The immediate effect of the intensification in spatial competition was a rise in economic conflicts. For example, "the satin guild in Soochow was forced to seek an injunction in 1898 against natives of Nanking who had illicitly begun making certain parts found on looms, a task which had historically been passed down from father to son among a particular subgroup within the guild" (Bradstock, 1984, p. 224).

Consistent with this timing of events, the *gongsuo* began to decline at the end of the nineteenth century during to the late Qing period, with the final ones disbanding when the Chinese communist party came to power in 1949 (Moll-Murata, 2008). The decline of the professional guilds in China coincided with the increase in spatial competition, driven by an intensification of foreign competition and a greater integration of China's internal market. As late as 1870, there was no railroad system in China, but by 1913 there were 13,441 kilometers of railroads, greatly facilitating internal trade. By that time China had also become increasingly integrated into the world economy. Whereas at the end of the First Opium War China opened five "treaty ports" to international trade, this number increased to 92 by 1917. As described by a spokesman for the Shanghai builders' guild in the early twentieth century, "our knowledge gradually narrows, our skills deteriorate, and our tools fall out of date. Foreigners then exploit this opportunity to export their goods to our country... The European fad comes sweeping through our country like a flood, and there is no stopping it" (Bradstock, 1984, pp. 228-9).

5.3 The Great Divergence

Having provided a history of Chinese guilds and having shown how their rise and decline related to the degree of spatial competition, we now explore the importance of spatial competition for the *Great Divergence* within our calibrated structure. In particular, we examine whether the greater

[31] For a discussion of other reasons, such as population growth, military defeats and limited taxation capacity, see, for example, Bradstock (1984), Rosenthal and Wong (2011) and Vries (2015).

distance between Chinese cities can explain the delay in China's industrialization.

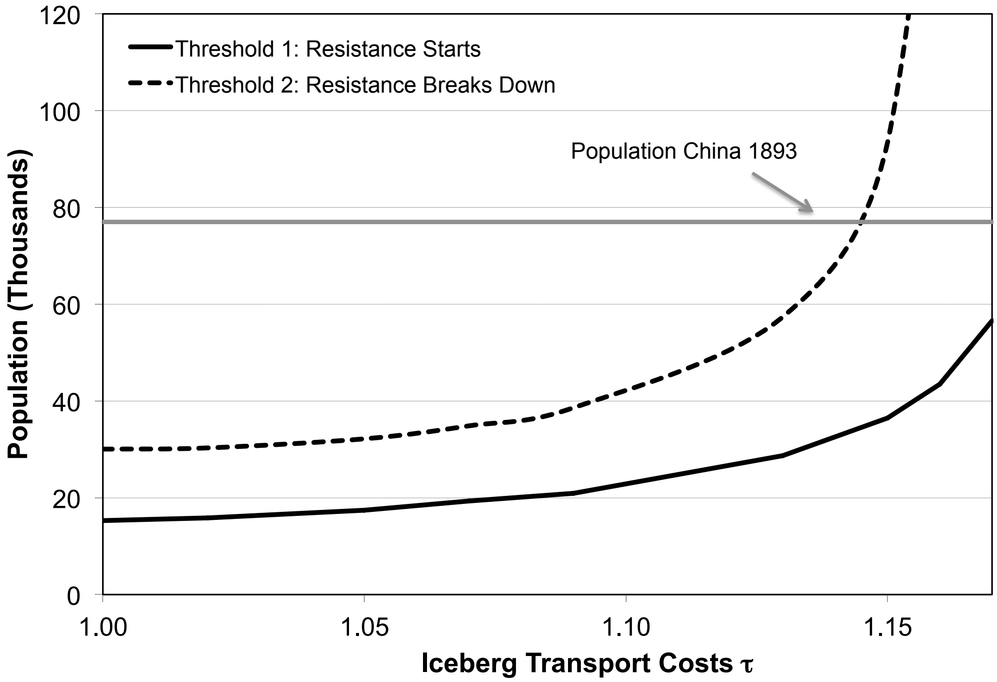
Rather than narrowly focusing on the model's predictions for iceberg costs consistent with the average distance between same-size cities in China between 1700 and 1893, we start by exploring the general role of transport costs. In the calibrated model we solve for the city size threshold where guilds first form and the city size threshold where guilds first disband as we increase transport costs. Figure 2 shows these two thresholds in function of the iceberg costs. As expected, both thresholds increase as iceberg costs increase. Less expected is the sensitivity associated with the upper threshold. In particular, for $\tau > 1.15$, the upper threshold rapidly goes to infinity, implying that increases in city size no longer cause resistance to break down.[32] For these high iceberg costs, a deviating industry in the East cannot gain enough market share by adopting the more advanced technology and selling it a lower price in the West. Effectively, this is similar to the no trade case where Proposition 1 applies: as industry profits from deviating do not change sufficiently as the city size increases, skilled workers cannot be compensated for reduced wages, and hence there is no take-off.

To determine the city sizes and dates when guilds should have appeared and when they should have started to disappear in China, we need to have values for the iceberg costs in China between 1700 and 1893. We obtain those by using the estimated iceberg cost for England in 1400 of $\tau = 1.09$ and multiplying it by the ratio of the average distance to same-sized cities in China in a given year to the average distance to same-sized cities in England in 1400. As listed in Table 4, the distance between same-sized Chinese cities was 181 km in 1700, 173 km in 1776 and 157 km in 1893. Recall, that for England in 1400 the distance between same equal-size cities was 93 km. With these differences and a calibrated England's inter-city iceberg trade cost of 1.09 in 1400, we arrive at an iceberg cost in China of 1.18 in 1700, 1.17 in 1776 and 1.15 in 1893.

For $\tau = 1.15$, the calibrated model implies that guilds should have stopped blocking labor-saving technology in China when average city size reached $93,300$. This is well above the average

[32] When cities become larger and the distance between neighboring varieties becomes smaller, two forces are at work. On the one hand, it becomes easier attract additional customers, because competition between neighbors strengthens. On the other hand, it becomes harder to attract additional customers, because the curvature of the Lancaster compensation function when $\beta < 1$ implies that customers who are very close to their ideal variety are difficult to pull away. For relatively low values of τ, the former force dominates the latter, whereas for relatively high values of τ, the latter force dominates the former. The intuition is straightforward: higher values of τ are associated with less competition, but more varieties. Stealing away customers is harder both because competition is weaker and because more customers are relatively close to their ideal varieties. As a result, for a high enough value of τ, we find that the upper threshold goes to infinity.

Figure 2: China: Resistance to Technology Adoption



city size in 1893 of $77,000$. Recall from the historical account of guilds in China that many of the *gongsuo* remained in existence until the Communist Revolution. We conclude from this experiment that our theory offers a plausible explanation for the *Great Divergence*.

Although successful in this respect, the model is less successful in predicting the date at which technology-blocking guilds formed in China. For $\tau = 1.17$, the lower threshold as predicted by the model occurs when city size reaches 56,600, similar to the actual city size of 57,200 in 1776. Although a few *gongsuo* did form in the second half of the seventeenth century, Figure 1 shows that the big shift towards *gongsuo* happened in the second half of the nineteenth century.

This inability of the model to match the late appearance of technology-blocking guilds in China is not surprising. For resistance to occur, the labor-saving modern technology must first become available. Our reading of the historical evidence strongly suggests that the major labor-saving technologies in China were imported from England, and this did not happen until after the Treaty of Nanking in 1842, at the end of the First Opium War. In that sense, the question of China's late industrialization is not why it did not happen between 1750 and 1850, but rather why it failed to materialize once the country got access to modern technologies after its opening up to trade with England. A separate and equally important issue, not addressed in this paper, is why

China did not develop its own labor-saving technologies earlier.

Before ending this section, we should point out that all parameters except the iceberg costs are kept at the values calibrated to the English experience. An obvious question is whether it is appropriate to use the benchmark values for the purpose of examining China's economic history. One clear difference between England and China in the seventeenth century is the urbanization rate. According to Table 2, the English urbanization rate in 1600 was 7.5%, whereas for China in 1700 it was roughly half this number, 4%. When examining the Chinese case, we could solve the model with $\mu = 0.96$, but this would imply a skill premium of more than 3, well above the estimates by Van Zanden (2009), between 1.25 and 1.85 for China in this era. Thus, to calibrate to $\mu = 0.96$, it would be necessary to adjust α for China as well. When this is done, the results are essentially the same as using the English values for both μ and α.

6 Concluding Remarks

In this paper we have argued that spatial competition may be a key determinant of long-run development. The novel mechanism we have proposed is based on the interaction between the spatial distribution of cities and the endogenous rise and decline of technology-blocking institutions. Because these institutions — which we refer to as guilds — are organized at the level of cities, their monopoly power is limited by the competition from neighboring cities. With strong enough inter-city competition, profits from introducing labor-saving technology are sufficient to compensate guild members for the negative effects of innovation, and their resistance breaks down.

Our theory contributes to a better understanding of the *Industrial Revolution* and the *Great Divergence*. England experienced a large increase in spatial competition in the seventeenth and eighteenth centuries. In a calibrated version of our model, this increase in inter-city competition is able to predict the timing of England's take-off. Historical and empirical evidence further support the hypothesis that spatial competition critically affected the profitability for firms to adopt new technologies and the incentives for guilds to block those innovations. When comparing China to England, our model correctly predicts the later development of China. Although China's cities were larger than England's, they were geographically much farther apart. The lower intensity of spatial competition in China meant that industries in a particular city could not easily capture customers of those same industries in neighboring cities, making it less likely for guilds to give up resistance.

We believe that the mechanism described in this paper can be used to gain insight on a number of issues. One such area relates to the argument that political fragmentation contributed to Europe's earlier take-off. A possible interpretation is that inter-state competition for resources spurred military innovation that spilled over into civil society (Jones, 1981; Lagerlöf, 2014). Extending our model to the national level would provide an alternative interpretation, based on the relation between spatial competition and innovation. This would be consistent with Mokyr (2007) who describes how political fragmentation led to greater inter-city competition for talent in Europe. Another area that deserves further attention relates to the geographic span of technology-blocking institutions. Whereas craft guilds were typically organized at the level of industries and cities, in a world with greater inter-city competition we would expect guilds to expand their reach to control multiple cities. In fact, as the *Industrial Revolution* unfolded, we saw the emergence of social movements, such as trade unions, organized at the national, and sometimes even at the international, level.

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