

A Service of

ZBW

Leibniz-Informationszentrum Wirtschaft Leibniz Information Centre for Economics

Gragnolati, Ugo; Moschella, Daniele; Pugliese, Emanuele

# Working Paper The spinning jenny and the guillotine: Technological diffusion at the time of revolutions

LEM Working Paper Series, No. 2011/19

**Provided in Cooperation with:** Laboratory of Economics and Management (LEM), Sant'Anna School of Advanced Studies

*Suggested Citation:* Gragnolati, Ugo; Moschella, Daniele; Pugliese, Emanuele (2011) : The spinning jenny and the guillotine: Technological diffusion at the time of revolutions, LEM Working Paper Series, No. 2011/19, Scuola Superiore Sant'Anna, Laboratory of Economics and Management (LEM), Pisa

This Version is available at: https://hdl.handle.net/10419/89508

#### Standard-Nutzungsbedingungen:

Die Dokumente auf EconStor dürfen zu eigenen wissenschaftlichen Zwecken und zum Privatgebrauch gespeichert und kopiert werden.

Sie dürfen die Dokumente nicht für öffentliche oder kommerzielle Zwecke vervielfältigen, öffentlich ausstellen, öffentlich zugänglich machen, vertreiben oder anderweitig nutzen.

Sofern die Verfasser die Dokumente unter Open-Content-Lizenzen (insbesondere CC-Lizenzen) zur Verfügung gestellt haben sollten, gelten abweichend von diesen Nutzungsbedingungen die in der dort genannten Lizenz gewährten Nutzungsrechte.

#### Terms of use:

Documents in EconStor may be saved and copied for your personal and scholarly purposes.

You are not to copy documents for public or commercial purposes, to exhibit the documents publicly, to make them publicly available on the internet, or to distribute or otherwise use the documents in public.

If the documents have been made available under an Open Content Licence (especially Creative Commons Licences), you may exercise further usage rights as specified in the indicated licence.



# WWW.ECONSTOR.EU



Laboratory of Economics and Management

Sant'Anna School of Advanced Studies Piazza Martiri della Libertà, 33 - 56127 PISA (Italy) Tel. +39-050-883-343 Fax +39-050-883-344 Email: Iem@sssup.it Web Page: http://www.Iem.sssup.it/

# LEM

# **Working Paper Series**

The Spinning Jenny and the Guillotine: Technological Diffusion at the Time of Revolutions

> Ugo Gragnolati° Daniele Moschella° Emanuele Pugliese°

° Institute of Economics, LEM-Scuola Superiore Sant'Anna, Italy

2011/19

August 2011

# The Spinning Jenny and the Guillotine: Technological Diffusion at the Time of Revolutions<sup>\*</sup>

Ugo M. Gragnolati<sup>1</sup>, Daniele Moschella<sup>1</sup>, and Emanuele Pugliese<sup>1</sup>

<sup>1</sup>Institute of Economics, LEM - Sant'Anna School of Advanced Studies, Pisa, Italy.

August 1, 2011

<sup>\*</sup>All the authors of this work share equal responsibilities. We feel greatly indebted with Alessandro Nuvolari for how much he helped us in focusing and improving our work.

#### Abstract

Which features did belong peculiarly to England so as to make it the only possible cradle of the Industrial Revolution? The present work shows that, by combining the effect of relative prices with the joint effect of scale economies and demand, it is possible to provide a purely economic explanation to the location and timing of the Industrial Revolution. The labor-saving innovations which characterized it were profitable only if output could expand after their adoption, thus covering the fixed costs they entailed. The importance of market size is illustrated by means of a detailed case study centered on the cotton industry and on the adoption of the spinning jenny in England and in France during the 18th century. By then, the sufficiently large and relatively well-off English middle class could guarantee an increase in consumption that was not viable in France, where income was lower and more concentrated in the hands of the upper classes. In this sense, demand possibly mattered in the Industrial Revolution.

KEYWORDS: Industrial Revolution, income distribution, economies of scale, choice of technique, spinning jenny.

JEL CLASSIFICATION: N00, N01, N70.

# 1 Introduction

For at least half a century the innovations at the roots of the Industrial Revolution originated and diffused almost exclusively in England. This fact leads to suppose that England benefited from some unique features, which did not exist in other countries, and that were necessary to allow the invention and the diffusion of the new technologies. What, then, made the difference?

One answer in the literature argues that, while the cognitive *capability* to produce inventions was relatively widespread in Western Europe, England was comparatively more endowed of the practical *competences* that were necessary to implement and ameliorate such inventions. In this view, while everywhere progress depended on the notorious breakthroughs accomplished by a mechanical elite, England benefited also from the greater availability of skilled artisans capable to carry out the myriads of anonymous micro-inventions that allowed a wide diffusion of the new technologies. In particular, it is argued, this differential in human capital stemmed from the sharper inclination of the English culture toward useful and pragmatic knowledge, which in fact characterized the English declination of the Enlightenment.<sup>1</sup> In this sense, then, a cultural element would possibly constitute the differential factor that spurt a major economic change like the Industrial Revolution.

A partly competing answer, instead, argues in favor of a solely economic explanation of the Industrial Revolution. According to this view, only in England the price of labor relative to capital was high enough to induce the adoption of the new labor-saving technologies of the Industrial Revolution, regardless of the quality of human capital that characterized the various countries. That is why inventions appeared and diffused in England but not elsewhere: only English manufacturers found it profitable to adopt them, thus implying that their inventors could not have a market outside of England. In this story, then, the conditions of the relative prices of input factors are considered sufficient to explain why England industrialized first. Moreover, the fact that England may have benefited from a greater availability of skilled labor is possibly seen as a consequence of the fact that advanced technical skills paid in England but not elsewhere, precisely because only in England it was convenient to use more advanced technologies.<sup>2</sup>

The present work provides a strictly economic account of the Industrial Revolution, but it also shows that demand can predict its location and timing much more accurately than relative prices. Possibly for the same reasons described by Allen (2009a, pp. 23–131), by the second half of the 18th century England was benefiting from a higher level and from of a more even distribution of average real income as compared to its "most similar country", France. In particular, while giving stronger incentives to substitute labor with capital, higher wages generated also an higher average demand per manufacturer. Both factors entailed a higher profitability of the new technologies in England relative to France. On one hand, the higher demand allowed English manufacturers to cover the fixed costs involved in the new technologies, while forcing French manufacturers below the minimum output threshold. On the other hand, the more favorable English relative prices implied a lower output threshold in England as compared to France. However, although in general both factors could have a role, demand was likely more decisive than relative prices: to put it loosely, while an inversion of demand between England and France could invert the industrial fortunes of the two countries, an inversion of relative prices would have left history unchanged. By the same token, the timing of industrialization in each country is matched very poorly by the evolution of relative prices, while it is accurately predicted by the evolution of demand.

<sup>1</sup>Mokyr (2009, pp. 99–123).

 $<sup>^2 \</sup>mathrm{See}$  Allen (2009a, pp. 8–11 and 238–271) and Broadberry and Gupta (2009).

The general argument outlined above is conducted here focusing on the cotton industry, which was the first one to industrialize. In particular, a detailed case study is developed on the diffusion of the spinning jenny in England and France during the 18th century. As it will be discussed, the relatively limited fixed cost entailed by the jenny guarantees that scale effects were relatively small as compared to the technologies that followed. Hence, if scale effects mattered for the jenny, they must have mattered *a fortiori* also for the subsequent technologies: in this sense the jenny is an helpful case study since it allows, to some extent, to generalize the conclusions that are to be presented here.

### 2 Demand analysis

Was cotton demand higher in England than it was in France during the 18th century? A premise is necessary before replying to this question: demand will serve here to evaluate how much a new technology like the spinning jenny was profitable for its *user*, not for its *inventor*. As a consequence, the analysis is interested in the quantity of cotton demanded *per spinner* rather than in the *aggregate* demand for cotton. For this reason, any claim of the kind "Demand was greater in France because the French population was bigger than the English one" is simply irrelevant to the present case; in fact, as population grows also the number of spinners presumably does, thus leaving possibly unchanged the demand per spinner.

Data on cotton demand per spinner in the 18th century are scanty. The best game in town are possibly the data on aggregate net imports of raw cotton: given the absence of domestic plantations of cotton both in England and France, dividing these figures by the number of domestic spinners provides the cotton demand per spinner, q. Figure 1 shows the evolution of q in England and France over the span 1700–1820. In fact, q turns out being systematically higher in England than in France throughout the whole 18th century and beyond; for instance, in almost all observations q is at least three times as high in England relative to France. Clearly, the different tendency to fluctuate of the two lines in Figure 1 reflects the greater scantiness of French data relative to English ones. Despite this limitation, Figure 1 does not seem to leave doubts about the fact that cotton demand per spinner has been higher in England than in France throughout the 18th century and beyond.

Could this differential derive from foreign markets? It would seem unlikely. During the 18th century the international market for manufactured cotton was negligible compared to the domestic one, both for England and France.<sup>3</sup> Moreover, given that most of the exports were directed to colonies, until the late 1780s England and France had similar international markets; therefore, if a difference existed in the demand expressed by each country, it was unlikely to be due to international markets.<sup>4</sup>

Could the differential derive from domestic markets? The combination of the level of real income per capita with the distribution of income in each country seem to provide a positive answer. To fully appreciate this point it is sufficient to think of a rather "classical" type of consumer: one who aims first at attaining a respectable subsistence level, and then spends her extra income by scrolling down a list of gradually more superfluous goods coming in fixed quantities. No item on the list can be bought before all the previous ones have been purchased. It follows that the consumption basket of the richer will differ from the one of the poorer by including more items on the list, rather than greater quantities of the same items. Moreover, if all consumers have the same list, the demand for a certain item will be represented by the share of people earning enough to buy all the previous items on the list plus the one of interest, which instead cannot be afforded by poorer people. This stylized picture bears as an implication that two countries with the same aggregate income and equal preferences may express different demands for a given item, due to their underlying differences in income distribution. For example, the demand for extreme luxury items would tend to be higher where income is more concentrated, since a greater share of the population will be rich enough to buy them. Vice versa, a mass-good in the country with a more equal income distribution may well become an upper-class good in the other country.<sup>5</sup> Now suppose that cotton was the first-ranked good on the list of consumers after the subsistence basket: then, the eligible cotton customers are represented by the share of the population whose income is above the subsistence level.

Looking at income data with this reasoning in mind reveals that English customers could buy more cotton than French ones. To begin with, average real income per household was higher in England than it was in France, respectively in 1759 and 1788. This can be deduced by comparing the mean values of the nominal

<sup>&</sup>lt;sup>3</sup>Baines (1835, pp. 111, 525).

 $<sup>^{4}</sup>$ This argument has been recently recalled and used by Daudin (2010, p. 738). However, such work does not identify any decisive role of demand during the Industrial Revolution precisely because it evaluates market size with aggregate demand rather than with the average demand per firm.

 $<sup>^{5}</sup>$ See Murphy et al. (1989, pp. 540–41) for a more formal definition of the utility function sketched informally here.



Figure 1: Imports of raw cotton per spinner (logarithmic scale).

Source: Figures for each country in each year are obtained by interpolation of the available data. In particular, the (interpolated) imports of raw cotton are divided by the number of spinners in each country, which is 1% of the (interpolated) population data, as reasonably assumable from Mitchell and Deane (1971, p. 187) and Morrisson and Snyder (2000, p. 66). English data on imports of raw cotton for each single year in the span 1700–1820 are taken from Mitchell and Deane (1971, p. 177). English population estimates come from Mitchell and Deane (1971, p. 5): these data are available at a decennial frequency in the span 1700–80, then every five years in the span 1780–1800, and again at a decennial frequency in the span 1800–20. French data on imports of raw cotton come from: Mulhall (1892, p. 160), for years 1688 and 1750; Crouzet (1966, p. 267), for year 1786; Chaptal (1819, p. 15), for year 1812; Baines (1835, p. 525), for year 1822. French population data come from: Maddison (2010), for years 1700 and 1820; Morrisson and Snyder (2000, p. 66), for year 1788.

income distributions shown in Figure 2 with the cost of the subsistence basket in each country reported in Table 1 at current prices. The subsistence basket of Table 1 corresponds to the "respectable" basket defined by Allen (2001) but for the addition of rent, which is here included since this datum is reliably available for each of the two countries taken in consideration. Yearly average nominal income per household amounted to 3381.1 grams of silver in England and only 2021.6 grams of silver in France, while the cost of Allen's "respectable" subsistence basket was actually slightly higher in France (2217g.s.) than it was in England (2201g.s.).<sup>6</sup> Yet, the sole average real income per household would be insufficient to infer anything about cotton demand, according to the consumption model sketched above: income could be concentrated in the hands of a few, thus implying that only a relatively small portion of the population could actually demand a non-subsistence good like cotton. In this respect, it is in fact worth noting that the subsistence basket defined in Table 1 accounts for basic clothing necessities by including the consumption of linen, while the need for a finer textile like cotton is plausibly excluded from subsistence. Hence, income distributions have to be considered. Doing so further confirms that England, as compared to France, could express a greater demand of cotton per spinner thanks to its more even income distribution: the Gini coefficient in England was 0.48 in 1759, while in France it was 0.56 in 1788.<sup>7</sup> As a consequence, the fraction of the population earning more than the subsistence level was 51%

 $<sup>^{6}</sup>$ The fact that average real income per capita was higher in England than in France has been discussed at greater depth by Allen (2009a, pp. 25–26).

<sup>&</sup>lt;sup>7</sup>Notice that the difference between England and France in terms of income distribution is even more striking when the "inequality extraction ratio" (IER) is considered rather than the sole Gini coefficient, as discussed by Milanovic et al. (2011). The IER is computed by subtracting the cost of the subsistence basket from each income class to then compute the Gini coefficient



Figure 2: Income distributions per household in England (1759) and France (1788).

Source: All data have been downloaded from the web site http://gpih.ucdavis.edu/Distribution.htm, of the the Global Price and Income History Group (GPIHP). The GPIHP files quote the following sources: income distribution data for England are taken from Lindert and Williamson (1982); population data for England are taken from Mitchell (1988); income distribution and population data for France are taken from Morrisson and Snyder (2000). A log-normal smoothing has been applied to each class for purely aesthetical purposes.

in England and only 22% in France: these shares are represented by the red bars in Figure 2. Considering as constant the ratio of spinners per person, the level and the distribution of income can well explain why cotton demand per spinner was higher in England than it was in France at the dawn of the Industrial Revolution.

Two remarks are worth noting. First, while the demand for a middle-class good like cotton differed substantively between England and France, it could well be the case that the demand for luxury goods did not differ much, or was even higher in France than it was in England. For instance, despite a lower average income, the percentage of people who earned four times the income necessary to attain subsistence was higher in France than it was in England. For out attain subsistence was higher in France than it was in England. In other terms, the French aristocracy could probably afford luxuries that were not as widely affordable by the corresponding English class. Second, the consumption model that was sketched here to put forward an explanation of demand differentials does not rely at any stage on a variation of consumer tastes. This does not mean that the tastes of consumers did not actually change, possibly in favor of "new goods" like cotton: all it implies is that changes in tastes are not a necessary ingredient for the story that will be told here.<sup>8</sup>

Crucially, the fact that cotton demand per spinner was higher in England than in France is not sufficient to make it an eligible explanation of technological diffusion during the Industrial Revolution. Other clues need to be gathered in order to identify demand not only as one of the possible suspects, but rather as the trigger of the "wave of gadgets [that] swept over England" by 1760.<sup>9</sup> In particular, although it was possibly lower than the English one, the demand recorded in France might have been already high enough to make profitable

on the remaining income levels. The computations made by Milanovic et al. (2011, pp. 263–264, Table 2) show that the IER amounted to 55.4% in England and 76.1% in France, respectively in 1759 and 1788.

 $<sup>^{8}</sup>$ See De Vries (1994, especially pp. 255–57) and Berg (2004, especially pp. 91–95), to find arguments supporting an explanation of the Industrial Revolution that rests also upon a variation of tastes.

<sup>&</sup>lt;sup>9</sup>Ashton (1955, p. 42).

Item	$\begin{array}{c} \text{QUANTITY} (p.c.) \\ \text{(Yearly)} \end{array}$	UNIT PRICE (gs.) (Base year)	Cost per hou London (1759)	SEHOLD $(gs.)$ Paris (1788)
Bread	$182.0 \ kg.$	0.693		
Beans/peas	$52.0 \ l.$	0.477		
Meat	$26.0 \ kg.$	2.213		
Butter	$5.2 \ kg.$	3.470		
Cheese	$5.2 \ kg.$	2.843		
Eggs	$52.0 \ each$	0.010		
Beer	$182.0 \ l.$	0.470		
Soap	$2.6 \ kg.$	2.880		
Linen	$5.0 \ m.$	4.369		
Candles	$2.6 \ kg.$	4.980		
Lamp oil	$2.6 \ l.$	7.545		
Fuel	$5.0 \ MBTUb$	4.164		
Total of the above		414.899	1704.000	1991.500
Rent London (1769)		556.800	497.579	
Rent Paris (1788)				225.648
Total cost			2201.579	2217.148

Table 1: Respectable subsistence basket in England (1759) and France (1788).

Source: All monetary values are expressed in grams of silver (gs.) at the conversion rates 1d. = 0.464gs. and 1livre = 4.701gs., as taken from Allen (2011a). Apart for data on rent, the base year price of each good (column 3) is the average of its price in Strasbourg over the span 1745–54. In columns 4 and 5, the total value at current prices of the basket per household (excluding rent) is obtained using the following expression:  $414.899 \times CPI \times consumers per household$ . The consumer price index (CPI) of London and Paris at the relevant years come from Allen (2001, p. 426). The number of consumers per household is set to 3, assuming that the average household size was 4 and the two children consumed each half the quantities of an adult, similarly to Allen (2001, p. 426). For what concerns the cost at current prices of rent, the original English datum for 1769 has been deflated to its current value in 1759, while the original French datum was already expressed in its 1788 current value. Apart for the cost of rent, all data on single items are taken from Allen (2001, p. 421). The cost of rent in London in 1769 comes from Young (1770, p. 438): the rent in Kensington was used for the calculations. The cost of rent in Paris in 1788 comes from Young (1794, p. 450): the rent in Isle of France was used for the calculations.

the adoption of the new technologies; vice versa, these could turn out being profitable in England even if the English demand had been as low as the French one. In these cases, demand would not help to explain technological diffusion during the Industrial Revolution. Otherwise, if output had to grow in order to render adoption profitable, demand would hold an essential role. In parallel, if demand was central, also income distribution may have mattered in the way discussed above. In this perspective, the famous motto ascribed to the French Revolution, "Liberté, *egalité*, fraternité", may well have found some economic justifications especially with respect to the promotion of greater equality in terms of income. This, however, does not imply at all that the intentions of the motto were coherently followed by the revolutionary actions: how much, if at all, and in favor of whom wealth moved after the French Revolution remains an entirely empirical issue beyond the scope of the present analysis.

### **3** Profitability of adoption

Had France recorded the same cotton demand per spinner as England, would a new technology like the spinning jenny find reasons to diffuse also in France rather than only in England? And vice versa, had the English cotton demand per spinner been equal to the French one, would the jenny not diffuse in England? One way to address these questions is to evaluate technological diffusion in terms of the profitability of adoption. A potential user must evaluate whether the revenues obtainable by producing with the new technology would exceed costs by an amount superior to the profit generated by the old technology. Only in this case the new technology would be preferred to the old one and thus diffuse.

When the new technology operates at constant returns to scale (CRS), adoption depends solely on the relative prices of input factors. The new technology will be convenient as long as it saves on dearer inputs by substituting them with cheaper ones, regardless of the output quantity to be produced. Instead, when the new technology operates at increasing returns to scale (IRS), both the relative prices of input factors and the output quantity matter in deciding the profitability of adoption. Under IRS, average and marginal costs vary with the output quantity, and so does the profitability of adoption. Crucially, bringing output quantity in the picture implies that also final demand becomes relevant. Namely, the adoption of a new IRS technology is generally viable above a certain output level: if such level is higher than the one currently attained, adoption will take place only in the presence of some spare demand ready to absorb the output growth that is necessary to make the new technology profitable. Clearly, the presence of a fixed cost is sufficient to generate increasing returns to scale. Yet, the extent to which costs decrease varies across technologies, precisely because each of them is associated to a different fixed cost. With this consideration in mind, the present work focuses on a specific technology, the spinning jenny, which entailed an especially low upfront cost of capital relative to the other major inventions of the Industrial Revolution. By choosing the spinning jenny as a case study, it is ensured that any scale effect acting upon the profitability of adoption would have been even stronger for the other contemporary technologies.

The most profitable between two alternative techniques of production is the one generating a higher net present value. The invention of the jenny in 1764 allowed spinners to evaluate the profits that had been granted until then by the spinning wheel against those that could be granted from then on by the jenny. Accordingly, a general formula for the profitability of the jenny (superscripted by J) relative to the spinning wheel (superscripted by S) would read:

$$K^{J} = \sum_{t'=t+1}^{t+T} \frac{p(q_{t'}^{J} - q_{t'}^{S}) - w(L_{t'}^{J} - L_{t'}^{S}) - m^{J}}{(1+r)^{t'-t}} , \qquad (1)$$

where t identifies the year of the adoption choice, K is the upfront cost of capital, m its yearly maintenance cost, w is the daily wage paid for each of the  $L_{t'}$  work days in the year t', p is the price obtained for each of the  $q_{t'}$  units of output sold in that year, T is the life time of the jenny, and finally the unknown r is the rate of return from choosing the jenny over the spinning wheel. Equation (1) neglects the upfront cost and the maintenance cost of the spinning wheel just to simplify the notation: the spinning wheel cost only one shilling and such amount does not affect any of the results presented here.<sup>10</sup> Given the data summarized in Table 2, the computation of equation (1) can be made viable through different assumptions, of which one fits especially well the purpose of this work. Before moving to them, it is necessary to introduce the following notation. Define the labor input coefficients  $\alpha^S$  and  $\alpha^J$  such that  $q^S = L^S/\alpha^S$  and  $q^J = L^J/\alpha^J$ : it follows that  $\alpha^{-1}$  is labor productivity, and the term  $\eta = \alpha^S/\alpha^J$  indicates the labor productivity of the jenny relative to the spinning wheel.

 $<sup>^{10}</sup>$ The cost of the spinning wheel is reported by Allen (2009b, p. 916).

VARIABLE ENGLAND FRANCE 6.25 *d*. per day 9.00 st. per day w $L_0^S$ 100 days per year 100 days per year  $K^{j}$ 840 d. 2800 st.  $\mu$ 0.10.1 $m^{J}$ 84 d. 280 st. T10 years 10 years

3

Table 2: Data for England and France.

Note: Money values are expressed in pence (d.) and sous tournois (st.). The variables summarized in the table are the following: w, daily wage;  $L_0^S$ , full working days of a wheel spinner in a year;  $K^J$ , purchase price of the jenny;  $\mu$ , yearly maintenance rate;  $m^J = \mu \cdot K^J$ , yearly maintenance cost of the jenny; T, years of life of the jenny;  $\eta$ , labor productivity of the jenny relative to the spinning wheel.

Source: All data come from Allen (2009b, p. 916).

η

One possibility to allow the computation of equation (1) is to assume that output stays constant across technologies and over time, thus forcing labor to decrease with adoption by a share equal to the productivity gain. This implies that the price drop determined by the productivity gain would not reflect into greater sales: demand would thus be assumed to be perfectly inelastic. Hence, any effect of demand on profitability would be ruled out *ex hypothesis*. An alternative assumption is to consider labor as constant over time and across technologies. This corresponds to a situation in which the decrease in labor that would be allowed by the productivity gain is exactly offset by the labor increase required by the expansion in output. In this case, the productivity gain would reflect entirely on output through price: demand would thus be assumed to be unitary elastic with respect to productivity.<sup>11</sup> As a third possibility, a *priori* assumptions on demand elasticity can be avoided entirely in favor of a more empirical approach. This is the strategy that will be adopted here in order to ensure a more agnostic starting point on demand, which is precisely the issue at stake. Profitability will be computed directly as a function of q assuming only that  $q_{t'}^J = q_{t'}^S = q_{t'}$ , while allowing  $q_{t'}$  to change over time. Labeling as  $q_0$  the base-year output quantity corresponding to the labor input  $L_0^S$ , labor will vary with output according to  $L^S = L_0^S \cdot q/q_0$  and  $L^J = L^S/\eta = L_0^S/\eta \cdot q/q_0$ . In particular, the base-year quantity,  $q_0$ , will be set at the average output level across 1764-65,  $\bar{q}_{1764-65} \approx 53lbs$ , recorded just before the introduction of the jenny in England.

As a first exercise, in this Section q will be assumed constant over the life of the jenny but possibly different from  $q_0$ . Summing this to the assumptions mentioned above, equation (1) can be rewritten as

$$K^{J} = \sum_{t'=t+1}^{t+T} \frac{w L_{0}^{S} \frac{q}{q_{0}} \left(1 - \frac{1}{\eta}\right) - m^{J}}{\left(1 + r\right)^{t'-t}} .$$
<sup>(2)</sup>

3

Given  $q_0$  and the data summarized in Table 2, equation (2) allows to plot the value of r as a function of q in England and France, as shown in Figure 3: the two curves differ due to the different levels of w and  $K^J$  that characterized each country. Figure 3 also takes in consideration that investors did not have necessarily to put money on spinning: since the average rate of return on economic activities was 15% (represented in Figure 3 by the horizontal line), investment in the jenny would not have taken place unless it guaranteed a greater or equal rate of return.<sup>12</sup> In the attempt to "take a picture" of the profitability conditions at a given point in time, Figure 3 highlights also the value of r associated with the output quantities  $q_E$  and  $q_F$  recorded right after the invention of the jenny, respectively in England and France. Such quantities amount to the average value of q in each country across the years 1766–67, that is  $q_E \approx 74 lbs$  and  $q_F \approx 24 lbs$ . At least three important results emerge from Figure 3.

First, the simple profitability computations presented here provide an economic explanation to why the jenny diffused in England but not in France. Namely, at the output levels existing in each country right after the invention of the jenny, it was profitable to adopt in England but not in France: the value of r associated to the English output,  $q_E$ , is above 15%, while the one associated to the French output per spinner,  $q_F$ , is far below.

<sup>&</sup>lt;sup>11</sup>See Gragnolati et al. (2011); Allen (2011b) for further details on these two scenarios.

 $<sup>^{12}\</sup>mathrm{The}$  15% value is taken from Allen (2009b, p. 917).

Second, the value of r is always higher in England than it is in France thanks to the more favorable relative prices of input factors, w/K. As reported in Table 2, the ratio between wages and the cost of capital was higher in England than in France; hence, English spinners had a stronger incentive than French ones to substitute labor with capital. Since the jenny was labor-saving relative to the spinning wheel, its rate of return results to be always higher where labor was dearer.

Third, scale and demand mattered to adoption choices regardless of the relative prices of input factors. The value of r is increasing in q, and in particular it is higher than 15% only above a certain output threshold in each country (about 32*lbs* and 74*lbs* respectively in England and France). This simple fact substantiates the case for increasing returns in manufacturing even at the early stage of the Industrial Revolution.<sup>13</sup> Furthermore, an output level equal to  $q_E$  would have made the jenny profitable also for French spinners, despite the adverse relative prices they faced. Vice versa, if at the same moment English spinners had recorded a demand equal to  $q_F$ , the jenny would have been unprofitable for them in spite of the favorable relative prices they faced. In this sense, demand mattered regardless of relative prices, and the questions that were posed at the beginning of this Section are now answered.

As a remark, it is worth considering whether capacity constraints played any role on adoption choices. Given that the jenny tripled the productivity of spinning (i.e.  $\eta = 3$  in Table 2), the way in which the working time varied with adoption depended on how output quantity behaved. For instance, right before the invention of the jenny 100 days of work were needed to spin  $q_0 \approx 53 lbs$  with the wheel in England; then, the adoption of the jenny co-occurred with an output increase from  $q_0 \approx 53 lbs$  in 1764–65 to  $q \approx 74 lbs$  in 1765–66, which required about 46 days of spinning with the jenny. However, this amount of time covered only a part of the work that was necessary to convert raw cotton into yarn: each pound of yarn required also an additional 1.067 days to carry out other preparatory and finishing activities.<sup>14</sup> Taking this in consideration, in 1765–66 the typical English spinner had to work about 125 days, which amounted to half of the regular working days in a year.<sup>15</sup> Hence, right after the invention of the jenny it was possible for the spinner to carry out the entire process of converting raw cotton to yarn, while still having free a considerable part of her working time. This is particularly relevant since it was normally women who operated the jenny while also devoting time either to household activities or to agricultural work.<sup>16</sup> In this sense, then, the typical spinner was not affected in her output decision by any binding capacity constraint, at least not immediately after the invention of the jenny.<sup>17</sup> For instance, the maximum capacity attainable by a spinner with the jenny in the 250 working days of the year was approximately 148lbs: as shown by Figure 1, this output level was much higher than the one actually attained by the typical spinner at the time of invention of the jenny, but it was eventually reached in England by 1780 and later in France. Yet, as the capacity threshold approached, new opportunities for profit developed. In particular, the drastic reorganization of labor that took place during the Industrial Revolution could be seen as a way to take up those opportunities: contrarily to cottagers, factories could exploit specialization while being much less constrained on output quantity, which in turn allowed them to push scale economies further.

At this point of the investigation, evidence on the possible relevance of demand in deciding the diffusion of the spinning jenny starts to be more binding. Nonetheless, a source of skepticism could regard the link between demand conditions and the timing of industrialization. Given the relative prices of input factors, it could turn out that the demand level necessary for adoption was reached in England and France at a different timing from the actual start of industrialization in each country. Vice versa, given a demand level, it could turn out that the relative prices of input factors allowing for adoption in each country were reached way before or way too late with respect to the actual pace of industrialization. Overall, then, it is necessary to assess the extent to which demand and relative prices can match with history.

## 4 Timing

So far it was shown that the adoption of a representative Industrial Revolution technology like the jenny was not viable in France *at the same time* as it was in England, due to differences in demand and relative prices. Now the relevant question becomes another one, namely: given either demand or relative prices, *since when* was the adoption of the jenny viable in each country?

 $<sup>^{13}</sup>$ To the contrary, Mokyr (1977, p. 995) claimed that "it is not an easy task to substantiate the case for increasing returns in manufacturing anywhere before, say, 1870".

<sup>&</sup>lt;sup>14</sup>Allen (2009a, p. 185) and Allen (2011b, p. 426).

<sup>&</sup>lt;sup>15</sup>Allen (2009b, p. 916).

<sup>&</sup>lt;sup>16</sup>This point is discussed in Allen (2009a, pp. 194, 214).

 $<sup>^{17}</sup>$ This shows that the comprehensible worry on capacity constraints raised by Allen (2011b, pp. 462–463) is not relevant to the present case.



Figure 3: *r* as a function of *q*, with  $q_0 = \bar{q}_{1764-65}$  and  $q_{E,F} = \bar{q}_{1766-67}$ .

The first counterfactual exercise consists in fixing relative prices while allowing demand to vary. In particular, relative prices are fixed at the year of invention of the jenny, while demand for each year,  $q_{t'}$ , is set at the corresponding value of q reported in Figure 1. This allows to evaluate how the profitability of the jenny changed over time according to the evolution of the cotton demand per spinner. In order to do so, it is sufficient to include explicitly a year index for q in equation (2), so that it becomes

$$K^{J} = \sum_{t'=t+1}^{t+T} \frac{w L_{0}^{S} \frac{q_{t'}}{q_{0}} \left(1 - \frac{1}{\eta}\right) - m^{J}}{(1+r)^{t'-t}} .$$
(3)

The value of r as computed with equation (3) is plotted in Figure 4 at the English and French 1764–65 relative prices, taken from the values of w and K reported in Table 2. The plot shows that a technology like the jenny would have been profitable since 1740 in England, and after 1790 in France. Considering the ideal beginning of industrialization to be 1760 and 1810 respectively in England and France, the estimates on the timing of adoption provided by equation (3) are reasonably lagged backwards by 20 years. In the case of England, the discrepancy between the timing of adoption predicted by profitability computations and the historical record may be justified by the fact that inventions need time to become marketable. For instance, the first major (but unsuccessful) attempt to mechanize cotton spinning is surprisingly close in time to 1740: namely, Lewis Paul patented for the first time his roller spinning machine in 1738 and then obtained a second patent for a perfected version in 1758.<sup>18</sup> Similarly, the jenny likely underwent significant period of experimentation and improvement before it reached the minimum efficiency that was necessary to make it profitably adoptable and thus marketable. As for what concerns France, it may seem that the discrepancy between the economic prediction and history does not concern only the time lag but also the very fact that the jenny did not diffuse much in France after 1790.<sup>19</sup> However, by that time the jenny had already been superseded by the spinning

<sup>&</sup>lt;sup>18</sup>See English (1973); Hills (1979) for two detailed technical assessments of the roller spinning and of its timing of invention.

<sup>&</sup>lt;sup>19</sup>According to Allen (2009a, p. 193), by 1790 there were 900 jennies in France and 20000 in England.



Figure 4: r as a function of  $q_{t'}$ .

mule, which in fact started to spread also in France  $^{20}$ : that is why the diffusion of the jenny in France cannot be observed. Overall, then, demand variations seem to explain quite accurately the timing of industrialization.

The second counterfactual exercise consists in fixing demand while allowing the relative prices of input factors to vary. When demand is fixed so that  $q_{t'} = q_0$ , recalling that  $m^J/K^J = \mu$  and dividing both terms in (2) by  $K^J$  allows to write

$$1 = \sum_{t'=t+1}^{t+T} \frac{\left(\frac{w}{K^{J}}\right)_{t_{0}} z_{t'} L_{0}^{S} \left(1 - \frac{1}{\eta}\right) - \mu}{(1+r)^{t'-t}} , \qquad (4)$$

Given  $(w/K^J)_{t_0}$ , equation (4) reveals how the value of r changes according the variation of relative prices of input factors, which are summarized by the index  $z = (w/K^J)_{t'} (K^J/w)_{t_0}$ . In England, setting  $(w/K^J)_{t_0}$  to its 1764–65 level reported in Table 2, r turns out being greater than 15% for any z > 0.6. According to the time series on relative prices elaborated by Allen, this condition was attained in the English economy since 1650!<sup>21</sup> But the jenny was invented and adopted one century later. Therefore, the time accuracy obtained with a varying demand cannot be replicated by allowing the relative prices of input factors to vary instead. In this sense, it seems possible to claim, at least, that demand explains the timing of adoption of the jenny more accurately than relative prices do.

 $<sup>^{20}</sup>$ For instance, Chaptal (1819, p. 5) describes the technological state of the French cotton industry by 1819 as follows: "L'état actuel de nos filatures par les mécaniques dites *mull-jennys* et *continues*, nous permet de fournir par an à la fabrication des tissus ou de la bonneterie plus de 25 millions de livres de fil de coton, indépendamment de ce qui se file encore au rouet ou à la main dans les montagnes : la filature est aussi parfaite qu'on peut le désirer; et si jusqu'ici on a paru négliger de filer les numros les plus fins, c'est qu'on a préféré ceux dont le débit et la consommation étoient plus assurés et plus étendus".

 $<sup>^{21}</sup>$ See Allen (2009a, p. 139, Figure 6.1) for the time series of the price of labor relative to capital. See instead Crafts (2010, pp. 158–59) for an assessment similar to the one presented here.

# 5 Conclusion

The present work has documented the essential role played by demand in deciding the diffusion of a representative Industrial Revolution technology like the spinning jenny. Both the average income level and its distribution were shown to be plausible reasons for which the British cotton demand per spinner kept higher than the French one throughout the 18th century and beyond. England could count on a sufficiently vast and well-off middle class capable to express a sufficiently ample demand for a non-subsistence good like cotton; to the contrary, the fact that income was lower and more concentrated in France blocked a considerable share of the French population from participating to the formation of the demand for cotton. Had France enjoyed a demand as high as the British one, French spinners would have found the jenny profitable despite the unfavorable relative prices they faced; vice versa, had England recorded a demand as low as the French one, the jenny would not have been profitable even under the favorable English relative prices. By the same token, the evolution of demand over the 18th century turns out to match both the early start of England and the late arrival of France in the race toward industrialization. These conclusions entail three major messages in relation to other contributions in the literature.

First, and contrarily to the argument made by Allen (2009a,b, 2011c); Broadberry and Gupta (2009), although being an ingredient of the story, the relative prices of input factors alone seem insufficient to explain the Industrial Revolution. This was shown through the various counterfactual exercises on the profitability of adoption: if only relative prices mattered, a technology like the jenny should have been invented one century before its actual invention. Why did history run otherwise? Whatever the possible reason, it implies that some other piece of an explanation needs to be added to the relative prices of input factors, if they are to be used to account for the Industrial Revolution. This extra piece can well be demand.

Second, and in contrast with the claim made by Mokyr (1977), demand did matter during the Industrial Revolution due to the interaction between scale effects and market size.<sup>22</sup> As a consequence, the analysis of supply conditions should go hand in hand with the analysis of demand, rather than walking alone.

Third, and in relation to the recent debate emerging from Allen (2009a) and Mokyr (2009), the market for the early inventions of the Industrial Revolution could exist in England but not in France, notwithstanding the level of technical competence of the two countries.<sup>23</sup> For instance, any effort to invent and sell the jenny to French spinners would have normally failed, even if French inventors and engineers had had the same technical competence as English ones. In this perspective, it may be possible that the reason why England had a higher level of technical competences was precisely because such competences paid in England but not elsewhere.

 $<sup>^{22}</sup>$ The reference is to Mokyr (1977, p. 1005): "[T]he traditional notion that supply and demand were somehow symmetric in the industrialization process is unfounded. The determination of 'when', 'where', and 'how fast' are to be sought first and foremost in supply, not demand related processes".

 $<sup>^{23}</sup>$ See Mokyr (2009, pp. 99–123) and Allen (2009a, pp. 8–11 and 238–271), as a reference to the two sides of the debate. See Crafts (2010) for an insightful assessment of each of the two sides.

# References

- Allen, R. (2001). The Great Divergence in European Wages and Prices from the Middle Ages to the First World War. Explorations in Economic History 38(4), 411–447.
- Allen, R. (2009a). The British Industrial Revolution in Global Perspective. Cambridge: Cambridge University Press.
- Allen, R. (2009b). The Industrial Revolution in Miniature: The Spinning Jenny in Britain, France, and India. Journal of Economic History 69(4), 901–927.
- Allen, R. (2011a, June). Data: Wage and Price History. London and Paris. In Conversions, Sources, and Comments. http://www.nuffield.ox.ac.uk/General/Members/allen.aspx.
- Allen, R. (2011b). The Spinning Jenny: A Fresh Look. Journal of Economic History 71(2), 461–464.
- Allen, R. (2011c). Why The Industrial Revolution was British: Commerce, Induced Innovation, and the Scientific Revolution. *Economic History Review* 64(2), 1–28.
- Ashton, T. (1955). An economic history of England: The eighteenth century. London: Methuen.
- Baines, E. (1835). History of the cotton manufacture in Great Britain. London: Fisher, H., Fisher, R., Jackson, P.
- Berg, M. (2004). In pursuit of luxury: Global history and british consumer goods in the eighteenth century. *Past & present 182*(1), 85–142.
- Broadberry, S. and B. Gupta (2009). Lancashire, India, and Shifting Competitive Advantage in Cotton Textiles, 1700–1850: The Neglected Role of Factor Prices. *Economic History Review* 62(2), 279–305.
- Chaptal, J. (1819). De l'industrie française, Volume II. Paris: Antoine-Augustin Renouard.
- Crafts, N. (2010). Explaining the First Industrial Revolution: Two Views. European Review of Economic History 15, 153–168.
- Crouzet, F. (1966). Angleterre et France au XVIIIe sicle : Essai d'analyse compare de deux croissances conomiques. Annales. Histoire, Sciences Sociales 21e Anne(2), 254–291.
- Daudin, G. (2010). Domestic Trade and Market Size in Late-Eighteenth-Century France. Journal of Economic History 70(3), 716–743.
- De Vries, J. (1994). The Industrial Revolution and the Industrious Revolution. Journal of Economic History 54(2), 249–270.
- English, W. (1973). A Technical Assessment of Lewis Paul's Spinning Machine. Textile History 4(1), 68–83.
- Gragnolati, U., D. Moschella, and E. Pugliese (2011). The Spinning Jenny and the Industrial Revolution: A Reappraisal. *Journal of Economic History* 71(2), 458–463.
- Hills, R. (1979). Hargreaves, Arkwright and Crompton. Why Three Inventors? Textile History 10(1), 114–126.
- Lindert, P. and J. Williamson (1982). Revising England's Social Tables, 1688-1812. Explorations in Economic History 19(4), 385–408.
- Maddison, A. (2010, March). Statistics on World Population, GDP, and Per Capita GDP, 1–2008 AD. http://www.ggdc.net/Maddison/content.shtml.
- Milanovic, B., P. Lindert, and J. Williamson (2011). Pre-industrial Inequality. *Economic Journal* 121(551), 255–272.
- Mitchell, B. (1988). British Historical Statistics. Cambridge: Cambridge University Press.
- Mitchell, B. and P. Deane (1971). Abstract of British Historical Statistics. Cambridge: Cambridge University Press.

- Mokyr, J. (1977). Demand vs. Supply in the Industrial Revolution. *Journal of Economic History* 37(4), 981–1008.
- Mokyr, J. (2009). The enlightened economy: An economic history of Britain, 1700-1850. Yale University Press.
- Morrisson, C. and W. Snyder (2000). The income inequality of France in historical perspective. *European Review of Economic History* 4(1), 59–83.
- Mulhall, M. (1892). The dictionary of statistics Part 1. A-P. London: Routledge and sons.
- Murphy, K., A. Shleifer, and R. Vishny (1989). Income Distribution, Market Size, and Industrialization. *Quarterly Journal of Economics* 104(3), 537–564.
- Young, A. (1770). A Six Months Tour Through the North of England (Second ed.), Volume IV. London: Strahan and Nicoll.

Young, A. (1794). Travels during the Years 1787, 1788, and 1789 (Second ed.), Volume I. London: Richardson.