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Spatial competition, innovation and institutions: the Industrial Revolution and the Great Divergence

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Abstract
This paper considers the possible contribution of spatial competition to the *Industrial Revolution* and the *Great Divergence*. Rather than exclusively focusing on the incentives of producers to adopt labor-saving technology, we also consider the incentives of factor suppliers' organizations such as craft guilds to resist. Once we do so, industrialization no longer depends on market size per se, but on spatial competition between the guilds' jurisdictions. We substantiate our theory's claim of spatial competition being an important channel for industrialization (i) by providing historical evidence on the relation between spatial competition, craft guilds and innovation, and (ii) by showing that the calibrated model correctly predicts the timings of the *Industrial Revolution* and the *Great Divergence*.

Keywords Industrial Revolution · Great Divergence · Craft guilds · Spatial competition · Inter-city competition · Market size · Endogenous institutions · Innovation · Adoption of technology

JEL Classification N10 · O11 · O14 · O31 · O43

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1 Introduction

Why do some countries develop earlier than others? Why was England the first nation to experience sustained increases in its living standard? One common answer, dating back to Smith (1776), emphasizes increases in market size in the period leading up to the *Industrial Revolution*.[1] Larger markets, it is argued, made it more profitable for firms to incur the fixed costs of introducing modern technologies that favored large-scale production, thus spurring industrialization. Although the assertion that market size matters is not unreasonable when comparing England to other European countries, it is less compelling when comparing England to China for the simple reason that, by almost any measure, markets were larger in China in the pre-modern period, and yet industrialization there had to wait until the second half of the twentieth century.[2] Even upon gaining access to the modern technologies of the West following the Opium Wars, China failed to industrialize, giving rise to the so-called *Great Divergence* between the West and the East.

This paper argues that a market-size-only theory of the *Industrial Revolution* is incomplete because it ignores the incentives of other actors in the economy, particularly those with interests vested in the status quo, to counter the efforts of would-be innovators and derail the industrialization process. On the eve of the *Industrial Revolution*, these actors were, to a large extent, craftsmen who expected a reduction in their earnings due to the diffusion of new technologies.[3] Faced with the prospect of lower earnings, these factor suppliers reacted by organizing themselves with the goal of preventing the introduction of modern modes of production. In many instances, this response involved a transformation of existing professional societies, such as craft guilds, from organizations with some positive economic or social significance, to ones bent on stopping technological change. In our view, the endogenous comparative evolutions of these institutions in China and England are important for understanding the *Industrial Revolution* and the *Great Divergence*.

The key tenet of this paper is that once we allow for the emergence of organized groups of factor suppliers, industrialization no longer depends on the size of the market, but on the degree of spatial competition between jurisdictions, which in the pre-modern era corresponded to cities, as power was concentrated at that level, rather than at the national one. Though spatial competition and market size are related concepts, they differ in a crucial way. In particular, whereas market size measures a producer's access to consumers, both in the own city and in other locations, spatial competition measures the ease by which a producer in one city is able to capture consumers in other cities. Although greater inter-city competition implies a bigger market size, the reverse is not always true. For example, an increase in the population size of cities obviously increases the market for producers in these cities but it does not make it easier to capture consumers from other cities if trade is prohibitively costly.

This difference between market size and spatial competition translates into an important asymmetry in the theory we develop: although having access to a greater number of own-city and other-city customers gives an individual firm greater incentives to adopt labor-saving technology, it is only by having access to a larger number of other-city customers that

1 See, for example, Kremer (1993), Kelly (1997), Peretto (1998) and Desmet and Parente (2012). In addition to market size, other factors that have been shown to contribute to industrialization include natural resources (Pomeranz 2000), the demographic transition (Galor and Weil 2000), education (Galor and Moav 2002), and institutions (North 1981).

2 The evidence on whether market size was greater in England than in other Western European countries is mixed. Shiue and Keller (2007), for instance, supports this view, whereas Daudin (2010) does not.

3 Other actors who also resisted industrialization and mechanization were large-scale landowners (see, e.g., Galor et al. 2009) and sometimes agricultural workers (see, e.g., the Swing Riots of 1830).

industries can overcome the resistance by factor suppliers with interests vested in the status quo. Thus, an increase in market size without an increase in inter-city competition will see the emergence of institutional barriers to development, but will never lead to their breakdown. Market-size-only theories of the *Industrial Revolution* miss this point. This paper's premise is that intensifying spatial or inter-city competition in England between the sixteenth and eighteenth centuries led to an early demise of the craft guilds and the introduction of labor-saving technology, whereas in China the absence of meaningful spatial competition meant that these events had to wait until the twentieth century.

We demonstrate this mechanism in a model that consists 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 one, which all producers start out using, and a modern one, which can be adopted. The modern technology has two advantages: it can employ unskilled workers drawn from the hinterland, and it is characterized by greater output per production worker. However, it comes at the disadvantage of requiring a fixed adoption cost. The assumption that the modern technology does not require skilled labor provides the incentives for artisans to form groups to block the introduction of the modern technology. These are the types of institutions whose endogenous evolution we study in this paper.

The model aims to capture the idea that stronger inter-city competition makes varieties produced in different cities more substitutable. This is the essential feature of the model in terms of its mechanics. To that end, we choose a preference construct that yields a price elasticity of demand that is increasing in the intensity of competition.[4] As a result, when spatial competition is stronger, mark-ups fall and firms must become larger to break even. This increases the gains from switching to the modern technology because a larger firm can spread the fixed cost of adoption over a greater quantity of output. Therefore, more intense spatial competition increases the incentives of firms to adopt the modern technology. Spatial competition, however, also affects the incentives of skilled workers to organize for the purpose of blocking the modern technology's introduction for the simple reason that they face the unpleasant prospect of seeing their wage earnings decrease as they must compete with unskilled workers from the hinterland. Firms in a given industry and city must overcome this resistance if they want to operate the modern technology by compensating them for any reduction in earnings. This can only happen if industry profits are sufficiently large to compensate skilled workers for any reduction in earnings.[5] Resistance ends and the economy takes off when profits reach this point.

Because the profitability thresholds are different for when adoption is profitable and when skilled craftsmen can be sufficiently compensated, the model predicts three stages in a nation's trajectory. Starting off in a situation where spatial competition is weak, either because populations are small, transport costs are large, or distances between cities are small, no firm can pay the fixed innovation cost associated with making the new production process operational. In this case the equilibrium is characterized by all firms in all industries and cities using the artisanal technology and no technology-blocking guilds existing anywhere. As spatial competition strengthens, a first threshold is reached where an individual firm in a given city and

[4] In particular, we choose a preference construct based on Lancaster's (1979) trade in ideal variety model, which in turn is an extension of Hotelling (1929). This preference structure and the implied mechanism is at the heart of Helpman and Krugman (1985) and Hummels and Lugovskyy (2009).

[5] The use of industry profits to buy out craftsmen is meant to capture a variety of methods employed to break worker resistance. One such method was the poor laws, financed by local taxes and put in place to help displaced workers. Other methods included hiring private security to fortify factories, appealing to the judiciary to rule in the favor of industry on worker petitions, and lobbying the government to send out troops.

industry becomes large enough so that its profits cover the fixed innovation cost. In spite of this, no firm in that city and industry is able to switch to the modern technology because the profits are too small to compensate the incumbent skilled workers for their reduced wages, prompting organized opposition by craft guilds. 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 spatial competition becomes sufficiently intense that the second threshold is met where industry profits from innovation are large enough to compensate the skilled workers. At that point guilds disband, the modern technology is adopted and the economy takes off.

Importantly, whereas an increase in city size, if large enough, is sufficient for guilds to form, it is never sufficient, *per se,* for guilds to end their resistance and for industrialization to take hold. An increase in own city size works like a reduction in transportation costs or distance between cities to affect the date the first profit threshold is reached, but it does nothing with respect to the second profit threshold. This is the key insight of the model. To understand why this is the case, consider a world where for whatever reason there is no inter-city trade. For a firm to find it profitable to introduce the modern technology, it must be able to capture customers at the expense of other firms in its industry. As city size becomes larger, this becomes easier, because varieties are more substitutable. Thus, even in the absence of inter-city trade, with a large enough increase in city size, an innovating firm will be able to capture enough customers from non-innovating competitors so as to justify paying the fixed cost of adopting the modern production process. However, once this happens and the skilled workers form a guild to block adoption by any firm in their city and industry, further increases in city size will not change the incentives of the guild to resist the modern technology if there is no inter-city trade. Given that the guild is organized at the level of the city and industry, its resistance can only be overcome if profits of all firms in its city are large enough to compensate its members for the reduction in wages. However, since household expenditures on a particular good are independent of the technology used, industry revenues (and profits) can only be increased if the innovating city can gain customers at the expense of the non-innovating city. Inter-city trade, and not intra-city trade, is thus critical for an economy's take-off.

To evaluate the historical relevance of the causal relation between spatial competition and industrialization, no single piece of evidence or methodology is perhaps sufficient. We therefore take a multifaceted approach, providing historical and quantitative support for our conjecture. In particular, we supply four different types of evidence, which together suggest that inter-city competition could have been an important determinant of the timing and location of the *Industrial Revolution*. First, using city size and location data, we quantify how spatial competition increased in England between 1600 and 1800. Using the same metric, we show that China at the end of the nineteenth century was about 200 years behind England. These observations form the starting point of our theory. Second, we provide a historical account of guilds in England and China, as they relate to spatial competition and innovation. In particular, we show that the degree of spatial competition affected the prevalence and intensity of resistance to labor-saving technologies. Third, we undertake a calibration exercise to examine whether the model is quantitatively consistent with England's development. More specifically, we calibrate the model to the date when English guilds started blocking the introduction of labor-saving technologies on a large scale, and then determine the date predicted by our model when resistance should have ended, given the degree of spatial competition in England. We find that the model predicts the timing of the *Industrial Revolution* fairly well. Fourth, as a final assessment, we apply our model to Northwest Europe and China. Using data on spatial competitions on these regions of the world, the model predicts an industrial take-off in Northwest Europe lagging that of England's, and an industrial take-off in China being delayed until well into the twentieth century.

The literature that seeks to understand why the *Industrial Revolution* first occurred in England is extensive. Diverse explanations abound, some of which are: proximity to cheap energy (Pomeranz 2000), greater patience or stronger preferences for education (Galor and Moav 2002; Clark 2007), better institutions (North 1981; Mokyr 1990), and market size and integration (Voigtländer and Voth 2006; Shiue and Keller 2007; Boucekkine et al. 2007; Desmet and Parente 2012). [6] Among the subset of papers that focuses on market size, none suggests that the degree of spatial competition was relevant. Indeed, in these other theories, 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 not enough to bring about the economy's take-off.

Our paper is related to at least three 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 same preference construct as in this paper to show how an increase in market size facilitates the adoption of more productive technology. Although we borrow their basic setup, there are some key differences, the most important one being in this paper he endogenous formation and collapse of institutions that block the introduction of more productive technology. As a result, in our paper spatial competition, rather than market size, is what drives take-off.

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), Dinopoulos and Syropoulos (2007) and Greenwood and Weiss (2018). 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 local market size and the theory remains silent on how an economy escapes an equilibrium where both regions block innovation. Their theory is useful to understand historical examples where a city relaxed guild regulations when faced with stronger competition from the hinterland or from non-guilded cities. However, it is far less useful to understand how modern technologies were introduced when their large-scale use outside of guilded cities was legally prohibited or when the relevant geographical areas were all under guild control. In this regard we see our work as being complementary to theirs and together encompassing the full range of possibilities. In Desmet and Parente (2014), although workers form guilds or unions to block the introduction of a better production process until they can be defeated, there is no role for spatial competition and geography in their break-up because guilds form at the firm level rather than at the industry level. Increases in own-city size are therefore sufficient to bring about the demise of the guilds in Desmet and Parente (2014).

A last strand is the vast economic history literature on guilds and their attitude towards innovation. Although scholars disagree on the precise role of guilds in economic growth, there

[6] For a comprehensive list, see McCloskey (2010).

is a broad consensus on two key facts that are important for our theory.[7] First, although craft guilds did not start off as anti-competitive organizations bent on slowing down technological progress, they increasingly turned anti-technology when innovation threatened jobs (Epstein 1998; Mokyr 1997). Second, there was less resistance to new technologies when spatial competition was stronger. Adoption of new labor-saving machinery was more likely when nearby locations were doing the same (Randall 1991).

The rest of the paper is organized as follows. Section 2 provides historical and empirical evidence for England and China 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 of firms to innovate, and the incentives of guilds to resist. Section 4 examines the quantitative predictions of our theory for the timing of take-off in England, Northwest Europe and China. Section 5 concludes.

2 Spatial competition, guilds and innovation

The paper's central thesis is that inter-city competition in England may have been instrumental for its earlier take-off compared to China. In this section, we document the significant increase in spatial competition in England in the centuries leading up to the *Industrial Revolution*, and show that China at the end of the nineteenth century was comparable to England in the seventeenth century. For later use in the quantitative exploration of our theory, we additionally document the degree of inter-city competition in Northwest Europe.[8] The section also describes the history of the craft guilds in England and China, focusing on how their attitude towards innovation depended on the strength of inter-city competition.

2.1 The evolution of spatial competition

We proceed to describe the evolution of spatial competition between the fifteenth and nineteenth centuries in England, Northwest Europe and China. Doing so requires estimates of population by city, as well as distances between cities.

Population data For England and Northwest Europe, city populations are taken from Bairoch et al. (1988). We focus on the 1400–1850 period, restricting attention to cities with populations exceeding 5000 inhabitants.[9] Northwest Europe includes Great Britain, France, the Benelux, Germany and Italy.

China poses a greater challenge as there is no readily available panel of city-level population data for the corresponding period. To construct such a panel, we make use of three different data sources. The first is Yue et al. (2007), which provides the most detailed historical data on city populations, but only for a single year, 1893. It covers all of China, with the exception of Tibet, and it lists 2403 cities that served as administrative capitals of prefectures or counties during the period 1820–1893.[10] The data set includes population estimates for

[7] Whereas some argue that they were anti-competitive and anti-technology (Smith 1776; Pirenne 1936; Ogilvie 2008), others take a more benign view, emphasizing that guilds fostered the diffusion of knowledge (Hickson and Thompson 1991; Epstein 1998, 2008; Richardson 2004; De la Croix et al. 2018).

[8] Another reason for considering Northwest Europe is that its total population is more comparable to China's.

[9] Bairoch et al. (1988) panel covers the period from 800 to 1850, with one observation per century until 1600, and two observations per century after that. It includes all cities that had a population of at least 5000 in one of the years for which there are observations.

[10] In addition to the 18 provinces of China Proper, it also includes Xinjiang and four provinces-in-the-making north of the Great Wall: Shengjing (later Liaoning), Jilin, Heilongjiang, and Nei Menggu.

many small towns; in fact, 38% of cities listed have a population below 4000. As we apply the same population size cutoff as Bairoch et al. (1988), we are confident that the Chinese data are exhaustive in their 1893 coverage of cities with a population above 5000 .[11] This makes the detail of the Chinese data comparable to that of the English data. The second data source is Cao (2000), which reports population data by prefectures for 1776, 1820, 1851, 1880 and 1910, and the last is Maddison (2001) which provides information on urbanization rates in China going back to 1500.

Starting with the 1893 data, the two additional data sources allow us to impute city-size data for earlier years. In particular, we calculate the growth rate of the prefecture populations between consecutive dates given in Cao (2000), and then assume that each of the cities in the Yue et al. (2007) dataset grew at the same rate as its closest prefecture-level city. This yields imputed city population levels in 1776 and 1820. For 1700, we also rely on the finding of Maddison (2001) that the urbanization rate in China was stable between 1700 and 1820. Therefore, the imputation of the 1700 city sizes assumes that cities in China grew at the same rate as the overall population between 1700 and 1820. Of course, these imputations only give an approximate picture of the degree of inter-city competition before 1893 in China. However, as we will make clear later, our main conclusion does not depend on these imputed numbers; the central quantitative finding of this paper is that China did not have the conditions to industrialize even in 1893, implying that China's take-off had to wait until the twentieth century.

Urban population and city size Before turning to the construction of different measures of the degree of spatial competition, we present some descriptive statistics that have been used in the literature as proxies for market size. These proxies, reported in Table 1, Panels A through C, are total population, urban population and average city size.[12] In terms of total population and urban population, China was well ahead of England and Northwest Europe at any point in the 1700–1820 period. As for average city size, shown in Panel C, although it more than tripled between 1400 and 1800 in England, it still was not any larger than average city size in China on the eve of the *Industrial Revolution*. In Northwest Europe, average city size was far below that of China in any comparable year. These different proxies suggest that a theory of take-off based on either city size or aggregate (urban) population alone is not plausible.

Measures of spatial competition By measuring the degree of spatial competition, we aim to capture the ease by which an industry in one city can sell to customers of *other* cities. Since there is no single accepted measure of inter-city competition, we construct three different indices. Before doing so, we introduce some notation. Denote the set of cities by $\mathcal{R}$, with $r \in \mathcal{R}$ referring to a particular city; denote the distance between cities r and r' by $\delta^{rr'}$; and denote the population size of city r by L^r.

[11] To be precise, Yue et al. (2007) do not report exact city sizes, but rather classify cities by size bins, with the first bin consisting of cities with 500–1000 inhabitants, and with the upper limit of each subsequent bin being twice its lower limit, until reaching 512,000. Thus, the bins consist of: 500–1000; 1000–2000; 2000–4000; …; 256,000–512,000; and more than 512,000. Except for the highest bin, we use the mid-value of each bin to define the size of a city's population. For the highest bin, we use city population data from 1900 from Eggimann (1999). 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 only increases to 85.

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

Our first measure of the spatial competition faced by city r is the total population of other cities located within a certain kilometer 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 located in 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 round-trip was close to the upper limit of travel in a single day. Panel D of Table 1 reports the average of S_1^r across cities in the three regions. According to this measure, there was effectively no inter-city competition in England prior to 1600, but thereafter it increased, so that it was 150 times more intense by 1850. China actually was characterized by more spatial competition compared to England in 1700 according to this measure, but saw only a small increase in spatial competition over the next two centuries. At the end of the nineteenth century, China had essentially the same degree of spatial competition that England attained at the beginning of the eighteenth century. Northwest Europe likewise started off the eighteenth century with much stronger inter-city competition than England, and similarly did not experience as large an increase in this measure of spatial competition than England. It was far more advanced along this measure compared to China, however; in 1850 Northwest Europe had the same degree of spatial competition that England had attained at the end of the eighteenth century.

Our second measure weights consumers in other cities by their distance. As such, 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 greater the value of γ, the smaller the weight given to distant populations. Panel E reports the average of S_2^r across cities for γ equal to 1.5 with distances measured in kilometers.[13] This measure of spatial competition essentially mimics the pattern for S_1^r.

Our final 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 turns out to be the most empirically relevant in light of the theory. To construct this measure, define for each city r 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 can then define our third measure of spatial condition as

$$S_3^r = \sum_{i=1}^{\bar{\iota}} \delta_i^r L_i^r / \sum_{i=1}^{\bar{\iota}} L_i^r \tag{3}$$

$$\text{where } \bar{\iota} = \text{argmin} \sum_{i=1}^{\bar{\iota}} L_i^r$$

[13] 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 $\gamma = 1.5$.

Table 1 Spatial competition: England and Northwest Europe versus China

Year	1400	1600	1700	1776	1800	1820	1850	1893
A. Total population (millions)								
England		4	5		8	11	17	27
China		160.0	138.0			381.0	412.0	386.0
NW Europe		56.9	62.2			103.3	129.3	170.9
B. Urban population (millions)								
England	0.1	0.3	0.9	1.5	2.6	3.8	7	
China			7.9	20.1		25.9		31.4
NW Europe	2.8	6	7.7	10.2	14.9	17.6	25.3	
C. Average city size (thousands)								
England	11.2	19.1	25.1	30.5	21.2	30.3	50.8	
China			24.2	31.2		33.0		31.1
NW Europe	17.9	16.1	17.5	19	14.4	17.4	22.8	
D. Population access ≤ 20 km (S_1, thousands)								
England	0	0	1.3	26.6	73.8	107.2	190.6	
China			5.2	7.0		7.9		6.8
NW Europe	3.9	16.9	20.1	29.1	54.3	65.4	96.1	
E. Population access, spatial decay $\delta = 1.5$ (S_2, thousands)								
England	0	0.2	0.6	1.5	4.1	6.1	11.6	
China			1.2	2.4		3.0		3.2
NW Europe	0.6	1.4	1.8	2.5	4.3	5.3	7.7	
F. Distance to reach same number of consumers (S_3, km)								
England	93	70	44	37	21	21	20	
China			71	54		50		53
NW Europe	60	36	33	29	22	22	21	

Panels B through F refer to cities with a minimum population of 5000. England is defined as Great Britain without Scotland and Wales; China corresponds to modern-day China without Tibet; Northwest (NW) Europe includes Great Britain, France, the Benelux, Germany and Italy. Panels D, E and F correspond to the average across cities of, respectively (1), (2) and (3). Data sources. Panel A: Maddison (2010), GB Historical GIS (2019), Wrigley and Schofield (1989) and Chen (1923). Panel B–F: Bairoch et al. (1988), Yue et al. (2007), Eggimann (1999), Cao (2000), Maddison (2001) and own calculations as explained in text

$$\text{s.t.} \sum_{i=1}^{\bar{\imath}} L_i^r \geq L^r$$

$$L_{\bar{\imath}}^r = L^r - \sum_{i=1}^{\bar{\imath}-1} L_i^r.$$

As can be seen in Panel F of Table 1, this measure suggests that inter-city competition in England started to increase as far back as 1400. The average distance to reach the same number of consumers fell from 93 km in 1400 to 44 km in 1700. During the eighteenth century, this average distance continued to drop, reaching 21 km in 1800. China, in contrast, displayed far less spatial competition starting in 1700 and a far smaller increase thereafter compared to England. The differences are significant. In 1776, on the eve of the *Industrial Revolution*, the average distance to reach the same number of consumers was about 50% larger in China than in England. Maybe more tellingly, at the end of the nineteenth century the degree of spatial competition in China had not yet reached the level in England in 1700. For Northwest Europe, spatial competition was greater there or more or less on par with spatial competition in England over the entire period studied.

Taken together, all three measures document an increase in spatial competition in England in the era leading up to the *Industrial Revolution*. Relative to the average Chinese city, the capacity of the average English city to gain market share at the expense of its close-by neighbors was stronger for most, if not all, of the period. Northwest Europe was far more similar to England in this regard, displaying slightly less inter-city competition according to the first two measures and slightly more according to the third, particularly early on. The *Industrial Revolution* itself may, of course, have further strengthened spatial competition, but it cannot explain the initial increase in inter-city competition that pre-dated industrialization. In other words, the substantial strengthening of inter-city competition between 1400 and 1750 must have happened for reasons other than large-scale industrialization. In addition, the rise in spatial competition in England during the eighteenth century reported in Table 1 constitutes, if anything, a lower bound, as it does not factor in the decline in transport costs associated 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 to innovation

In this subsection we describe the rise and decline of craft guilds in England and China, and their resistance to the adoption of labor-saving technologies, particularly as it relates to the intensity of inter-city competition. We also briefly refer to the experience of craft guilds in the rest of Europe. As a caveat ahead of our discussion, the existence of a craft guild was neither a necessary nor a sufficient condition for resistance. For example, the Luddites, with their machine-breaking attempts of 1811 and 1812, operated outside the guild system.[14] However, there is little doubt that the existence of guilds facilitated resistance through the coordination of skilled workers (Randall 1991). Because of the large number of well-documented cases where these organizations fiercely resisted the introduction of modern modes of production, we think it is useful to organize our discussion of resistance and spatial competition around the craft guilds.

England Craft guilds were city-level associations of craftsmen specialized in a particular profession. They arose in the medieval period, and were officially abolished in 1835 under the *Municipal Corporations Act*, although many had already disbanded by then of their own accord. There is a debate among historians and economists whether guilds had a positive or negative effect on England's economic development. In spite of this debate, there exists a consensus on a number of points relevant for our paper.

First, it is only in their later incarnation that craft guilds became anti-competitive and anti-technology. Originally guilds were created as private benevolent societies that engaged in mutual assistance and religious activities. However, by the seventeenth century, guilds had transformed into institutions that regulated the economic activity of its members. Their attitude towards innovation mirrored this transition. In their early, social club period, guilds

[14] Interestingly, the Luddite riots also coincided with changes in spatial competition. Binfield (2004) argues that mill workers associated with the Luddites only turned 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, their resistance stopped and violence ended.

were not particularly hostile to innovation. If anything, guilds may have given England an edge in the late medieval period, because guilds were better at transmitting knowledge than the clan, then prevalent in China (De la Croix et al. 2018).[15] However, eventually "much of the guild system was overtaken by technologically reactionary forces which instead of protecting innovators threatened them" (Mokyr 1997).

Second, guilds were not opposed to all forms of technological progress. Innovations aimed at either saving capital or enhancing skills were typically welcomed (Epstein 1998). However, it was a different matter with labor-saving technology that threatened workers' livelihoods. The means by which guilds resisted the introduction of labor-saving technology evolved over time. Before 1750, legal petitions to save jobs were common. These petitions were often supported by a judiciary that prioritized the maximization of employment and the common law right to work (Dent 2007; Letwin 1954). However, accompanying the acceleration in labor-saving innovations in the late-eighteenth century was a change in the balance of power, with the polity and the judiciary increasingly ruling in favor of industry and entrepreneurs. This led to a change in the form of resistance, with craft guilds increasingly resorting to violence (Mokyr 1990). Riots, demonstrations and vandalism became more frequent at the turn of the nineteenth century. Rather than being a sign of a strength, they were the death throes of a weakening guild system.

Third, the incentives to resist technology were limited by competition between cities. Spatial competition in England increased in the period leading up to the *Industrial Revolution*. Some of this greater competition came from unguilded towns and the countryside. When faced with the growth of industry in rural areas and new townships that were free of guilds, existing craft guilds often relaxed work rules.[16] However, the possibility of unguilded areas to industrialize was sometimes limited by legal restrictions.[17] Given these constraints and given the widespread existence of craft guilds, some of the effective increase in competition came from already guilded areas. This weakened resistance to innovation: when one guilded city adopted a new technology, other guilded cities often followed suit.

In this context, the example of the gig mill, used in the finishing of woolen cloth, is telling (Randall 1991). The shearers, which were among the best paid and strongest guilds, were initially able to prevent the widespread use of the gig mill in Gloucester, Wiltshire and Somerset, through legal appeals, violence and industrial actions. Resistance was weakest in Gloucester because the shearers there had previously used the gig mill for the purpose of finishing fine cloth. In contrast, the shearers in Wiltshire and Somerset readily relied on violence to prevent mill owners from introducing the gig mill. Not surprisingly, benefiting from a lower potential cost of adopting, Gloucester mill owners in 1794 were the first to use the gig mill to finish rough cloth. Soon after, the shearers in Wiltshire and Somerset ended

[15] How one views guilds depends on which institutions were available in a particular time period. De la Croix et al. (2018) analyze the creation and transmission of knowledge under four institutions: the nuclear family, the clan, the guild and the market. They argue that guilds were superior to clans (though inferior to markets). They use this insight to explain why in the preindustrial period Western Europe, where guilds were prevalent, was more advanced than other regions of the world where clans or families were the main institution. We, instead, focus on the eve of the *Industrial Revolution*, and argue that the decline of guilds and the emergence of markets was key to industrial takeoff.

[16] The importance of competition between unguilded and guilded areas for industrialization is consistent with the model by Holmes and Schmitz (1995).

[17] For example, in the case of Kay's Fly Shuttle used for the weaving of woolen cloth, 2&3 Philip and Mary c. 11 stated that "no clothier might own more than one loom, not let out looms for hire outside of a city, borough, market town or corporate town."

their resistance because they were losing business to the low-cost mills in Gloucester. This is the type of situation our theory is meant to address.[18]

Fourth, spatial competition also enhanced the capacity of industry to break workers' resistance. To the extent that greater spatial competition made technology adoption more profitable, it gave industry more means to overcome resistance. Profits were sometimes used to violently defeat the blocking efforts of workers. Randall (1991), for example, documents that strikes over the introduction of gig mills and shearing frames were less effective against larger employers because they had the capacity to turn their mills into armed fortresses by hiring security personnel. Another way profits helped mitigate opposition was through the financing of the state-sponsored local poor relief system. By the early seventeenth century, parishes were legally required to support their poor. The poor relief was an important means for alleviating those displaced by labor-saving technology (Eden 1797). The newly generated wealth and profits from industrialization and the local taxes paid on that wealth allowed for a continued increase in social spending, making it easier for society to compensate individuals whose inputs became redundant.

If increased spatial competition weakened guild power, we might have expected guilds to find ways to restrict inter-city competition. One such way could have been to form guilds that controlled multiple cities. This did not occur, probably because the power of guilds was too intertwined with the local political power at the city level.[19] Another way could have been to limit inter-city trade. However, such attempts by craft guilds were met with the opposition of merchant guilds, keen on keeping markets open. Eventually, royal charters guaranteed urban residents toll-free trade throughout the kingdom, making it impossible to restrict inter-city trade (Seligman 1887).

Our discussion thus far has focused on England, but the history of craft guilds in Northwest Europe followed a similar pattern. There as well, craft guilds tended to oppose technological improvements when their livelihoods were threatened. This is evident from the numerous documented case studies that cover a variety of industries and periods. For example, Ogilvie (2004) describes how in 1775 the Black Forest weavers guild in the Duchy of Wü rttemberg successfully blocked a textile manufacturer, fearing its novel technology would undermine their activities; Unger (1978) documents resistance to technological change by the Dutch shipbuilders guild in the seventeenth century; and Audin (1979) gives the example of the master printers guild of Basel preventing the introduction of a new printing press invented by Wilhelm Haas. In studying many of these cases, Mokyr (1990, p. 258) concludes that during the seventeenth and eighteenth centuries the craft guilds on the Continent were more successful than their English counterparts at blocking the introduction of several new technologies. As an illustration of this difference, the ribbon loom faced resistance all over the Continent, in contrast to its widespread adoption in Lancashire.

As in England, guilds in Northwest Europe were weaker in areas or industries that were characterized by greater spatial competition, and it is precisely in those areas and industries that productivity improved the most. One way to see this is to compare non-export industries with export industries, with the latter operating in more integrated markets, and hence exposed to tougher spatial competition. In his study of the Flemish city of Oudenaarde in the sixteenth

18 Spatial competition between guilded cities was also important to understand technology adoption on the continent. For example, 't Hart (1993) and Mokyr (1998) describe how in 1604 the city 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, where guilds were weaker.

19 Of course, in the second half of the nineteenth century, we did see an emergence of worker power that superseded the city level in the form of national trade unions. However, by that time, the *Industrial Revolution* had become irreversible.

century, Stabel (2004) finds that barriers against non-guild members were much weaker in export industries. For example, the city's main export industry of tapestries had many large-scale establishments, whereas non-export industries continued to employ just one or two apprentices. Those cities or industries that removed guild restrictions experienced substantial gains in productivity. For example, in the late sixteenth century, the stagnating city of Tournai, in the Low Countries, regained robust growth by granting mastership to all weavers, without examination, and by making it easier for immigrants to work in its textile industry (Ogilvie 2014).

The demise of the craft guilds in Northwest Europe mirrors their decline in England. Some regions, such as France and the southern Netherlands, officially decreed craft guilds illegal earlier than England. However, these decrees did not necessarily put an end to resistance by skilled laborers everywhere. For example, in France craft guilds were replaced by mutual aid societies, which often blocked entrepreneurs from introducing cost-cutting machines (Sewell 1980). Estimates suggest that these mutual aid societies contained close to 400,000 members in 1895. Based on this, the illegalization of guilds in France may have been more a change in name than an effective abolishment (Mokyr 1990). As a result, at least in the case of France, resistance is likely to have ended significantly later than in England.

China Craft guilds in China did not take off in earnest until the middle of the nineteenth century. Long before that, China already had a different type of guild, based on an individual's place of origin. These earlier native-place organizations, referred to as *huiguan*, allowed long-distance merchants from the same city or region to organize themselves and provide mutual assistance. Since they did not monopolize particular sectors, these institutions are not directly relevant for our analysis. If anything, they increased competition by facilitating trade, and in that sense were not unlike Europe's merchant guilds.[20]

Over time, the *huiguan* declined, and were replaced by European-style occupation-based craft guilds, referred to as *gongsuo* (Moll-Murata 2008). It is this type of guild that is relevant for our theory. Using data from Moll-Murata (2008), Fig. 1 shows that the rapid emergence of *gongsuo* occurred in the second half of the nineteenth century, coinciding with a growing European presence in the region following the Opium Wars. [21]

There are a number of parallels between the *gongsuo* and the European craft guilds, in addition to both being occupation-based. First, in spite of Chinese cities not being self-governed, the *gongsuo* were organized at the level of cities (Bradstock 1983). This implies that for our analysis the city continues to be the relevant unit of analysis, making inter-city competition the appropriate measure of spatial competition. Second, as in Europe, the *gongsuo* emerged earliest in the largest cities. The first *gongsuo* appeared between 1650 and 1700 in cities such as Beijing, the country's capital, and Suzhou, an important inland port city in Jiangsu province. Third, the Chinese *gongsuo* pursued policies similar to the European craft guilds in that they provided public goods, collected taxes for the authorities, and regulated production, prices and trade.

Although early on the *gongsuo* did not acquire the same judicial authority over their trades as their European counterparts, they were *de facto* very effective in monopolizing professions. The evidence reveals that the guilds obtained "an enormous and almost unrestrained control over their respective trades" (Morse 1909, p. 21), which greatly hindered innovation, and prevented the introduction of new, labor-saving technologies. MacGowan (1886) provides

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

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

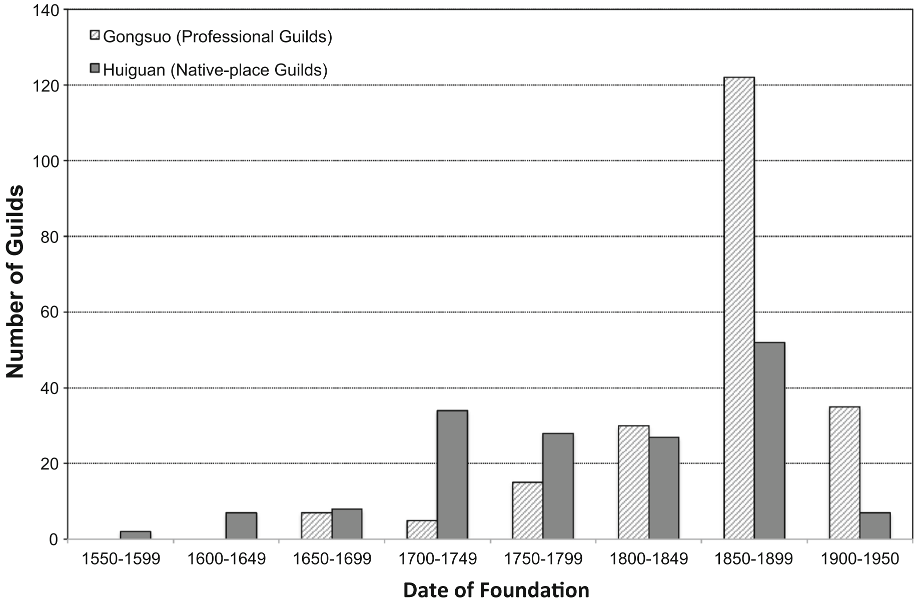

Fig. 1 Native-place *(huiguan)* versus professional *(gongsuo)* guilds by date of foundation in China

several first-hand accounts of their resistance to modern modes of production. For example, he describes how guild members destroyed imported sewing machines used in the production of shoe soles, and he tells of cotton growers refusing to send their raw material to steam-powered cotton mills. Similarly, Ma (2005) writes that the "fiercest resistance" to mechanizing the silk industry "came from the organized silk handicraft and commercial guilds". Reports to the Foreign Office in London at the time echo these accounts. For example, the plan to launch a modern steam-powered cotton mill in Shanghai in 1876 was shelved because of the opposition by the cotton cloth guild, and the withdrawal of support from local officials who feared a break out of riots amongst workers (Great Britain. Foreign Office 1875–1878. pp. 17–18 in the report for 1877).

One important institutional difference between China and England that surely affected the degree of resistance was a much less developed system to assist those displaced by technology. China did have different ways to help the poor in the Qing period: the granary system, run mainly by the state and aimed at alleviating food shortages, and the clan trust, the use of common property by the kin group to assist clan members in need. Both were ill-equipped, however, to handle the challenges of industrialization, as they did little to ameliorate the situation of workers becoming redundant. [22] The granary system, already in decline, was designed to dampen high grain prices when harvests failed, whereas the clan trust was confined to clan members, and hence limited to clans with sufficient resources. The inadequacy of the Chinese poor relief system gave Chinese workers a greater incentive to organize and block the introduction of labor-saving technology.

Despite the absence of an effective poor relief system, the forces of change eventually took hold in China too. By the early-twentieth century, Chinese industry was subject to increasing spatial competition. Although as late as 1870, there was no railroad system in China, there

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

were 13,441 km of track by 1913, 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. The period also witnessed a growing availability of labor-saving technology from the West. As expressed by a spokesman of a Shanghai guild in the early twentieth century, "our knowledge gradually narrows, our skills deteriorate, and our tools fall out of date…The European fad comes sweeping through our country like a flood, and there is no stopping it" (Bradstock 1984, pp. 228–229). The increased competition did not only come from abroad, but also from other cities in China. 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).

Just as in England, the rise in conflicts signaled the beginning of the demise of the Chinese craft guilds. During the late Qing period, in the early-twentieth century, government policy became less favorable towards guild privileges, focusing instead on economic development and growth. During that period the *gongsuo* began to disband, though the final ones did not disappear until after the victory of the Chinese Communist Party in 1949 (Moll-Murata 2008).

3 The model

Motivated by the historical evidence, we propose 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, and 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 never give up resisting 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 superscript $r \in \{W, E\}$. Each city-region produces a non-tradeable agricultural good, using unskilled labor, and a continuum of measure one of tradeable industrial goods, using skilled labor. For each type of industrial good, monopolistically competitive firms produce a number of varieties. Goods or industries can be thought of as textiles, furniture, wines, etc., whereas varieties correspond to different colors, flavors or textures of these goods. We use $i \in [0, 1]$ to denote a particular industrial good or sector, v_i to denote a particular variety of that good i, V_i to denote the set of varieties of good i produced in the entire economy, and V_i^r to denote the set of varieties of good i produced in city-region r.

Each city-region is populated by a continuum of measure L of one-period lived households, each of which is endowed with one unit of time. Measure $(1-\mu)L$ of these households are skilled whereas measure μL are unskilled. Unskilled households can only work in the agricultural sector. Once a skilled household commits to working in a particular industrial sector, its skill becomes specific to that sector. As a result, a skilled household cannot move between industrial sectors. Additionally, we do not permit household migration between city-regions. We denote a household's type by the superscript $h \in \{u, s_i\}$, where u refers to the unskilled and s_i to the skilled employed in sector i.

3.1.1 Preferences and utility maximization

Preferences Household preferences are Cobb–Douglas over an agricultural good and a continuum of industrial goods. For each industrial good, preferences are of the Hotelling–Lancaster type, implying that each household has a variety it prefers over all others. This preference construct generates a price elasticity of demand that is increasing in the size of the market and the degree of inter-city competition.

The variety space of each industrial good is represented by a unit circle, along which skilled households and unskilled households are each uniformly distributed with a household's location on the circumference identifying the variety that it prefers over all others. The greater the arc distance $d_{v_i \tilde{v}}$ between variety v_i and a household's ideal variety $\tilde{v}$ for a given good i, the less it likes variety v_i.[23] To build some intuition for this preference construct, if all varieties were sold at the same price, each household would choose to consume the variety closest to its ideal variety. The utility that a household of type h, 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 then 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 $1 + d_{v_i \tilde{v}}^{\beta}$, $\beta > 0$, is the quantity of variety v_i that gives the household the same utility as one unit of its ideal variety $\tilde{v}$.

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

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

[23] 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 and let p^r_a denote the price of the agricultural good in that region. 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 $p^r_a c^{rh}_a = (1-\alpha) y^{rh}$ and $p^r_{\hat{v}^r_i} c^{rh}_{\hat{v}^r_i} = \alpha y^{rh}$.

3.1.2 Technologies and profit maximization

Farms The farm sector is perfectly competitive and produces a homogeneous good according to a linear technology that uses labor. Without loss of generality, we assume the farm good is non-tradeable.[24] Let Q^r_a denote farm output in city-region r. Then,

$$Q^r_a = \Gamma_a L^r_a, \tag{8}$$

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

As farm TFP is by assumption identical in both city-regions, the agricultural good's price in each region can be normalized to 1, i.e., $p^r_a = 1$. Profit maximization then implies a common agricultural wage rate in both regions,

$$w_a = \Gamma_a. \tag{9}$$

As long as industrial firms use the artisanal technology, the farm sector plays no essential role in our model. However, once the modern labor-saving technology is introduced, unskilled farm workers put downward pressure on the wages of skilled artisanal workers. As we will show in Sect. 3.2, this is the force behind skilled workers' resistance to the adoption of modern technology.

Industries There is a continuum of industries, each characterized by a monopolistically competitive market structure. Each industry $i \in [0, 1]$ in each city-region produces a finite set of differentiated varieties, each produced by a different firm. Each industry can be represented by a unit circle, around which varieties (and firms) are located. As we will focus exclusively on symmetric Nash Equilibrium in the analysis, it is useful to envision varieties/producers being equally spread around the 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, $\tau \geq 1$ units must be shipped. Output is generated using an artisanal production technology that requires skilled labor. 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

$$Q^r_{v_i} = \Gamma_v [L^r_{v_i} - \kappa], \tag{10}$$

where κ is the fixed operating cost in units of labor, $L^r_{v_i}$ is the total input of skilled workers, and Γ_v is the marginal product.

When maximizing profits, each firm takes the wage rate and the choices of other firms in its industry and city as given. In the interest of space, we only present the profit maximization problem facing a firm located in the East; expressions for Western firms can be derived

24 Strictly speaking, this assumption is not necessary since in a symmetric equilibrium each region would consume its own production of the agricultural good.

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 to the consumption location.

Using the production function (10), together with the fact that the Eastern firm's production meets consumption of both Eastern and Western consumers, namely,

$$Q_{v_i}^{E} = C_{v_i}^{EE} + \tau C_{v_i}^{EW}, \tag{11}$$

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

$$\Pi_{v_i}^{E} = p_{v_i}^{EE} C_{v_i}^{EE} + p_{v_i}^{EW} C_{v_i}^{EW} - w_i^{E} \left[\kappa + \frac{C_{v_i}^{EE} + \tau C_{v_i}^{EW}}{\Gamma_v} \right], \tag{12}$$

where $p_{v_i}^{EE}$, $p_{v_i}^{EW}$, $C_{v_i}^{EE}$ and $C_{v_i}^{EW}$ are the prices and consumption levels of an Eastern-produced variety in the Eastern and the Western markets, and w_i^E is the Eastern wage rate in industrial sector i.

An Eastern firm producing variety v_i chooses the price in the East, $p_{v_i}^{EE}$, and the price in the West, $p_{v_i}^{EW}$, to maximize (12), subject to demand in the East and demand in the West, taking the wage rate in the industrial sector i, w_i^E, as given. The profit-maximizing price in each market is the usual mark-up over the marginal unit cost, so that

$$p_{v_i}^{EE} = \frac{w_i^E}{\Gamma_v} \frac{\varepsilon_{v_i}^{EE}}{\varepsilon_{v_i}^{EE} - 1} \tag{13}$$

and

$$\frac{p_{v_i}^{EW}}{\tau} = \frac{w_i^E}{\Gamma_v} \frac{\varepsilon_{v_i}^{EW}}{\varepsilon_{v_i}^{EW} - 1}, \tag{14}$$

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

3.1.3 Aggregate demands

We now derive the aggregate demands for the agricultural good and for each differentiated industrial variety.

Agricultural good By assumption, there is no inter-city trade in the agricultural good, and so the demand faced by farms in a given city-region is derived exclusively from its own residents. Since each household spends a fraction $1 - \alpha$ of its income on the agricultural good, the aggregate demand for the agricultural good in city-region r is

$$C_a^r = (1 - \alpha) Y^r, \tag{15}$$

where Y^r is the aggregate income of city-region r.

Differentiated industrial goods As mentioned earlier, our analysis focuses exclusively on the properties of the model's symmetric Nash equilibria, with all firms in each industry being equally spaced around the unit circle and alternating between Eastern and Western firms. Since the closest neighbors to the right and to the left of the Eastern firm producing variety v_i^E are located at the same distance, d_i, we do not need to differentiate between these two Western competitors, and denote each by v_i^W.

Because of trade, aggregate demand for variety v_i^E emanates from households in both the East and the West. To determine the measure of households in the East that buys variety v_i^E, we identify the household who is indifferent between buying varieties v_i^E and v_i^W.[25] The indifferent Eastern household is the one located at distance d_i^{EE} from v_i^E, where d_i^{EE} satisfies

$$p_{v_i}^{WE}\left[1+(d_i-d_i^{EE})^\beta\right]=p_{v_i}^{EE}\left[1+(d_i^{EE})^\beta\right]. \tag{16}$$

Given this indifference condition applies to Eastern households both to the right and to the left of v_i^E, a share $2d_i^{EE}$ consumes variety v_i^E.[26] As households are uniformly distributed along the unit circle and each household spends a share α of its earnings on a single variety in any given industry, the total demand for v_i^E emanating from Eastern households is

$$C_{v_i}^{EE}=\frac{2d_i^{EE}\alpha Y^E}{p_{v_i}^{EE}}. \tag{17}$$

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

$$C_{v_i}^{EW}=\frac{2d_i^{EW}\alpha Y^W}{p_{v_i}^{EW}}, \tag{18}$$

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

$$p_{v_i}^{WW}\left[1+(d_i-d_i^{EW})^\beta\right]=p_{v_i}^{EW}\left[1+(d_i^{EW})^\beta\right]. \tag{19}$$

Price elasticity With these equations in hand, we can solve for the price elasticities of demand that determine the mark-ups in the firm's optimal pricing decisions (13) and (14). The first step is to differentiate (17) with respect to $p_{v_i}^{EE}$ to arrive at the following relation

$$-\frac{\partial C_{v_i}^{EE}}{\partial p_{v_i}^{EE}}\frac{p_{v_i}^{EE}}{C_{v_i}^{EE}}=1-\frac{\partial d_{v_i}^{EE}}{\partial p_{v_i}^{EE}}\frac{p_{v_i}^{EE}}{d_{v_i}^{EE}}. \tag{20}$$

Next, we solve for the partial derivative, $\partial d_{v_i}^{EE}/\partial p_{v_i}^{EE}$, by taking the total derivative of the indifference equation (16) with respect to p^{EE}. Using this result, we obtain

$$\varepsilon_{v_i}^{EE}=1+\frac{[1+(d_{v_i}^{EE})^\beta]p_{v_i}^{EE}}{[p_{v_i}^{EE}\beta(d_{v_i}^{EE})^{\beta-1}+p_{v_i}^{WE}\beta(d_i-d_{v_i}^{EE})^{\beta-1}]d_{v_i}^{EE}}. \tag{21}$$

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

$$\varepsilon_{v_i}^{EW}=1+\frac{[1+(d_{v_i}^{EW})^\beta]p_{v_i}^{EW}}{[p_{v_i}^{EW}\beta(d_{v_i}^{EW})^{\beta-1}+p_{v_i}^{WW}\beta(d_i-d_{v_i}^{EW})^{\beta-1})d_{v_i}^{EW}}. \tag{22}$$

In contrast to Spence–Dixit–Stiglitz preferences that yield a constant price elasticity of demand, Hotelling–Lancaster preferences give us more complex expressions. As we will

[25] 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. If we assume that households can only choose between the closest variety to the left and the closest variety to the right of their ideal variety, then this is not a concern. However, in that case there may be corner solutions where the indifference condition does not hold. In the numerical section we check for this possibility.

[26] This indifference condition applies to both the unskilled worker who are uniformly distributed around the unit circle and the skilled workers who are also uniformly distributed around the unit circle.

later see, the boundedness of the variety space implies that the price elasticity of demand increases with the number of varieties and the degree of competition between neighboring varieties.

3.1.4 Equilibrium conditions

In addition to utility and profit maximization, all markets must clear in equilibrium and profits in each industry must be zero because of free entry. Symmetry implies that all industrial sector variables, such as w_i and d_i, are equal across sectors. Similarly, all firm-level variables, such as p_{v_i} and $\varepsilon_{v_i}^{EE}$, are equal across firms. Hence, in what follows we drop i and v_i subscripts.

Goods and labor market clearing The market clearing conditions for each of the goods is straightforward. For each industrial differentiated variety, the output of the firm must equal the demand from its own city-region customers plus the demand from the other city-region's customers adjusted for the iceberg cost, namely, (11). The corresponding condition for the agricultural market is

$$\Gamma_a L_a^r = C_a^r. \tag{23}$$

The labor markets must also clear. As long as $w > w_a$, which is guaranteed if $(1-\alpha)\mu > (1-\mu)\alpha$, only unskilled labor is used in farming. Thus, there are two labor market clearing conditions in each region:

$$\begin{aligned}(1-\mu)L &= \frac{1}{2d}\left[\kappa + \frac{C^{EE} + \tau C^{EW}}{\Gamma_v}\right] \\ \mu L &= \frac{C_a^E}{\Gamma_a}.\end{aligned} \tag{24}$$

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 $1/d$, with each city-region producing $1/(2d)$ varieties.

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

$$p^{EE}C^{EE} + p^{EW}C^{EW} - w^E\left[\kappa + \frac{C^{EE} + \tau C^{EW}}{\Gamma}\right] = 0. \tag{25}$$

The zero profit condition is important because it determines the number of varieties produced in the East, which in turn determines the price elasticities of demand. It also implies that a household's income is equal to its wage, so that

$$\begin{aligned}y^{rs} &= w^r \\ y^{ru} &= w_a^r.\end{aligned} \tag{26}$$

Aggregate income is then:

$$Y^r = w_a^r \mu L + w^r(1-\mu)L. \tag{27}$$

We are now ready to define a symmetric equilibrium of the economy.

Definition of Symmetric Artisanal Equilibrium *An Artisanal Technology Symmetric Equilibrium (ARTSE) is a vector of elements* (p^{kk*}, ε^{kk*}, p^{kl*}, ε^{kl*}, w^{k*}, w_a^{k*}, Y^{k*}, d^*, d^{kk*}, d^{kl*}, Q^{k*}, Q_a^{k*}, C^{kk*}, C^{kl*}, C_a^{k*}, V^{k*}), *where* $k, l \in \{E, W\}$, $k \neq l$, *with* $x^{kk*} = x^{ll*}$, $x^{kl*} = x^{lk*}$

and $x^{k*} = x^{l*}$ *for any variable* x^**, that satisfies conditions* (8)*,* (9)*,* (11)*,* (13)*,* (14)*,* (15)*,* (16)*,* (17)*,* (18)*,* (19)*,* (21)*,* (22)*,* (23)*,* (24)*,* (25)*,* (26) *and* (27)*, 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 now consider what happens when a modern labor-saving technology becomes available. 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, operating the modern technology does not require skilled labor. The output of a firm in city-region r that produces variety v_i using the modern technology is:

$$Q^r_{v_i} = \Gamma^r_v (1+\gamma)[L^r_{v_i} - \kappa - \phi], \tag{28}$$

where $\phi > 0$ is the increase in the fixed operating cost and $\gamma > 0$ is the proportional improvement in the marginal productivity, compared to the artisanal technology.[27] In the rest of this section we analyze the effect of inter-city competition on the incentives of an individual firm to adopt the modern technology, the incentives of the skilled workers of a city-industry to form a guild that blocks adoption, and the capacity of an industry in a city to compensate skilled workers and overcome guild resistance.

3.2.1 Incentives for firms to adopt modern technology

When analyzing the incentive of an individual firm to deviate from the *ARTSE* and switch to the modern technology, we assume that all other firms in the economy continue to use the artisanal technology. In what follows, we focus on the incentives of a single Eastern firm; analogous expressions for a Western firm can easily be derived. For notational purposes, variables with a prime symbol ($'$) pertain to deviations from the *ARTSE* .

An Eastern firm switches to the labor-saving technology if the profits from doing so, $\Pi^{E'}$, are positive:

$$\Pi^{E'} > 0, \qquad \text{where}$$
$$\Pi^{E'} = \max_{p^{EE'}, p^{EW'}} \left\{ p^{EE'} C^{EE'} + p^{EW'} C^{EW'} - w_a \left[\kappa + \phi + \frac{C^{EE'} + \tau C^{EW'}}{\Gamma_v (1+\gamma)} \right] \right\}$$
$$\text{s.t.} \quad C^{EE'} = \frac{2d^{EE'} \alpha [(1-\mu) w^E + \mu w^E_a] L}{p^{EE'}}$$
$$C^{EW'} = \frac{2d^{EW'} \alpha [(1-\mu) w^W + \mu w^W_a] L}{p^{EW'}}. \tag{29}$$

As we assume parameter values that yield $w_a < w^r$, the relevant wage in the above expression for an adopting firm is w_a. Solving the above problem follows the same steps as in Sect. 3.1.3. In the interest of space, we briefly recall the different steps, without going through all the details. We first identify the Eastern household and the Western household that are indifferent between the deviating firm's variety and its neighbors' varieties. This allows us to derive expressions for both total demand and the price elasticities of demand. With this in hand, we

[27] The fact that the modern technology does not require skilled workers applies to both the fixed and the variable workers. Additionally, we make assumptions on the parameter values that guarantee $w_a(\kappa + \phi) > w\kappa$, so that there is a a disadvantage associated with the modern technology.

can determine the profit-maximizing prices in both city-regions, as well as the profits of the deviating firm.

When is an individual firm more likely to deviate and adopt the modern technology? The following claim states that larger cities, L, and lower iceberg costs, τ, increase the profitability of deviating. Hence, larger markets, whether coming from an increase in city size or stronger inter-city competition, incentivize a firm to switch to the modern technology.

Claim 1 *Starting off in an equilibrium where all firms use the artisanal technology, a larger population, L, or a lower iceberg cost, τ, increases the incentives of an individual firm to switch to the modern technology.*

Here we limit ourselves to providing intuition for this claim.[28] With Hotelling–Lancaster preferences, the unit circle implies a bounded variety space. As population increases and more varieties enter, neighboring varieties become more substitutable, leading to an increase in the price elasticity of demand. This implies 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 (29) is thus more likely to be satisfied in larger city-regions. A drop in transport costs has a similar effect, as it too leads to greater competition between neighboring varieties, and thus to lower mark-ups and larger firms.[29] 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 Incentive for workers to resist and create guilds

We now turn to analyzing the decision of skilled workers in an industry and city-region to form a professional guild for the purpose of blocking the introduction of the modern technology.[30] A guild forms if there is a conflict between firms and skilled workers: firms find it profitable to switch to the modern technology, but skilled workers suffer from lower earnings. A guild disappears if profits from adoption are sufficiently high to fully compensate guild members for any reduction in earnings.

Again, in what follows we focus on industry i in the East. The skilled workers of that industry form a guild if at least one firm finds it profitable to use the modern technology and if the industry profits, were all firms in that city and industry to adopt, are too small to compensate skilled workers for lost wages. The first condition simply requires the deviation condition (29) to be satisfied. Clearly, if the first condition is not met, then no industry will have a guild for the simple reason that skilled workers are not at risk of earning lower wages. The second condition says that the profits from all firms in industry i adopting are not enough to compensate the skilled workers, so that

[28] A formal proof for the case of an increase in population, L, is available upon request. The rest of the claim that relates to lower iceberg costs relies on numerical simulations (see also Desmet and Parente 2010, 2014).

[29] In contrast to an increase in population, a decrease in iceberg costs actually leads to a decrease in the number of varieties produced by each region. Nevertheless, the price elasticity of demand still increases on account of the greater competition from producers of the other region.

[30] Of course, as already discussed, there are other reasons why historically guilds might have formed in the first place, but they are not considered here. Thus, the question this paper addresses is: if skilled workers in a given industry and city-region did not form a guild earlier for some other reason, would 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 would that guild turn anti-technology?

$$\frac{V_i^{E*}\Pi_i^{E'}}{G_i^{E*}} + w_a^{E*} \leq w^{E*}, \tag{30}$$

where G_i^r denotes the size of the guild in industry i and city-region r.[31] As there is measure $(1-\mu)L$ of skilled workers in each region, and measure one of industries in each region, the size of a guild that forms in industry i and city-region r is $(1-\mu)L$. Of course, if skilled workers in an adopting industry could frictionlessly reallocate to another industry that still uses the artisanal technology, there would be no reason for guilds to emerge. However, as mentioned before, once assigned to an industry, a skilled artisanal worker cannot move to another industry. Condition (30) assumes that the transfers to the skilled workers are financed by the profits of the industry that switches to the modern technology. This compensation mechanism could arise from a bargaining process between the industry and the guild or from a tax on industry profits. The latter interpretation is not unlike the English poor laws which were financed locally by taxes on the wealthy. [32,33]

When profits from innovating are positive but too small to fully compensate the losers, there is a symmetric equilibrium in which all prices and allocations correspond to those associated with the *ARTSE*, but where each industry in each city-region has a guild that blocks the use of the modern technology. In effect, the set of skilled workers in each industry and city-region, by forming a guild, are able to sustain the same equilibrium allocations and prices as before. 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* (29) *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.,* (30) *is satisfied.*

3.3 Spatial competition and the demise of guilds

In light of Claim 1, one would expect guilds to form when market size reaches a certain threshold and disband when it reaches a second higher threshold. The second part of this statement is not completely correct, however. As we show next, an increase in market size, L, is *by itself* not enough for guilds to disappear. Instead, what is critical is the spatial distribution of city-regions: only with sufficient inter-city competition will the guilds disband. Hence, while the first threshold depends on market size, the second threshold depends on inter-city competition.

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

[31] Note that the deviation condition (29) is the same whether we consider the deviation of one firm in a particular industry and city-region or whether we consider the deviation of all firms in that industry and city-region. There are two reasons for this result. First, the incentive for an Eastern firm to deviate only depends on its two Western-produced neighboring varieties, and second, each industry is measure zero, so that even if all firms in a given industry and city-region were to deviate, there would be no effect on aggregate income.

[32] 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 (30).

[33] As a practical matter, resistance could also be overcome through the polity or the judiciary. If one assumes that this only occurs successfully if industry profits from adoption are big enough, either because industries need to lobby or because the polity becomes more favorable to adoption when the gains are large, then the results regarding the relation between spatial competition and innovation would be qualitatively unchanged. However, to keep things simple, we do not consider this alternative here.

(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 a sufficient increase in profits to compensate the original workers. We now formally state and prove this proposition.

Proposition 1 *For an economy in GARTSE that faces prohibitive trade costs, an increase in own city-region population will never lead to the violation of* (30)*, 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. Hence, switching technologies does not affect an industry's total earnings.

Because the number of firms in the adopting industry is kept constant, the price elasticity of demand does not change, so that mark-ups remain unchanged. With Cobb–Douglas preferences between different industrial goods and $w_a < w$, the drop in the price resulting from adoption is greater than the increase in the marginal productivity. As a result, the number of variable (and total) workers employed in the adopting industry increases. Since all of the industry's revenues before the technology switch were going to the industry's original workers, and since the industry's revenues have not changed with the adoption of the modern technology, it is impossible to make all those original workers better off because the number of workers the industry employs has gone up. Hence, (30) is never violated, and guilds never disband. □

This proposition suggests a fundamental asymmetry between the incentives of producers to adopt the modern technology and the incentives of craftsmen to accept industrialization. Whereas inter-city competition determines both the incentives of producers and craft guilds to industrialize, market size by itself only affects the producers' returns to industrialization. As a result, an increase in market size without an accompanying strengthening of inter-city competition does not suffice for an economy to take off. Market-size theories of the *Industrial Revolution* are therefore incomplete, and may lead to erroneous conclusions.

The above proposition assumes that trade costs between city-regions are prohibitive. Once we allow for trade, an increase in market size may be accompanied by an increase in inter-city competition. For example, if both city-regions grow in size, then each city-industry gains access to more consumers, both locally and in the other city-region. In that case, market size increases and inter-city competition strengthens, making economic take-off more likely. This does not change the main insight of Proposition 1 though: it is a city-industry's greater access to consumers in the *other* city-region, rather than in the own city-region, that increases its incentives to innovate. Hence, what matters for economic take-off is the increase in inter-city competition, rather than the greater market size by itself.

The assumption that guilds operate at the city-region level rather than at the national level is key to understanding the role of inter-city 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 the skilled workers it originally employed in its own city. This it can do by capturing market share from firms in the other cities. This possibility of capturing market share between cities is greater when inter-city competition intensifies.

The Proof of Proposition 1 depends partly on industries being small and on the elasticity of substitution between industries being one. If industries were large or the elasticity of substitution between industries were greater than one, then innovation by a local industry would expand the industry's local market, hence changing the incentives to adopt the modern technology. However, even then, spatial competition continues to be key to understand the rise and decline of guilds, and hence industrial take-off.[34]

4 Calibration

To assess the plausibility of our theory, we calibrate the model economy to the evolution of spatial competition in England between 1400 and 1600. The first model period, without loss of generality, is associated with the year 1400, and the model period when skilled artisans first organize for the purpose of blocking the modern technology is associated with the year 1600. As discussed in Sect. 2, although guilds appeared 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 for the calibration 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 theoretical analysis above, which assumes that only the artisanal technology is available originally.[35] 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* first exists.

We test the plausibility of our theory in three ways. First, factoring in the post-1600 increase in spatial competition in England, we determine the model's predicted date for England's take-off. Specifically, we identify the date when (30), the second condition for the guilds to exist, ceases to hold. The second and third tests apply the theory to Northwest Europe, which lagged England somewhat in its take-off, and to China, which had to wait until the twentieth century. Specifically, we feed in the measures of spatial competition for these two regions as documented in Sect. 2, and determine the dates predicted by the model for when guilds should have formed and for when they should have ended their resistance in each region.

34 If the elasticity of substitution is large enough, adoption by an entire industry might be sufficiently profitable to compensate existing workers even in the absence of inter-city trade. However, this result can be shown to be independent of market size, so that if adoption is profitable enough for one market size, it will be profitable for any market size. In such a case, we would never see guilds emerging, because there would never be a reason to resist adoption. Hence, without inter-city competition, we would be unable to explain the rise and decline of guilds. Results based on this and other alternative assumptions are available upon request.

35 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., $\Pi^{E'} \leq 0$.

4.1 Parametrization

The calibrated parameter values are shown in Table 2. As the model structure is not common in the growth literature, we discuss the choice of the parameter values in some detail. The easiest to explain are the transport costs, and so we begin with them. Their values are based on several studies that allow us to estimate average transport costs in pre-industrial Europe to be around 0.1% per kilometer.[36] To assign a value for inter-city transport costs, τ, we multiply this per-kilometer cost by the average distance between cities. In the context of our symmetric model, the appropriate distance measure is S_3^r, the average distance for a city to reach the same number of consumers as its own city, reported in Table 1. For England, this distance is 93 km in 1400, 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. As S_3^r dropped to 70 km in 1600 and to 21 km between 1800 and 1850, we set $\tau_{1600} = 1.07$ and $\tau_{1800-50} = 1.02$.

The assignment of values for the technology related parameters, Γ_a, Γ_v, and γ, is also fairly straightforward. Because of the Cobb–Douglas nature of 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).

The assignment of the share of unskilled households in the economy, μ, and the expenditure share of the industrial goods in the household utility function, α, is also straightforward. The share of unskilled households in the economy, μ, is set to 0.80. This is based on Clark (2001), who estimates that for England in 1600, 60% of the population was employed in farming, with half of the non-farm workers being unskilled. Given a value for μ, the expenditure share on the industrial goods, α, is then set so that the skill premium in the *ARTSE* is 60%, which is consistent with the wage premium for urban craftsmen relative to urban and rural laborers, as estimated by Clark (2001) for England in 1600 and by Luo (2017) for Western Europe for the period 1600–1914.[37]

The next three parameter values, κ, β, and ϕ are set jointly based on the following targets: (i) a firm size of roughly 2 workers in 1600, the first period that guilds form; (ii) a ratio of non-production to total workers between 5 and 10% in the pre-1600 era, and (iii) a ratio of non-production to total workers between 10 and 20% in the post-1820 era.[38] The firm-size target of 2 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

[36] We base our estimate on information of four different goods: grain, wine, luxury woolens and semi-worsted woolens. Masschaele (1993) finds that transporting grain in fourteenth century England added around 0.25% per km to the price. Based on data from the end of the sixteenth 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 fourteenth 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 fourteenth century. Taking these four numbers, we find an average transport cost of around 0.1% per km.

[37] Clark (2001) reports wages for urban craftsmen, urban laborers and farm laborers. He defines the skill premium as the wage ratio of urban craftsmen to urban laborers. This is the same as the wage ratio of urban craftsmen to rural laborers, when adjusting for the cost-of-living differences between urban and rural areas.

[38] Given this last target, it is not exactly correct to say that the model is calibrated exclusively to the pre-1600 period.

Table 2 Parameter values

Parameter	Target/comment
1. Transport costs	
$\tau_{1400} = 1.09$	Willan (1976), Masschaele (1993) and Munro (1997)
$\tau_{1600} = 1.07$	Drop in average distance between same-size cities (Table 1)
$\tau_{1800-1850} = 1.02$	Drop in average distance between same-size cities (Table 1)
2. Preferences and endowments	
$\mu = 0.80$	Fraction of non-skilled population in 1600 (Clark 2001)
$\alpha = 0.29$	Skill premium of 60% in 1600 (Clark 2001)
$\beta = 0.675$	Average firm size in 1600 of roughly 2 (Minns and Wallis 2012)
$L_{1400} = 134$	Ratio of average city size between 1400 and 1600 (Table 1)
3. Technologies	
$\Gamma_a = 1.0$	Normalization
$\Gamma_v = 1.0$	Normalization
$\gamma = 1.50$	Productivity gains in textiles (Randall 1991)
$\kappa = 0.15$	5% to 10% share of non-production workers in 1600
$\phi = 4.90$	10% to 20% share of non-production workers in 1800–1850

period. For example, in Bristol in the seventeenth century the average master employed 1.0 apprentice, whereas in London, this average was slightly larger, at 1.6 apprentices. Given that an apprentice most likely supplied less efficiency units of labor than the master, we set the firm size to be approximately equal to 2. The fixed operating cost target in the pre-1600 era corresponds to κ/L_v in the *ARTSE*. Our pre-1600 target is not based on any historical study, as we are unaware of estimates for the share of time skilled workers spent on non-production activities in this period. However, a time allocation between 5 and 10% does not seem unreasonable to us in light of the small scale of operation in the medieval period. We take the non-production to total worker ratio in the post-1820 period to correspond to $(\kappa + \phi)/L_v$ in a symmetric equilibrium where all firms use the modern technology and everyone is paid a common wage.[39] While we do not have numbers for England, according to Atack and Bateman (2006) the share of nonproduction workers in the U.S. manufacturing sector in 1889 was around 11%. Since the ratio of non-production workers to total workers in the *ARTSE* declines over time as the population grows and firms become larger, it is likely to have been larger earlier on, so we assume a range for this target between 10 and 20%. These three targets lead to the following parameter value assignments: $\beta = 0.65$, $\kappa = 0.15$, and $\phi = 4.9$.

To complete the parametrization, we need to assign the initial population of a city-region in 1400, L_{1400}. Average city-size in the model is $(1-\mu)L$. As the fraction of skilled households is assumed constant over time in the experiments, growth in the population is the same as growth in average city-size. To determine L_{1400}, we first find the growth in average city size in England between 1400 and 1600. Next, we determine from the model the size of the population when guilds first form, which is associated with 1600. Lastly, we divide this number by the factor increase in average city size experienced by England between 1400 and 1600. The resulting quotient is our 1400 population. This particular number has no consequences for the model results, but rather facilitates comparisons in some of the counterfactuals.[40] With this endowment parameter specified, the calibration is complete.

4.2 Evaluating the theory in the historical mirror

Having calibrated the model to England's experience between 1400 and 1600, we proceed to evaluate its prediction for the date when resistance should have ended in England and the modern technology should have been introduced. We also perform two other tests of the theory. First, we use data on city sizes and transportation costs for Northwest Europe to predict when that region should have seen guilds block the adoption of labor-saving technology and when those guilds should have disbanded. Second, we perform the same test for China using data on city sizes and inter-city transport costs there.

4.2.1 England

The first test of the theory is to determine the city size at which guilds disband, and compare this predicted city size with actual city size of England. Specifically, we set the iceberg cost to

39 To be precise, this is just the *ARTSE* when there is no wage premium, the artisanal technology is $A_x(1+\gamma)$, and the operating cost is $\kappa + \gamma$.

40 An obvious question is why we did not set the population to the actual 1400 average city size 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 variety circle. This would not change anything, but it would come at the cost of introducing one more parameter, so we refrain from doing so.

its 1800–1850 value, $\tau_{1800-50} = 1.02$, and determine the smallest average city size for which the *GARTSE* ceases to exist. We find that the model predicts that resistance ceases when the average city is 2.8 times greater than its 1400 size. How does this match up with England's historical record? Going back to Table 1, average city size was 2.7 times greater in 1820 than in 1400. Thus, the model predicts that guilds should have stopped blocking labor-saving technology in England around 1820. This is within the main period when guilds ended their resistance to labor-saving technologies. In this sense, the theory is fairly successful.

To provide some additional perspective on the relative importance of the increase in average city size versus the increase in inter-city trade for England's industrialization, we perform the following counterfactual experiment: we determine the city sizes that would have been needed for guilds to form and for resistance to break down if inter-city transportation costs had remained at their 1600 value of 1.07 forever. For exposition, we convert L_{1400} in the model to the actual average English city size in 1400 of 11,200 inhabitants. What the counterfactual reveals is that in the absence of any decline in inter-city distances subsequent to 1600, guilds would have blocked the modern technology until city size reaches 60,691. For the benchmark, and using this same expositional conversion, guilds end their resistance when city size reaches 32,195. The counterfactual, therefore, suggests that industrialization would have required a city size twice as large had inter-city distance remained at its 1600 level. This is a significant difference, suggesting that the increase in inter-city trade is important for understanding England's early take-off.

4.2.2 Northwest Europe

Our second test is to examine the model's predictions for Northwest Europe's development. To do so, we estimate inter-city transport costs, based on the same 0.1% cost per kilometer used for England, but using the average distance between cities in Northwest Europe over the historical period. Based on data in Table 1, the implied inter-city iceberg costs for this region are: 1.06 in 1400, 1.036 in 1600, 1.029 in 1700, and 1.022 from 1800 to 1850. Compared to England, average city size was smaller for all periods, whereas inter-city distances were generally lower, particularly in the early part of the period.

Using the iceberg costs that prevailed in the 1600 period, i.e., $\tau = 1.036$, the model predicts an average city size of 15,403 when guilds start blocking the labor-saving technology. This is close to the average city size for Northwest Europe in 1600 of 16,100. To determine the predicted date when guilds stop resisting, we use the inter-city iceberg cost that prevailed in the nineteenth century, i.e., $\tau = 1.022$. For this iceberg cost, the model predicts that guilds should have disbanded when average city size reached 32,528. This is larger than the last reported average city size of 22,800 corresponding to 1850 by Bairoch et al. (1988) and shown in Table 1. If we assume that average city size between 1850 and 1913 increased by the same proportion as the Maddison (2001) population figures, the model predicts that guilds should have stopped blocking labor-saving technology around the turn of the twentieth century.

Factually, within the countries of Northwest Europe, there is a good deal of heterogeneity in take-off dates. There are no studies that give exact years or decades when countries took off. Instead, take-off periods are usually discussed in the context of the first half or second half of a century. Belgium is thought to have industrialized not too long after England; France and Germany by the middle to end of the nineteenth century; and the Netherlands and Italy following later with take-offs near the turn of the century. As discussed earlier, it is not easy to determine the dates when skilled labor groups on the Continent opposed to innovation disbanded. Although guilds in France, for example, were decreed illegal by 1815, they effectively continued to operate in the form of "mutual aid societies" throughout the entire nineteenth century. Certainly, the model's prediction is consistent with the take-off periods of the Netherlands and Italy and the demise of resistance in France, although it seems a bit late in its prediction for Belgium.

4.2.3 China and the great divergence

Lastly, we explore the implications of our theory for the *Great Divergence*. In particular, we examine whether the greater distance between Chinese cities can explain the delay in China's industrialization relative to England's. For this purpose, we solve for the model equilibria using inter-city iceberg costs that are relevant for China between 1700 and 1893. As before, we apply the same 0.1% transport cost per kilometer to the average distance between same-sized cities in China listed in Panel F of Table 1, and obtain inter-city iceberg costs of 1.07 in 1700, 1.05 in 1776 and 1.05 in 1893.

For $\tau = 1.05$, the calibrated model implies that guilds should have stopped blocking labor-saving technology in China when average city size reached 38,759. This is almost 25% above the average city size in 1893 of 31,100. Using the population growth rates for China from Maddison (2001) and assuming that average city size grew at the same rate as the population, the model predicts that resistance to technology would have ended around 1925. Recall from the historical account of guilds in China that the *gongsuo* started to disappear in the early twentieth century, with some remaining in existence until the Communist Revolution. We therefore conclude that the theory offers a plausible explanation for China's late development.[41]

Although successful in predicting China's late industrialization, the model is less successful in predicting the date at which technology-blocking guilds formed in China. Using the 1700 iceberg cost for China of 1.07, the model predicts a city size threshold of 19,100 for the appearance of guilds. The average city size in China was already 24,200 in 1700, implying that we should have seen technology-blocking guilds in China by the late seventeenth century. Although a few *gongsuo* did form in the second half of the seventeenth century, Fig. 1 shows that the big shift towards *gongsuo* happened in the second half of the nineteenth century. The inability of the model to match the late appearance of technology-blocking guilds in China is not a reason to reject the theory, however. 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 did not arrive until after the Treaty of Nanking in 1842, at the end of the First Opium War. Therefore, in the context of our theory of technology adoption, the relevant question for China is why it failed to industrialize once the country got access to modern technologies. Our theory is able to answer that question: faced in the mid-nineteenth century with new labor-saving technologies coming from overseas, craft guilds emerged to resist industrialization.

4.3 Sensitivity

We conclude this section by discussing the sensitivity of the results to some of the targets used in the calibration. In particular, we examine the model's sensitivity to the share of unskilled households and to the skill premium, since these are targets that might be subject to greater inaccuracy in measurement.

41 This conclusion only relies on the 1893 data from Yue et al. (2007), and hence does not depend on the imputation of city size data in earlier time periods.

We start by changing the fraction of unskilled in the population, μ, but maintain the skill premium of 60%. This requires an adjustment in the utility share parameter, α. Importantly, we find no difference in the firm size when adoption first becomes profitable and the *GARTSE* first exists. Additionally, we find no difference in the ratio of non-production workers to total workers in the pre-guild period or the post-guild period. The population cutoffs, however, do change, with larger populations needed when there is a greater fraction of unskilled workers. This is intuitive: with fewer skilled workers in the population, there are fewer varieties in any industry in the *ARTSE*, and hence mark-ups are higher and firm sizes are smaller. Thus, a larger population is required before firms reach the critical size to find innovation profitable. The same is true for the critical size needed for guilds to disband. However, despite these larger absolute population cutoff levels, the ratio of the two cutoffs remains unchanged (1.68). Consequently, the model predicts the same time lag between when guilds start blocking and when they end their resistance. Hence, using a different share of unskilled households does not change the quantitative predictions of the model provided the skill premium is maintained.

In light of the above finding, we next explore how sensitive our results are to changes in the skill premium. To that end, we recalibrate the model to a lower skill premium of 30%, which is obtained from Clark (2001) by assuming that all urban workers are skilled and all rural workers are unskilled, and adjusting for cost of living differences between regions. With this assumption, the fraction of skilled households in the population is 40%, so that $\mu = 0.60$. To match the skill premium of 30%, this requires resetting $\alpha = 0.47$. The 30% skill premium requires recalibrating the parameters values for β, κ, and ϕ. None of the technology parameters or the iceberg cost parameters change in the recalibration. Keeping the same three general targets as in the benchmark, the recalibrated values are $\beta = 0.41$, $\kappa = 0.23$, and $\phi = 3.7$. The predictions of the model are little changed with this alternative calibration: for England, guilds are predicted to disband when own-city size reaches 31,881; for Northwest Europe, guilds form when city-size reaches 15,796 and disappear when city-size grows to 32,168; and for China, guilds form when city size reaches 19,100, and disband when city size reaches 37,913. These are approximately the same city-size numbers as in the benchmark case.

Taken together, these two experiments show that our results are not very sensitive to the share of the skilled in the population or the wage premium used in the calibration. This is further reason to view our theory as being a plausible explanation for the *Great Divergence*.

5 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 economic activity and the endogenous rise and decline of technology-blocking institutions. In the Middle Ages, the craft guilds served this purpose when faced with the introduction of labor-saving technology that threatened their livelihoods. Being organized at the level of cities, their monopoly power was limited by the competition from neighboring cities, implying that the degree of inter-city competition constrained their effectiveness. With strong enough inter-city competition, profits from introducing labor-saving technology were sufficient to overcome guild resistance.

We have provided evidence in a variety of forms that suggest that this mechanism may have been important in understanding the timing of the *Industrial Revolution* as well as the *Great Divergence*. Specifically, we have documented that England experienced a large increase in spatial competition in the seventeenth and eighteenth centuries whereas China did not. Additionally, we have provided historical evidence that strongly suggests that spatial competition critically affected the incentives of firms to adopt new technologies and the incentives of skilled workers to block those innovations. Finally, we have shown via a calibration exercise that the theory predicts England's take-off as well as China's stagnation. Although China's cities were on average similar in size to 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 think the mechanism developed in this paper can be used to understand a number of related issues. One such area relates to the argument that political fragmentation contributed to Europe's earlier take-off. One interpretation, favored by Jones (1981) and Lagerlöf (2014), is that inter-state competition for resources spurred military innovation that spilled over into civil society. Extending our model to the national level would provide an alternative interpretation based on the relation between inter-state competition and innovation. This would be consistent with Mokyr (2007) who describes how political fragmentation led to a competitive market 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 endogenously 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. The mechanism put forth in this paper could be easily extended to study these issues by interpreting regions as states and nations, and by taking spatial competition to be international competition.

References

Aghion, P., Bloom, N., Blundell, R., Griffith, R., & Howitt, P. (2005). Competition and innovation: An inverted-U relationship. *Quarterly Journal of Economics*, *120*, 701–728.

Atack, J., & Bateman, F. (2006). Manufacturing summary—Establishments, persons engaged, payroll, value added, capital expenditures, and inventories: 1849–1995, Table Dd1-12. In S. B. Carter, S. S. Gartner, M. H. Haines, A. L. Olmstead, R. Sutch, & G. Wright (Eds.), *Historical statistics of the United States, earliest times to the present* (Millennial ed.). New York: Cambridge University Press.

Audin, M. (1979). Printing. In M. Daumas (Ed.), *A history of technology and invention. Vol. 3, the expansion of mechanization, 1725–1860*. New York: Crown.

Bairoch, P., Batou, J., & Chèvre, P. (1988). *La population des villes européennes de 800 à 1850*. Geneva: Centre d'Histoire Economique Internationale de l'Université de Genève, Librairie Droz.

Binfield, K. (2004). *Writings of the Luddites*. Baltimore: Johns Hopkins University Press.

Bogart, D. (2005). Turnpike trusts, infrastructure investment, and the road transportation revolution in eighteenth-century England. *Journal of Economic History*, *65*, 540–543.

Boucekkine, R., de la Croix, D., & Peeters, D. (2007). Early literacy achievements, population density, and the transition to modern growth. *Journal of the European Economic Association*, *5*, 183–226.

Bradstock, T. R. (1983). Ch'ing dynasty craft guilds and their monopolies. *Tsing Hua Journal of Chinese Studies, NS*, *15*, 1430–53.

Bradstock, T. R. (1984). *Craft guilds in Ch'ing dynasty China.* Unpublished Ph.D., Dissertation, Harvard University.

Cao, S. (2000). *Zhongguo renkoushi: Qing shiqi (population history of China: Qing period)*. Shanghai: Fudan University Press.

Chen, D. (1923). Chinese migrations, with special reference to labor conditions, Bulletin No. 340, United States Bureau of Labor Statistics, Washington, DC: Government Printing Office.

Clark, G. (2001). The secret history of the industrial revolution. UC Davis, unpublished working paper.

Clark, G. (2007). *A farewell to alms: A brief economic history of the world*. Princeton: Princeton University Press.

Daudin, G. (2010). Domestic trade and market size in late 18th century France. *Journal of Economic History*, *70*, 716–743.

Daumal, M., & Zignago, S. (2010). Measure and determinants of border effects of Brazilian states. *Papers in Regional Science*, *89*, 735–758.

De la Croix, D., Doepke, M., & Mokyr, J. (2018). Clans, guilds and markets: Apprenticeship institutions and growth in the pre-industrial economy. *Quarterly Journal of Economics*, *133*, 1–70.

Dent, C. (2007) Patent policy in early modern England: Jobs, trade, and regulation, Legal Studies Research Paper no. 237, Melbourne Law School.

Desmet, K., & Parente, S. L. (2010). Bigger is better: Market size, demand elasticity and innovation. *International Economic Review*, *2010*(51), 319–333.

Desmet, K., & Parente, S. L. (2012). The evolution of markets and the revolution of industry: A unified theory of growth. *Journal of Economic Growth*, *17*, 205–234.

Desmet, K., & Parente, S. L. (2014). Resistance to technology adoption: The rise and decline of guilds. *Review of Economic Dynamics*, *17*, 437–458.

Dinopoulos, E., & Syropoulos, C. (2007). Rent protection as a barrier to innovation and growth. *Economic Theory*, *32*, 309–332.

Eden, F. M. (1797). *The state of the poor; or, an history of the labouring classes in England, from the conquest to the present period* (Vol. i–iii). London: J. Davis.

Eggimann, G. (1999). *La population des villes du tiers monde, 1500–1950*. Geneva: Centre d'Histoire Economique Internationale de l'Universit é de Genève, Librairie Droz.

Epstein, S. R. (1998). Craft guilds, apprenticeship and technological change in preindustrial Europe. *Journal of Economic History*, *53*(684), 713.

Epstein, S. R. (2008). Craft guilds in the pre-modern economy: A discussion. *Economic History Review*, *61*, 155–74.

Foreign Office (Great Britain). (1875–1878). *Commercial reports from her majesty's consuls in China*. London: Harrison & Sons.

Galdón-Sánchez, J. E., & Schmitz, J. A, Jr. (2002). Competitive pressure and labor productivity: World iron-ore markets in the 1980s. *American Economic Review*, *92*, 1222–35.

Galor, O., & Moav, O. (2002). Natural selection and the origin of economic growth. *Quarterly Journal of Economics*, *117*, 1133–1192.

Galor, O., Moav, O., & Vollrath, D. (2009). Inequality in land ownership, the emergence of human capital promoting institutions, and the great divergence. *Review of Economic Studies*, *76*, 143–179.

Galor, O., & Weil, D. M. (2000). Population, technology and growth: From malthusian stagnation to the demographic transition and beyond. *American Economic Review*, *90*, 806–828.

GB Historical GIS. (2019). *A vision of Britain through time*, University of Portsmouth. http://www.visionofbritain.org.uk/place/20002. Retrieved March 2019.

Gelderblom, O., & Grafe, R. (2010). The rise and fall of the merchant guilds: Re-thinking the comparative study of commercial institutions in premodern europe. *Journal of Interdisciplinary History*, *40*, 477–511.

Greenwood, J., & Weiss, D. (2018). Mining surplus: Modeling James A. Schmitz's link between competition and productivity. *International Economic Review*, *59*, 1015–1034.

Greif, A., Iyigun, M., & Sasson, D. (2012). Social organizations, risk sharing institutions and economic development. In Aoki, M. (Ed.), *Proceedings of the 16th world congress of the International Economic Association*.

Greif, A., & Iyigun, M. (2013). Social organizations, violence, and modern growth. *American Economic Review Papers and Proceedings*, *103*(534), 38.

Helpman, E., & Krugman, P. R. (1985). *Market structure and foreign trade*. Cambridge: MIT Press.

Hickson, C. R., & Thompson, E. A. (1991). A new theory of guilds and European economic development. *Explorations in Economic History*, *28*, 127–68.

Holmes, T. J., & Schmitz, J. A. (1995). Resistance to technology and trade between areas. *Federal Reserve Bank of Minneapolis Quarterly Review*, *19*, 2–17.

Hotelling, H. (1929). Stability in competition. *Economic Journal*, *39*, 41–57.

Hummels, D., & Lugovskyy, V. (2009). International pricing in a generalized model of ideal variety. *Journal of Money, Credit and Banking*, *41*, 3–33.

Jacks, D. S., Meissner, C. M., & Novy, D. (2011). Trade booms, trade busts, and trade costs. *Journal of International Economics*, *83*, 185–201.

Jones, E. L. (1981). *The european miracle*. Cambridge: Cambridge University Press.

Kelly, M. (1997). The dynamics of smithian growth. *Quarterly Journal of Economics*, *112*, 939–64.

Kremer, M. (1993). Population growth and technological change: One million B.C. to 1990. *Quarterly Journal of Economics*, *108*, 681–716.

Krusell, P., & Rios-Rull, J. V. (1996). Vested interests in a positive theory of stagnation and growth. *Review of Economic Studies*, *63*, 301–329.

Lagerlöf, N.-P. (2014). Population, technology and fragmentation: the European miracle revisited. *Journal of Development Economics*, *108*, 87–105.

Lancaster, K. (1979). *Variety, equity and efficiency*. New York: Columbia University Press.

Letwin, W. (1954). *The English Common Law Concerning Monopolies* (Vol. 21, pp. 355–385). Chicago: University of Chicago Law.

Luo, R. (2017). *Skill premium and technological change in the very long run: 1300–1914*. Discussion Papers in Economics 17/09, University of Leicester.

Ma, D. (2005). Between cottage and factory: the evolution of Chinese and Japanese silk-reeling industries in the latter half of 19th century. *Asia Pacific Economy*, *10*, 195–213.

MacGowan, J. (1886). Chinese Guilds or Chambers of Commerce and Trade Unions. *Journal of the China Branch of the Royal Asiatic Society for the Year 1886*, XXI, new series, no. 1, 2, Article VIII, 133-92.

Maddison, A. (2001). *The world economy: A millennium perspective*. Paris: Development Centre of the OECD.

Maddison, A. (2010). *Statistics on world population, GDP and Per Capita GDP, 1-2008 AD*, University of Groningen.

Masschaele, J. (1993). Transport costs in medieval England. *Economic History Review*, *46*, 266–279.

McCloskey, D. (2010). *Bourgeois dignity: Why economics can't explain the modern world*. Chicago: The University of Chicago Press.

Minns, C., & Wallis, P. (2012). Rules and reality: Quantifying the practice of apprenticeship in early modern England. *Economic History Review*, *65*, 556–579.

Mokyr, J. (1990). *The lever of riches. Technological creativity and economic progress*. New York: Oxford University Press.

Mokyr, J. (1997). *The political economy of technological change: Resistance and innovation in economic history"*. Evanston: Northwestern University.

Mokyr, J. (1998). *Invention and rebellion: Why do innovations occur at all? An evolutionary approach*. Evanston: Northwestern University.

Mokyr, J. (2007). The market for ideas and the origins of economic growth in eighteenth century Europe. *Tijdschrift voor Sociale en Economische Geschiedenis*, *4*, 3–38.

Moll-Murata, C. (2008). Chinese guilds from the seventeenth to the twentieth centuries: An overview. *International Review of Social History, Supplement*, *53*, 213–247.

Morison, E. E. (1966). *Men, machines, modern times*. Cambridge: Cambridge University Press.

Morse, H. B. (1909). *The gilds of China*. London: Longmans, Green and Co.

Munro, J. H. (1997). The origin of the English 'new draperies': The resurrection of an old Flemish industry, 1270–1570. In N. B. Harte (Ed.), *The new draperies in the low countries and England* (pp. 1300–1800). Oxford: Oxford University Press.

Nickell, S. J. (1996). Competition and corporate performance. *Journal of Political Economy*, *104*, 724–46.

North, D. C. (1981). *Structure and change in economic history*. New York: Norton.

Ogilvie, S. (2004). Guilds, efficiency, and social capital: evidence from German proto-industry. Economic History Review, 57, 286–333.

Ogilvie, S. (2008). Rehabilitating the guilds: A reply. *Economic History Review*, *61*, 175–182.

Parente, S. L., & Prescott, E. C. (1999). Monopoly rights: A barrier to riches. *American Economic Review*, *89*, 1216–1233.

Peretto, P. F. (1998). Technological change, market rivalry, and the evolution of the capitalist engine of growth. *Journal of Economic Growth*, *3*, 53–80.

Pirenne, H. (1936). *Economic and social history of medieval Europe*. New York: Harcourt Brace & World.

Pomeranz, K. (2000). *The great divergence: China, Europe, and the making of the modern world economy*. Princeton, NJ: Princeton University Press.

Randall, A. (1991). *Before the luddites: Custom, community, and machinery in the English woolen industry, 1776–1809*. Cambridge: Cambridge University Press.

Richardson, G. (2004). Guilds, laws, and markets for manufactured merchandise in late-medieval England. *Explorations in Economic History*, *41*, 1–25.

Seligman, E. R. A. (1887). Two chapters on the mediaeval guilds of England. *Publications of the American Economic Association*, *2*, 9–113.

Sewell, W. (1980). *Work and revolution in France*. Cambridge: Cambridge University Press.

Shiue, C. H., & Keller, W. (2007). Markets in China and Europe on the Eve of the industrial revolution. *American Economic Review*, *97*, 1189–1216.

Smith, A. (1776). In E. Cannan (Ed.), *An inquiry into the nature and causes of the wealth of nations*. Chicago: Chicago University Press.
Stabel, P. (2004). Guilds in late medieval flanders: Myths and realities of guild life in an export-oriented environment. *Journal of Medieval History*, *30*, 187–212.
Szostak, R. (1991). *The role of transportation in the industrial revolution*. Buffalo, NY: McGill-Queens University Press.
’t Hart, M. C. (1993). Freedom and restrictions: State and economy in the Dutch Republic, 1570–1670. In K. Davids & L. Noordegraaf (Eds.), *The Dutch economy in the golden age*. Amsterdam: Nederlands Economisch-Historisch Archief.
Unger, R. W. (1978). *Dutch shipbuilding before 1800: Ships and guilds*. Assen: Van Gorcum.
Voigtländer, N., & Voth, H.-J. (2006). Why England? Demographic factors, structural change and physical capital accumulation during the industrial revolution. *Journal of Economic Growth*, *11*, 319–61.
Will, P.-É. & Wong, B. R. (1991). *Nourish the People. The State Civilian Granary System in China*, with Lee, J., Center of Chines Studies: University of Michigan.
Willan, T. S. (1976). *The Inland trade: Studies in English internal trade in the sixteenth and seventeenth centuries*. Manchester: Manchester University Press.
Wrigley, E. A., & Schofield, R. S. (1989). *The population history of England, 1541–1871: A reconstruction*. Cambridge: Cambridge University Press.
Yue, Z., Skinner, G. W., & Henderson, M. (2007). *ChinaW Dataset*. Davis: University of California, Regional Systems Analysis Project.