The Evolution of Markets and the Revolution of Industry *

Klaus Desmet
Universidad Carlos III
and CEPR

Stephen L. Parente
University of Illinois
and CRENoS

February 2008
Preliminary and Incomplete

Abstract

Why did the Industrial Revolution start sometime in the 18th century in England and not earlier and in some other country? This paper argues that the key to the start of the Industrial Revolution was the expansion and integration of markets that preceded it. Due to less regulation, increasing population, and declining trade costs, markets in England came to support an increasing variety of goods. As such, the demand became more elastic and competition intensified. This increased the benefits to process innovation. Sometime in the 18th century, these benefits became sufficiently large for firms to cover the fixed costs of innovation, giving rise to the Industrial Revolution. We illustrate this mechanism in a model with endogenous innovation and population and show that it generates a transition from a Malthusian era to a Modern Economic Growth era as well as a demographic transition and a structural transformation. We provide empirical support for our theory by documenting the evolution in markets in England prior to the Industrial Revolution and by documenting that markets at the start of the 18th century were more developed in England than in the rest of the world.

JEL Classification:
Keywords: Industrial Revolution, Innovation, Competition, Market Revolution

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*Desmet: Department of Economics, Universidad Carlos III. E-mail: `klaus.desmet@uc3m.es`; Parente: Department of Economics, University of Illinois at Urbana-Champaign. E-mail: `parente@uiuc.edu`.

1 Introduction

Sometime at the end of the 18th century England gradually escaped the Malthusian trap of stagnant living standards. As technological progress accelerated, output started to grow faster than population, and by the second half of the 19th century the country transitioned to the modern era of sustained income per capita growth. During the same time period two other important changes occurred: the demographic transition, with population growth turning from being positively to negatively correlated with income levels, and the structural transformation, with the share of manufacturing growing at the expense of agriculture. Since then many other countries have gone through their own industrial revolutions. Although different in time and place, these transitions to modern growth have followed the same broad pattern as England during the 19th century.

This paper proposes a novel mechanism for the transition from Malthusian to modern growth, based on the link between market size, competition and innovation. During the late-Malthusian phase population was slowly, but steadily, increasing. This, together with trade liberalization and improvements in transport infrastructure, led to an expansion in the size of the market. As a result, the economy started to produce a larger variety of products, making them more substitutable, raising the price elasticity of demand, and strengthening competition. The mechanism linking tougher competition to modern growth is as follows. The lower markups associated with greater competition oblige firms to become larger to break even. As firms become larger, they find it easier to cover the fixed cost of innovation and technology adoption. Therefore, once the market is big enough, competition is strong enough, and firms are large enough, innovation endogenously takes off. This, in turn, further increases the market size, providing additional incentives for innovation. The economy thus graduates to the era of modern growth.

The key building block of our model is the Hotelling-Lancaster preference construct. With such preferences, each household has an ideal variety that corresponds to his location on the unit circle. As shown by Helpman and Krugman (1985) and Hummels and Lugovskyy (2005), when the population increases, more varieties enter the market, making them more substitutable, and thus increasing the price elasticity of demand. Desmet and Parente (2007) exploit this feature and show in a one-period model how the higher elasticity of demand, due to a larger population or more liberalized trade, facilitates innovation.

The Hotelling-Lancaster construct naturally gives rise to a transition from stagnation to modern growth. As long as the market size experiences some minimal growth during the Malthusian phase, at some point it reaches a sufficient size for innovation to endogenously take off. This mechanism is by construction absent with Spence-Dixit-Stiglitz preferences, since its constant elasticity feature precludes a link between market size and elasticity. This difference is not only theoretically relevant, it is also empirically important. Indeed, there is ample evidence of a positive relation between market size and demand elasticity. This empirical regularity is present when markets expand because of either population growth (Campbell and Hopenhayn, 2005) or trade liberalization (Tybout, 2003; Hummels and Klenow, 2005).

The second building block of our model is a subsistence constraint in agriculture: people need a minimum amount of food to survive. This is a standard way of introducing nonhomotheticicities in preferences, implying that as consumers become richer, they dedicate a decreasing share of their incomes to food consumption (Galor and Weil, 2000; Caselli and Coleman, 2001). As economic growth takes off, this leads to a structural transformation, with the share of labor employed in agriculture falling in favor of manufacturing.

The last building block reflects the evidence that child rearing is more costly in the city than on the farm. It is well established that children are more likely to be involved in home production on a farm than in a factory (Rosenzweig and Evensen, 1977; Hansen and Prescott, 2002). In fact, the laws restricting child labor in England applied only to factory work, and explicitly excluded farm work (Doepke and Zilibotti, 2005). Therefore, whereas children could add to the family's hours worked on the farm, this was much less the case in the manufacturing towns. Although rising income increased the demand for children, it also spurred the structural transformation, leading to a compositional effect, decreasing the demand for children as a greater part of the labor force became employed in factories. If this second force dominates, a demographic transition occurs, with higher income levels reducing population growth.

In this model anything that affects the size of the market or the cost of innovation will also affect the timing of the industrial revolution. Greater population size, higher income per capita, longer working hours, better road infrastructure, and trade liberalization all increase the size of the market, and thus speed up the arrival of the industrial revolution. Some of these examples, such as trade liberalization, may be due to policy changes. Others, such as an increase in population, may arise endogenously. For instance, as in the standard Malthusian model, agricultural productivity growth allows the economy to support a larger population. As for the cost of innovation, better institutions and education may have played a role in stimulating R&D and the adoption of better technologies.

Clearly, the novelty of our theory lies in the mechanism that links market size to competition and innovation. The novelty is not in the list of factors we identify as being important for the timing of the industrial revolution. For example, Simon (1977) and Kremer (1993) have emphasized the importance of population growth for development. Schultz (1971), and more recently Diamond (2007), have argued that an agricultural revolution is a precondition for an industrial revolution. Williamson and O'Rourke (2005) and O'Rourke and Findlay (2007) have been at the forefront of the camp that stresses the role of international trade. Finally, North and Thomas (1973) have spearheaded the literature that stresses the role of institutions for development.

There is a large and growing literature on unified growth models that set out to show the transition from Malthusian to modern growth within a single framework. Important contributions include, amongst others, Kremer (1993), Jones (2001), Galor and Weil (2000), Hansen and Prescott (2002), and Voigtlander and Voth (2006). Once again, the main difference with our work lies in the novelty of the mechanism we emphasize. For example, whereas Hansen and Prescott (2002) is based on exogenous technological progress, Galor and Weil (2000) relies on increasing returns and externalities associated with human capital production to generate the industrial revolution. Our model, instead, focuses on the link between market size, competition and innovation.

In light of the existing empirical evidence, our framework presents a number of advantages. Voth (2003) has criticized part of the unified growth literature, because of relying exclusively on a positive link between population size and innovation, when this relation is empirically elusive. Instead, he suggests that the broader concept of market size is more appropriate, because at the end of the 18th century England was more populous than equally wealthy Holland, and much richer than more populous France. The key mechanism in our paper addresses this criticism, as the relevant variable for take-off is the size of the market.

Another point of debate is the role of human capital. The evidence shows that during the industrial revolution the skill premium did not increase (Feinstein, 1988). In our model, neither the industrial revolution nor the demographic transition depend on human capital. Technological progress takes off when the market size becomes large enough. The decrease in birth rates is not due to human capital changing the tradeoff between quantity and quality. Instead, it is a compositional effect, due to people moving from the farm to the city, where they face higher costs of raising kids.

The rest of the paper is organized as follows. Section 2 describes the model. Section 3 reports the main results. Section 4 provides empirical support for the theory. In particular, it shows that England's markets were better integrated than any other country in the world at that time. Section 5 concludes the paper.

2 The Model

Time is discrete and infinite. There are three sectors: a household sector, an agricultural sector and an industrial sector. The agricultural sector is perfectly competitive. Technological change is exogenous there. The industrial sector is monopolistically competitive. Each variety is located at a point on the unit circle. Technological change in the industrial sector is endogenous. Agents are distributed along the unit circle, and live for two periods. The first period represents childhood, whereas the second period represents adulthood. A child takes no decisions, does not consume and does not work. An adult's preferences are defined over consumption of the agricultural good, consumption of the industrial goods, and the number of children.

2.1 Household Sector

Endowments

At the beginning of period t there is measure N_t of adults, uniformly distributed around the unit circle. Each adult is endowed with one unit of time, which it supplies inelastically to either the agricultural or the industrial sector. Adults are perfectly mobile across sectors. Denote by N_{at} and N_{vt} the measure of adults employed in, respectively, agriculture and industry.

Preferences

The utility depends on the number of children, n_t, the quantity of the agricultural good consumed, c_{at}, and the amounts and varieties of the industrial goods consumed, c_{vt}, where v indexes the variety of the industrial good belonging to the set V.

In terms of the industrial goods, each agent has an ideal variety which corresponds to the agent's location on the unit circle. The farther away a particular variety of the industrial good, v, lies from an agent's ideal variety, $\tilde{v}$, the lower the utility derived from a unit of consumption of variety, v. Let $d_{v\tilde{v}}$ denote the shortest arc distance between variety v and the agent's ideal variety $\tilde{v}$. The utility of an adult located at point $\tilde{v}$ on the unit circle is

$$U = [(c_{at} - c_{\bar{a}})^{1-\alpha}[g(c_{vt}|v \in V)]^{\alpha}]^{\mu}(n_t)^{1-\mu} \tag{1}$$

where

$$g(c_{vt}|v \in V) = \max_{v \in V}[\frac{c_{vt}}{1 + d^{\beta}_{v,\tilde{v}}}] \tag{2}$$

Demographics

Rearing a child takes up a fraction an adult's time. If the adult is employed in agriculture, this fraction of time is denoted by τ_a; if the adult is employed in industry, the corresponding fraction is τ_v, where $\tau_v \geq \tau_a$.

2.2 Agricultural Sector

The farming sector is perfectly competitive. Agricultural goods are produced with a constant returns to scale technology, where labor and land are the inputs. For convenience, we assume land rents are equally distributed amongst the entire adult population N_t. The economy's endowment of land is fixed and normalized to one. Let Q_{at} denote the quantity of agricultural output and let L_{at} denote the corresponding agricultural labor input. Then

$$Q_{at} = A_{at} L_{at}^{\theta} \tag{3}$$

where A_{at} is agricultural TFP, which grows exogenously at $\gamma_a \geq 0$ between periods.

2.3 Industrial Sector

The industrial sector is monopolistically competitive, and produces a set of differentiated goods. There is free entry and exit of firms. Each firm is located at a specific point on the unit circle. Its location corresponds to the variety it produces. As in Lancaster (1979), firms can costlessly relocate on the circle. Each period firms have a choice between using a benchmark technology and upgrading to a more productive technology. The benchmark technology in period t is the technology used by firms in period $t-1$. We denote its marginal productivity of labor by A_t. Instead of using the benchmark technology, a firm in period t can choose to improve its marginal productivity of labor to $A_t(1+\gamma_t)$. The fixed labor cost associated with upgrading the marginal productivity by γ_t is

$$\kappa e^{\phi[(1+\gamma_t)(1+\delta_t[\frac{A_t}{A_0}-1])-1]} \tag{4}$$

where the parameter δ_t refers to the strength of intertemporal spillovers. This can easily be seen by considering the two extreme cases. If $\delta_t = 0$, then spillovers are complete, and the fixed cost simplifies to $\kappa e^{\phi\gamma_t}$. In that case, the fixed cost with operating the benchmark technology in each period is κ, and the fixed cost associated with upgrading the technology by γ_t is independent of the time period. If $\delta = 1$, then there are no intertemporal spillovers, and the expression simplifies to $\kappa e^{\phi[(1+\gamma_t)\frac{A_t}{A_0}-1]}$. In that case, the fixed cost of operating a certain technology is determined by how much more productive that technology is compared to the benchmark technology of period 0. Any δ_t strictly in between 0 and 1 reflects a situation of incomplete spillovers. Note that in our specification δ_t may change with time. For example, if the education system improves over time, facilitating the intertemporal transfer of knowledge, this would imply δ_t becoming smaller as time progresses. In the empirical section we assume that $\delta_t = \delta_0^{\sigma(t-s)+1}$, where s is the first period in which $\delta_s > 0$.

Let Q_{vt} be the quantity of variety v produced by a firm that chooses to upgrade its marginal productivity by a fraction γ_t in period t and let L_{vt} denote the units of labor it employs. Then,

$$Q_{vt} = A_t(1+\gamma_t)[L_v - \kappa e^{\phi[(1+\gamma_t)(1+\delta_t[\frac{A_t}{A_0}-1])-1]}] \tag{5}$$

2.4 Household Demand

We start by deriving the individual demand of an agent located at point $\tilde{v}$ on the unit circle. An agent working in sector i has two sources of income: labor income and land rental income. Denote the wage level in sector i by w_{it} and the rental price of land by r_t. Its budget constraint is then given by:

$$w_{it}(1-\tau_i n_t) + \frac{r_t}{N_t} = c_{at} + \int_{v\in V} p_{vt}c_{vt}dv \tag{6}$$

where the price of the agricultural good has been normalized to 1.

Maximizing (1) subject to (6) gives:

$$\begin{aligned} c_{at} &= \mu(1-\alpha)(w_{it} + \frac{r_t}{N_t} - c_{\bar{a}}) + c_{\bar{a}} && (7)\\ \int_{v\in V} p_{vt}c_{vt}dv &= \mu\alpha(w_{it} + \frac{r_t}{N_t} - c_{\bar{a}}) && (8)\\ n_t\tau_i &= (1-\mu)(1 + \frac{1}{w_{it}}(\frac{r_t}{N_t} - c_{\bar{a}})) && (9) \end{aligned}$$

We make the necessary assumptions to ensure that $w_{it}+r_t/N_t > c_{\bar{a}}$ for all $t \geq 0$. The sub-utility function given by equation (2) implies that each agent consumes a single industrial variety. The variety v' that an agent located at $\tilde{v}$ buys is the one that minimizes the cost of an equivalent unit of the agent's ideal variety, $p_{vt}(1+d^{\beta}_{v\tilde{v}})$, so that

$$v' = \text{argmin}[p_{vt}(1+d^{\beta}_{v,\tilde{v}})|v \in V]$$

A household located at $\tilde{v}$ buys the following quantity of variety v':

$$c_{v't} = \frac{\mu\alpha(w_{it} + \frac{r_t}{N_t} - c_{\bar{a}})}{p_{v't}} \tag{10}$$

In a symmetric equilibrium, aggregate demand is readily determined. Denote by d_t the distance between two neighboring varieties in period t, and by p_{vt} the price of any variety v. In that case, a fraction d_t of agents consume each variety. Aggregate demand for a given variety v is then

$$Q_{vt} = \frac{d_t\mu\alpha(N_{vt}w_{vt} + N_{at}w_{at} + r_t - N_t c_{\bar{a}})}{p_{vt}} \tag{11}$$

Similarly, aggregate demand for the agricultural good is:

$$Q_{at} = \mu(1-\alpha)(w_{at}N_{at} + w_{vt}N_{vt} + r_t - N_t c_{\bar{a}}) + N_t c_{\bar{a}} \tag{12}$$

The demand for kids allow us to write down the law of motion of the population.

$$N_{t+1} = (1-\mu)(\frac{N_{at}}{\tau_a}(1+\frac{1}{w_{at}}(\frac{r_t}{N_t} - c_{\bar{a}})) + \frac{N_{vt}}{\tau_v}(1+\frac{1}{w_{vt}}(\frac{r_t}{N_t} - c_{\bar{a}}))) \tag{13}$$

2.5 Agricultural Supply

If L_{at} is the labor input in the agricultural sector in period t, then the first order condition of profit maximization implies that the agricultural wage rate is

$$w_{at} = \theta A_{at}(L_{at})^{\theta-1} \tag{14}$$

The land rents generated by the agricultural sector are

$$r_t = (1-\theta)A_{at}(L_{at})^{\theta} \tag{15}$$

2.6 Industrial Supply

The fixed labor cost implies that each variety, regardless of the technology used, will be produced by a single firm. In maximizing their profits, firms behave non-cooperatively, taking the choices of other firms in both countries as given. Each firm chooses the price and quantity of its good to be sold in the Home country, the price and quantity of its good to be sold in the Foreign country, the number of workers to hire, and the technology to be operated.

An industrial firm's profits can be written as

$$\Pi_{vt} = p_{vt}Q_{vt} - w_{vt}[\kappa e^{\phi[(1+\gamma_t)(1+\delta_t[\frac{A_t}{A_0}-1])-1]} + \frac{Q_{vt}}{A_t(1+\gamma_t)}] \tag{16}$$

where w_{vt} is the wage in the industrial sector. A firm chooses (p_{vt}, γ_t) to maximize the above equation, subject to aggregate demand (11). As in the standard monopoly problem, the profit maximizing price in each market is a markup over the marginal unit cost $w_t/A_t(1+\gamma_t)$, so that

$$p_{vt} = \frac{w_{vt}}{A_t(1+\gamma_t)}\frac{\varepsilon_{vt}}{\varepsilon_{vt}-1} \tag{17}$$

where ε_{vt} is the price elasticities of demand for variety v:

$$\varepsilon_{vt} = -\frac{\partial Q_{vt}}{\partial p_{vt}}\frac{p_{vt}}{Q_{vt}}$$

Following the same procedure as in Hummels et al., it is easily shown that in a symmetric equilibrium the elasticity is the same across all varieties:

$$\varepsilon_{vt} = \varepsilon_t = 1 + \frac{1}{2\beta}(\frac{2}{d_t})^{\beta} + \frac{1}{2\beta} \tag{18}$$

The first order necessary condition associated with the choice of technology, γ_t, is

$$-\phi\kappa e^{\phi[(1+\gamma_t)(1+\delta_t[\frac{A_t}{A_0}-1])-1]} + \frac{Q_{vt}}{A_t(1+\gamma_t)^2} \leq 0 \tag{19}$$

where the inequality in the above expression corresponds to a corner solution, i.e., $\gamma_t = 0$.

2.7 Equilibrium

Free entry and exit gives us a zero profit condition, which can be written as

$$Q_{vt} = \kappa e^{\phi[(1+\gamma_t)(1+\delta_t[\frac{A_t}{A_0}-1])-1]} A_t(1+\gamma_t)(\varepsilon_t - 1) \tag{20}$$

Each firm therefore employs

$$L_{vt} = \kappa e^{\phi[(1+\gamma_t)(1+\delta_t[\frac{A_t}{A_0}-1])-1]}\varepsilon_t \tag{21}$$

The labor market clearing condition in the industrial sector is then

$$N_{vt} = \frac{1}{d_t}[\kappa e^{\phi[(1+\gamma_t)(1+\delta_t[\frac{A_t}{A_0}-1])-1]}\varepsilon_t] \tag{22}$$

The labor market condition in the agricultural sector is

$$L_{at} = N_{at} \tag{23}$$

The overall labor market clearing condition says that

$$N_t = N_{at} + N_{vt} \tag{24}$$

Since workers can freely move across sectors, in equilibrium their utilities should be the same:

$$u_{at} = u_{vt} \tag{25}$$

This condition determines the number of agents in the two sectors, N_{vt} and N_{at}.

We are now ready to define the *Symmetric Equilibrium.*

Definition of Symmetric Equilibrium. *A Symmetric Equilibrium is a vector of elements (Q_{at}, Q_{vt}, w_{at}, w_{vt}, r_t, N_t, N_{at}, N_{vt}, p_{vt}, d_t, ε_t, and γ_t) that satisfies (11), (12), (13), (14), (15), (17), (18), (19, (20), (22), (23), (24) and (25).*

3 Numerical Results

Table 1 reports some relevant statistics for England and Western Europe between 1770 and 1913. GDP per capita growth before 1820 was positive, though very low; it then picked up during the 19th century, to slow down somewhat in the decades before the Great War. Over the same time period, population growth rates increased gradually. Table 2 shows the same statistics for the longer time period 1760-2000. This gives a slightly different picture. GDP per capita growth continues to increase, whereas population growth rates increase during the 19th century, and then start dropping in the 20th century.

Table 1: England and Western Europe 1770-1913

Country	1770-1820	1820-1870	1870-1913
	Population		
England	0.76%	0.79%	0.87%
Western Europe	0.43%	0.70%	0.80%
	GDP per capita		
England	0.26%	1.26%	1.01%
Western Europe	0.16%	1.04%	1.33%

Table 2: England and Western Europe 1760-2000

Country	1760-1820	1820-1880	1880-1940	1940-2000
	GDP per capita			
England	0.26%	1.19%	1.14%	1.81%
Western Europe	0.16%	1.03%	1.30%	2.35%
	Population			
England	0.76%	0.82%	0.55%	0.35%
Western Europe	0.43%	0.71%	0.59%	0.45%

3.1 Benchmark Model

In what follows we illustrate the properties of our model numerically. The parameter values used in the benchmark experiment are given in Table 2. Note that this parametrization does not follow a calibration procedure.

Table 3: Parameter values

$\beta = 0.6$	$\delta_0 = 0.15$	$\phi = 4.5$	$\kappa = 0.35$
$\mu = 0.895$	$\alpha = 0.905$	$A_{a0} = 1$	$A_0 = 1$
$\theta = 1$	$\gamma_a = 0.005$	$\tau_a = 0.045$	$\tau_v = 0.17$
$c_{\bar{a}} = 0.235$	$\sigma = 0.0075$	$N_0 = 20$	

Figure 1 plots technological progress in the industrial sector. We interpret periods as years. As can be seen, until period 67 there was no technological progress in manufacturing. The reason is the lack of demand for industrial products, due to both the agricultural subsistence constraint and the small population size. In period 67 technological progress in the industrial sector takes off endogenously, and gradually increases over time, before peaking at around 2.1%.

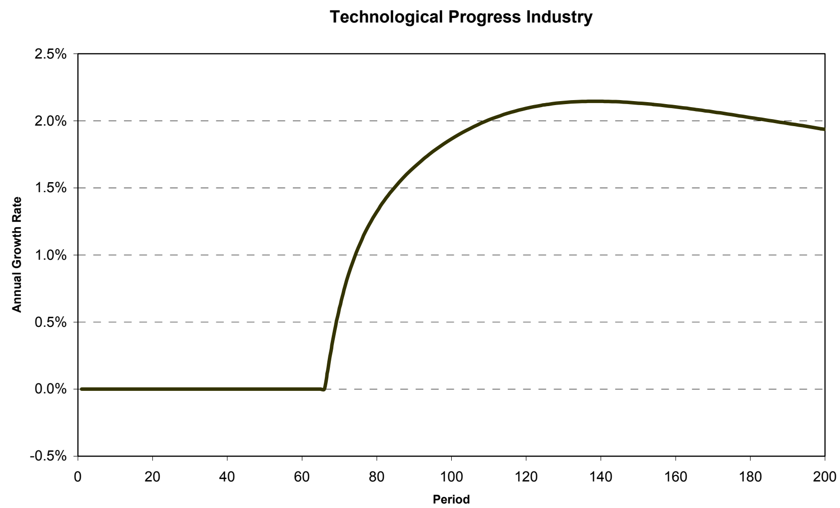

Figure 1: Technological Progess Industry

GDP per capita growth is initially close to zero. It is slightly positive though because agricultural TFP is assumed to growth at a rate of 0.5% per year. This corresponds to the Malthusian phase.[1] When technological progress takes off in the industrial sector, GDP per capita growth starts to increase, from around 0.02% to 2%.

Because of the subsistence constraint, the increase in GDP per capita leads to a relative decrease in the demand for agricultural goods. Figure 3 shows the share of labor employed in agriculture. It steadily declines. Note that the structural transformation starts before the industrial revolution. This is because GDP per capita is already increasing before.

The demand for kids is determined by two opposing forces. On the one hand, the increase in GDP per capita increases the demand for children. On the other hand, the move of people from the farm to the city, decreases the overall demand for children, as

[1] In contrast to Galor and Weil (2000), we do not distinguish between Malthusian, Post-Malthusian, and modern growth, but only between Malthusian and modern gorwth.

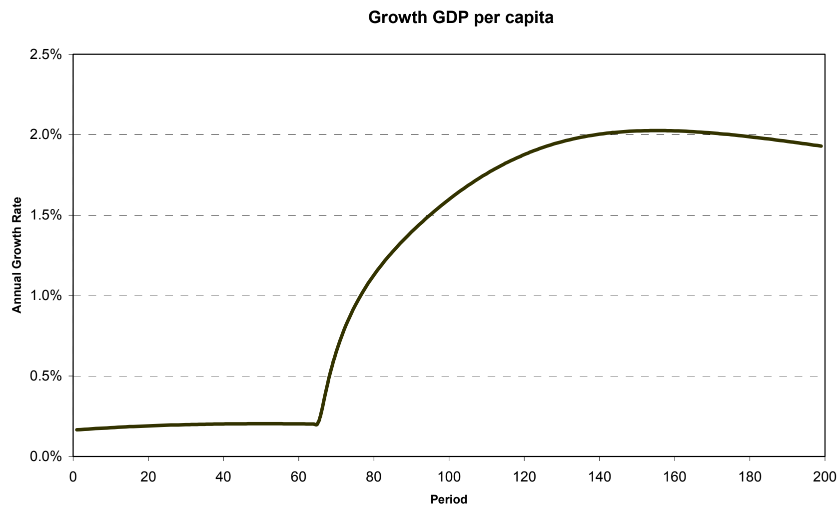

Figure 2: Growth GDP per capita

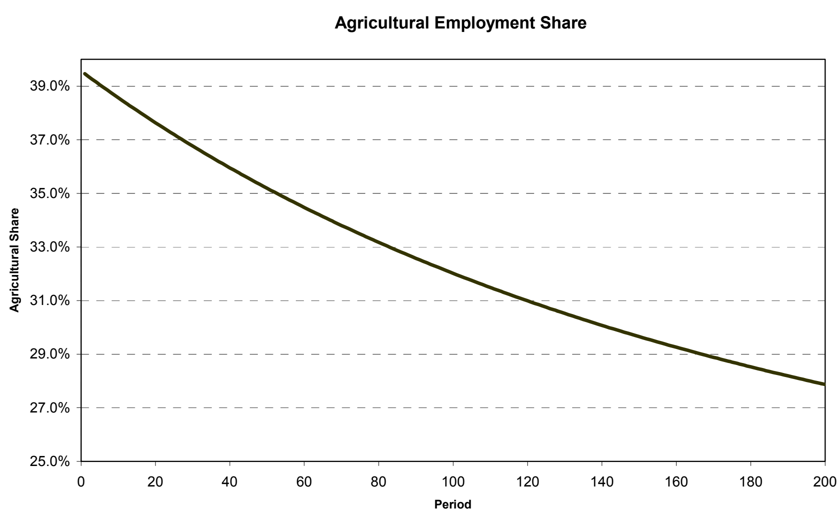

Figure 3: Agricultural Employment Share

the time cost of child rearing is higher in the city. In Figure 4 we see how population growth first increases and then decreases. This is the so-called demographic transition: population growth decreases, even though income per capita is increasing.

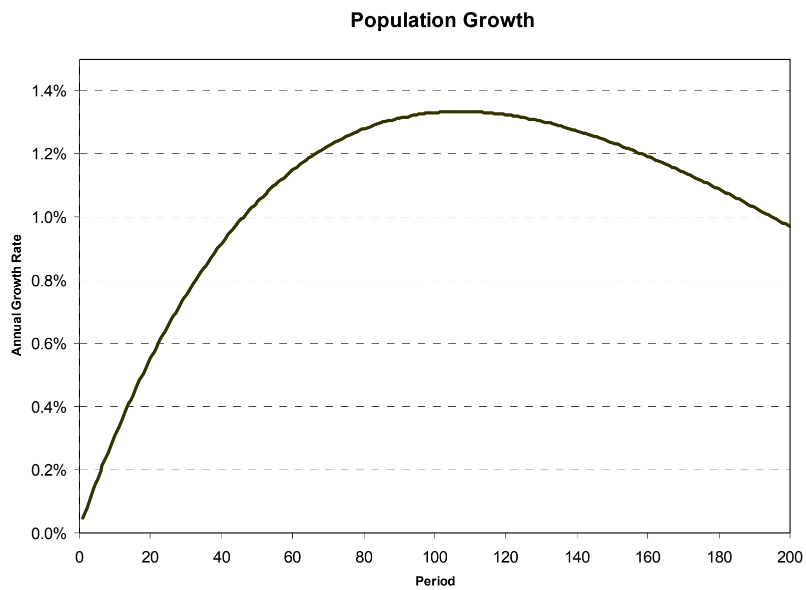

Figure 4: Population Growth

3.2 Market Size

In our model the timing of the industrial revolution has to do with the size of the industrial market. Several factors affect this market size, such as population size, GDP per capita, and the subsistence constraint. This can easily be seen by doing a number of comparative statics exercises.

If we increase the initial population, N_0, by 25%, the industrial revolution starts about 20 years earlier, in period 48 instead of 67. This can be seen in Figure 5. If we increase the initial GDP per capita by raising initial agricultural TFP by 10%, then the industrial revolution starts 15 years earlier, in period 52 instead of 67. Figure 6 shows this. Something similar occurs when we weaken the subsistence constraint by 15%, from $c_{\bar{a}} = 0.235$ to $c_{\bar{a}} = 0.20$. This increases the demand for industrial goods, and as a result, the industrial revolution starts about 20 years earlier, in period 45 instead of 67. Figure

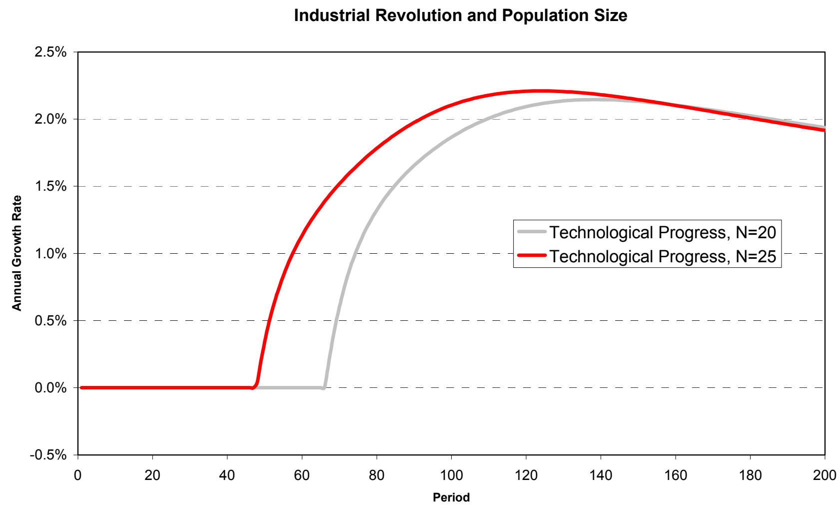

Figure 5: Industrial Revolution and Population Size

7 illustrates this.

It is important to emphasize that market size is a broader concept than population size. Voth (2003) is critical of unified growth models that rely exclusively on population size to generate the industrial revolution, and argues that historical evidence points to market size being a more relevant factor. In the comparative statics exercises we have focused on population size, GDP per capita, and the agricultural subsistence constraint affecting the industrial market size. Clearly, trade and transportation costs are also relevant. O'Rourke and Findlay (2007) have made the point that free trade was crucial for the industrial revolution to happen. In Desmet and Parente (2007) we explore the effects of the reduction in trade barriers and the improvement in transportation infrastructure on innovation in a static model with Hotelling-Lancaster preferences. Not surprisingly, we find that freer trade and lower transport costs have the same positive effects on innovation as an increase in population size.

3.3 Institutions

The timing of the industrial revolution is also sped up if institutions and property rights are improved. This can be interpreted as a lower fixed cost to entry. In our model, the

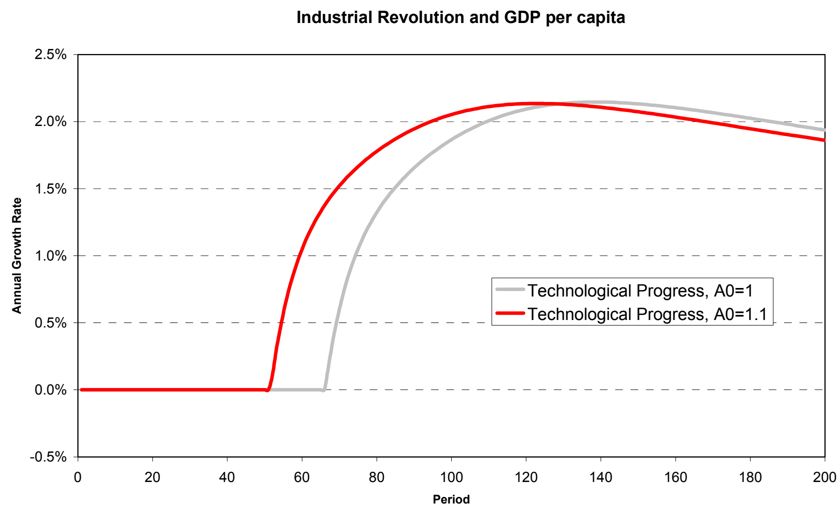

Figure 6: Industrial Revolution and GDP per capita

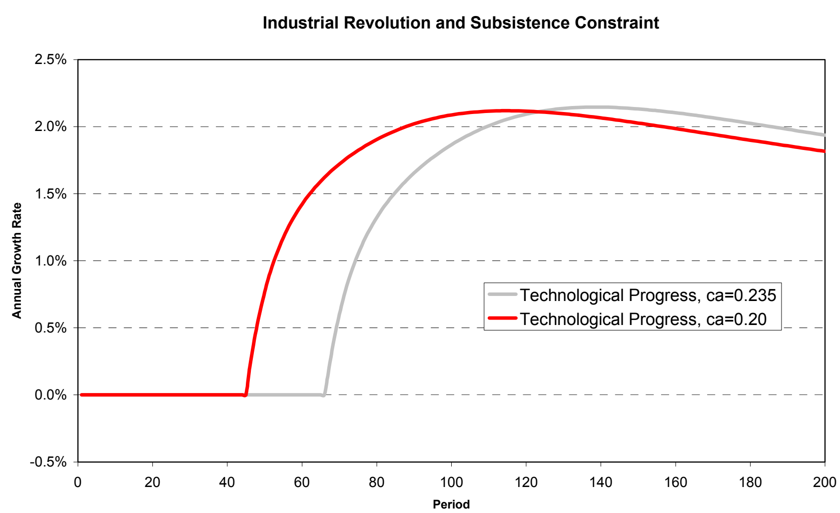

Figure 7: Industrial Revolution and Subsistence Constraint

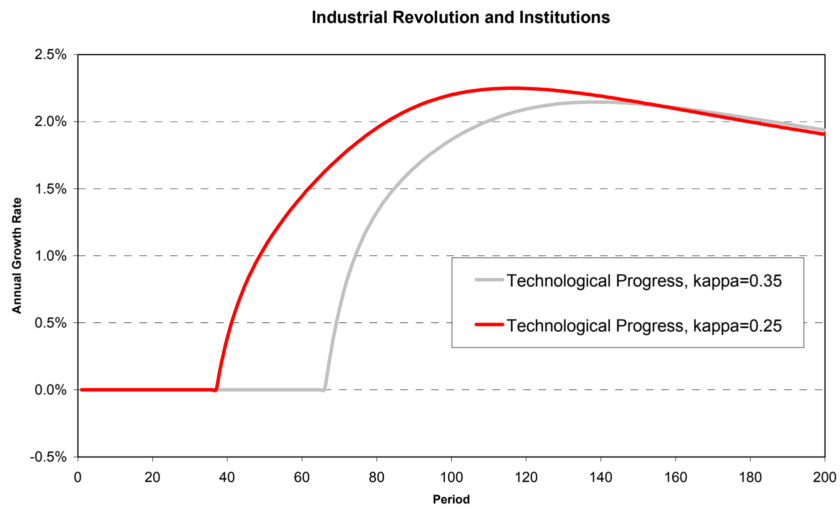

Figure 8: Industrial Revolution and Institutions: Effect of lower kappa

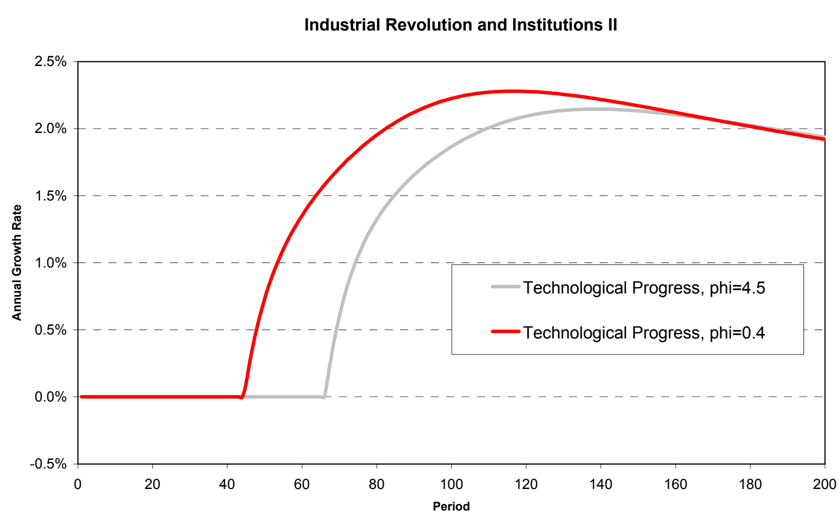

Figure 9: Industrial Revolution and Institutions: Effect of lower phi

fixed cost is made up of two parameters, κ, which determines the fixed cost of determining the benchmark technology, and ϕ, which determines how much the fixed cost increases when adopting better technologies.

Decreases in κ and ϕ should have similar effects. Figure 8 shows that if we decrease κ from 0.35 to 0.25, the industrial revolution starts 30 years earlier, in period 37 instead of 67. Figure 9 shows how a drop in ϕ from 4.5 to 4 speeds up the industrial revolution by about 20 years.

3.4 Agricultural Revolution

Some authors, such as Schultz (1971) and Diamond (1997), have argued that an agricultural revolution is a precondition for an industrial revolution. This can easily be seen by setting agricultural TFP growth to zero. In that case, population does not grow, and the market never becomes big enough for the industrial revolution to take place.

4 Empirical support

In this section we use the model to interpret the historical experiences of various regions and individual countries, and in doing so, hope to convince the reader that our theory provides a reasonable answer to the question why the *Industrial Revolution* had to wait until the 18^{th} century and did not occur in some other country. Recall that at the core of our theory is the mechanism by which various factors work to break down resistance. This mechanism corresponds to more intense competition and more price elastic demand for goods and services. The factors isolated by our theory as being critical for the degree of competition are the size of the urban population, openness to trade, barriers to entry, agricultural TFP and growth in that TFP.

We focus on two aspects of the historical experiences: the time series and the cross section. The time series evidence concentrates on the experience of England, and in particular, the developments in its institutions, agriculture, urban population, transportation and trade in the centuries leading up to the *Industrial Revolution.* The cross section compares other countries and regions to England along these same dimensions on the eve of the *Industrial Revolution.* We start by providing empirical support for important changes in these factors in England in the two centuries leading up to the *Industrial Revolution*. We then show that England was further ahead along these dimensions than other nations on the eve of the *Industrial Revolution*.

4.1 England, 1300-1800

Between 1300 and 1800 there were important improvements in England's institutions, agriculture, and transportation, in addition to large increases in the number of people living in urban areas. These developments were almost surely dependent. For instance, Acemoglu et al. (2005) argue that the rise in North Atlantic trade was an important factor shaping institutions in England and other parts of Europe.

A key date for improvements in English institutions is the *Glorious Revolution* of 1688. North and Weingast (1989), in particular, have argued that the Glorious Revolution was an important development because it made it far more difficult for the crown to expropriate wealth, raise customs and sell monopolies. Ekelund and Tollison (1981) argue that the balance of power brought on by the events of 1688 weakened the effects of mercantilism, primarily, in the amount of effective regulation. In fact, Ekelend and Tolllison characterize the situation in England as one of free trade as a result of the balance of power.

There were also large increases in agricultural productivity in England between 1300 and 1800. According to Allen (2000, Table 8, p 21), agricultural output per agricultural worker in England was stagnant from 1300 to 1600, but roughly doubled between 1600 and 1750. The reasons for these increases are numerous. Historians point to a number of factors to explain this. The four most important developments were land enclosure, mechanization, selective breeding and crop rotation. It is generally agreed that each of these developments allowed for a significant population increase in England. Land enclosure has also been related to the large increase in the urban population as tenant farmers were evicted.

The transportation system in England likewise was improved in the period leading up to the *Industrial Revolution*. In England, both roads and canals were important. According to Szostak (1991, p. 60) a network of turnpikes linking almost every town existed in England in the first half of the 18^{th} century. The turnpike was a fairly recent development, with the first one being built in the 17^{th} century. Turnpike trusts were an important institutional development for the English transportation system. Turnpike Trusts replaced local parishes as the main body responsible for the maintenance of roads. Before the creation of trusts, local parishes had responsibility for maintaining local roads. This they did through property taxes and by requiring up to six days of unpaid labor by residents. Trusts, in contrast, paid for maintenance by levying tolls and issuing debt. Non-turn pike roads were also important in this period. In 1770, turnpikes covered 15,000 miles and non-turnpike roads covered approximately 60,000 miles.

Canals were also an important means of transporting goods in the period. England was, in fact, blessed with a geographical advantage in this respect on account of the abundance of natural waterways and the lack of dramatic changes in elevation and seasonal temperatures which made water traffic profitable. According to Szostak (1991, p 55), England had 1,100 kilometers of navigable rivers in 1660, rising to 1,900 in 1725, to reach 3,400 km by 1830.

England was also blessed with a coastline that afforded natural ports. This contributed to the growth in international trade over the 1300 to 1800 period. Acemoglu et al. (2005) plot the dramatic rise in Atlantic voyages between 1500 and 1800. They show that between 1700 and 1800 there was roughly an 8-fold factor increase in the number of voyages per year.

Lastly, there was a large increase in England's urban population between 1400 and 1750. In terms of total population, the English population in 1700 stood at approximately the same number as in 1300, as it took 400 years for the total population to recover from the Black Death in 1347 that killed off half of England's population. While population size was approximately the same in 1700 and 300, the distribution of the population across rural and urban areas was radically different. In 1300, there were 220,000 people living in urban areas, which represented 4 percent of the population. In 1700, this number was

880,000, representing almost 14 percent of the population. This increase in urbanization occurred before the start of the Industrial Revolutions, and hence is not a result of an increase in the living standard. Some of this increase is attributed to the English Acts of Enclosure, which turned many common parcels of land into private holdings.

All of these developments are important in our theory. We see this as a virtue of our theory. Clark (2005), for instance, has challenged the branch of the literature that favors institutional developments, since the Glorious Revolution occurred 100 years before the Industrial Revolution. Our theory offers an explanation for this lack of immediate impact. Additionally, our theory would suggest that the Black Death was an important event for the timing of the *Industrial Revolution*. Had there been no Black Death, the *Industrial Revolution* would have likely occurred earlier. How much earlier, is a difficult question to answer because institutions, openness, and urbanization in England were very different in 1300 than in 1700.

4.2 England and the Rest of the World on the Eve of the Industrial Revolution

We now present evidence that England on the eve of the *Industrial Revolution* was far more advanced in the factors identified by our theory as being important than other countries and regions. It is certainly true that England had a smaller land mass and smaller total population than many other countries in the beginning of the 18th century. However, as we shall argue, it compensated for this in terms of better transport, better institutions, more open trade, and greater urbanization. These factors meant that markets in England tended to more national in coverage, whereas markets in the larger nations were much more regional. In fact, as we shall argue, in the case of China, the relevant comparison is not with China as a whole, but the Jiangsu and Zhejiang regions in the Lower Yangzi Province.

4.2.1 Western Europe

We begin with evidence in the form of price data from Shiu and Keller (2007) that suggests that markets in England were far more national in nature compared to France, and the rest of Western Europe. Shiue and Keller (2007) compute the variance of grain prices across regions in Europe and China for the 17th, 18th and 19th centuries. What they find is that grain prices in the 17^{th} century were far less volatile in England compared to the rest of Europe, or China that was on par with the rest of Europe. By the 19^{th} century, they find that this volatility declined for Europe, but remained more or less the same for China.

Why were markets more national in England and more regional in the rest of the world. One reason is that England possessed a much more developed system of roads and canals. Szostak (1991) provides a thorough comparison of the English and French transportation systems in the period leading up to the *Industrial Revolution.* He provides estimates of the total mileage of roads and operating canals in England and France in the 17^{th} century, as well as the speed of transport by coach between cities. He also characterizes the state of these roads. Essentially, England, despite having one fourth the land mass as France, had the same amount of total road mileage. Whereas England by the 18th century had a transportation system that linked every town in England, France did not. Moreover, road in France were in a state of disrepair. (Szostak, 1991, p. 61). The superiority of the English roads is reflected in the travel time of stage coaches. In the 1760's, the average coach in England traveled between 80 to 120 kilometers per day. In France, in contrast, the average distance was between 40 and 55 kilometers per day. Water transport also was far more prevalent and developed in England than France on the eve of the *Industrial Revolution*. Additionally, France's transportation system was characterized by much larger tolls.

Why the transportation system was far more extensive and tolls significantly lower in England than in France is good question. The answer most likely involves geographical factors as well as political ones, including the greater power enjoyed by the French crown. In terms of geography, England had a number of advantages. For one, it was less mountainous. This was important not only for roads, but for water transport, as it meant that the difference in the up-stream and down-stream currents was less. Also, in contrast to England, France lacked any natural ports along its coastline, thus, making sea transport more difficult.

There is thus strong evidence that markets in England were national but not in France and the rest of Europe. Therefore, the relevant statistic is the amount of the total population living in all urban areas. Despite its smaller population and land mass, England by the 18th century was far more urbanized than any other country, having experienced a large and steady increase in the number of cities over the previous five centuries. According to Brewer (1988), the number of English towns with populations between 5,000 and 10,000 doubled between 1600 and 1750. This was in contrast to continental Europe, which experienced an absolute decline in the number of such populated towns. Bairoch (1976) presents data that shows that the fraction of the population living in urban areas was significantly higher in England than France after 1600. By 1750, England had 23 percent of the population living in cities, whereas in France only 13 percent of the population lived in cities. (See Allen, R. Table 1, p Urban Development and Agrarian Change in Early Modern Europe, 1998)

Institutions are generally viewed to have been more conducive to industrialization in England compared to the rest of Western Europe on the eve of the *Industrial Revolution*. Ekelend and Tollison (1981) compare the forms of mercantilism practices in England and France in the 16th through18th century and conclude that there were dramatic differences in the amount of regulation, because of important institutional differences determining the power of regulators. In France, this power was absolute, and hence the barriers to entry were large. In England, the weaker power of the crown and jurisdictional disputes with parliament meant that regulation was ineffective, and that free trade reigned.

That France did not develop before is not hard to understand. What is harder to understand is why the Netherlands and Belgium did not develop before or at the same time as England. Allen (2000) documents that agricultural productivity was very similar in the three countries on the eve of the *Industrial Revolution*. Additionally, the fraction of the population in urban areas was similar. However, the absolute size of that urban population in Belgium was about 50 percent the level of England and in the

Netherlands 80 percent the level of England. This may be one reason that Belgium and the Netherlands had to wait longer for their *industrial revolutions* to begin

4.2.2 Asia

Much attention has been paid to China's development between the 12th and 14th centuries when China appeared to be on the verge of an industrial revolution. In our estimation, the critical question is not why China failed to achieve an industrial revolution over the Song Dynasty period, 900 to 1200 AD, but instead the critical question is why it failed to realize and industrial revolution during the Qing period, 1600-1900 AD. It is fairly obvious why the technological vibrancy that characterized the Song period was not sustained. First, there is the Mongol invasion starting from 1205 and lasting to 1302 that resulted in X million deaths and a general move of the population from the northeast part of the country to the southwest. Second, there is Black death that similarly affected China's populations. Estimates of the fraction of the population who died in China from the Bubonic plague are less specific than for Europe, but most historians think that the effect was as large or larger, with possibly one third to two thirds of the population killed. (There is also a third pandemic that starts around 1855 that kills 12 million people in India and China.). In our theory, these two events certainly would have worked against China fully industrializing. Nevertheless, the more important factor in the long-run was the political developments in the middle 13th century associated with the start of the Ming dynasty. The emperor, Name, was against the merchant class. Important during this period was the outlawing of certain technologies, an increase in the number of state monopolies, and a de-industrialization policy that was aimed at returning to a more farm-based society.

The real question then is why didn't China undergo an industrial revolution during the Qing Dynasty, when it experienced a large increase in its population without any associated increase in its living standard. On the surface, this large increase in population without an industrial revolution would appear to be problematic for our theory. However, if we look more closely at the nature of this population increase, it is not. According to historians, the most vibrant region in China in the 17th century was the Lower Yangzi Province that consists of Jiangsu and Zhejiang regions. The land mass of the LYP is only slightly smaller than Britain. According to Pomeranz (2000), per capita GDP in the LYP was approximately 1.5 times higher than the living standard for the rest of China. If an industrial revolution were to start in China, the LYP is the logical place.

Interestingly enough, the LYP did not experience much by way of a population increase during the Qing Dynasty. According to Pomeranz (2000), the population growth in the LYP was approximately 0 while Ma (2006) estimates the average annual population growth rate in the LYP to be .14 percent. The large increases in China's population occurred in the west and is associated with the opening of previously uninhabited land and agriculture. In addition to land availability, important to this agricultural expansion was the introduction of new plant varieties from the new world, particularly corn and wheat.

Ma (2006) provides an interesting comparison between Qing LYP and Mejii Japan in the 19th century and a theory for their subsequent divergent paths. His theory fits well within our theory. In particular, Ma points out that in terms of land mass, population levels, population changes, arable land, the LYP and Japan were very similar in 1850. However, in the next 5 decades the two countries implemented very different policies, which in our theory corresponds to a lowering of entry barriers and transportation costs in Japan, but nothing like that in China. According to Ma, whereas the Japanese decided to open up to the rest of the world, China under the leadership of the Qing Emperor decided to return and strengthen its Neo-Confuscian ideology. The policies followed by the two economies after 1850 were dramatically different. Japan's ruling factions fully supported private initiative, and even sold off some of the government enterprises. China in its Self-Strengthening movement took nearly the opposite course of action, even opposing private initiatives to improve the transportation system. Not surprisingly, whereas Japan began its industrial revolution in the second half of the 19th century, China did not.

China, or more narrowly, the LYP had to wait nearly 50 years later to start an industrialization. Following China's naval defeat to Japan in the 1894-96, an industrialization began in the LYP with Shanghai at the center of this revolution. The humiliating defeat brought a sharp end to the Self-Strengthening movement. Additionally, the Treaty of Shimonoseki gave foreigners the right to start up firms in the treaty ports. Thus, there was both a lowering of entry costs and trade costs. As Ma (2006) documents, the growth rate of per capita GDP in the LYP was essentially the same as Japan's growth rate of per capita GDP.

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