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The Spinning Jenny and the Industrial Revolution: A Reappraisal

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Abstract

Was the adoption of the spinning jenny profitable *only* in England? No. The present work finds that the jenny was profitable also in France. Such result contrasts recent findings on the topic by revising basic computations on the profitability of the spinning jenny.
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1 Introduction

Why was the Industrial Revolution British? In a recent article, Robert Allen argues that only in England was the price of labor relative to capital high enough to justify the adoption of the labor-saving technologies which characterized the Industrial Revolution [2] (see also [3, 4]). To support his argument he uses the spinning jenny as a case study. The jenny was indeed an important labor-saving technology that was invented and widely adopted in England but not in France. Allen explains this fact by calculating the returns to adopting the jenny in each country: according to his calculations the jenny was profitable in England but not in France.

The present note shows that Allen's conclusions rest on implausible profitability computations. In particular, Allen assumes that output remains constant after the adoption of the jenny, while the labor supply decreases according to the efficiency gain. As soon as these restrictive assumptions are abandoned the jenny turns out being profitable both in England and in France.

2 Profitability computations

The most profitable between two alternative techniques of production is the one generating a higher net present value. Accordingly, a general formula for the profitability of the jenny (indexed by J) relative to the spinning wheel (indexed by S) would read:

$$K_J - K_S = \sum_{t=1}^{T} \frac{p(q_J - q_S) - w(L_J - L_S) - (m_J - m_S)}{(1+r)^t} \ . \tag{1}$$

On the side of outflows, K is the upfront cost of capital and m its yearly maintenance cost, while w is the daily wage paid for each of the L work days in a year. Inflows are instead constituted by the price p obtained for each of the q units of output sold in a year. Finally, T is the life time of the jenny and the unknown r is the rate of return from choosing the jenny over the spinning wheel. Since the purchase price and the maintenance costs of the spinning wheel were negligible, equation (1) can be simplified into

$$K_J = \sum_{t=1}^{T} \frac{p(q_J - q_S) - w(L_J - L_S) - m_J}{(1+r)^t} \ . \tag{2}$$

Starting from equation (2), two alternative assumptions can be made to carry out viable profitability computations given the available data. Before moving to them, the following notation is introduced. Each technology is characterized by a labor input coefficient α such that $\alpha \cdot q = L$; consequently, α^{-1} is the labor productivity of the technology in question and the term $P = \frac{\alpha_S}{\alpha_J}$ is the labor productivity of the jenny relative to the spinning wheel.

2.1 Scenario 1: Fixed output and decreased labor

To reach the specific profitability computation used by Allen output has to be assumed constant. In fact, when

$$q_S = q_J \ , \tag{3}$$

the general formula of profitability expressed by equation (2) is equivalent to the formula used by Allen ([3], p.915, eq.(1)):

$$K_J = \sum_{t=1}^{T} \frac{w(L_S - L_J) - m_J}{(1+r)^t} \ . \tag{4}$$

Given (3), the amount of labor supplied by the spinner has to decrease with the adoption of the jenny by an amount equal to the gain in relative efficiency generated by the jenny its self ([3], p.915, eq.(2)):

$$L_J = L_S \, \frac{\alpha_J}{\alpha_S} = Y \cdot D \, \frac{\alpha_J}{\alpha_S} \ , \tag{5}$$

being $L_S = Y \cdot D$, where Y is the number of working days in a year and $0 < D \leq 1$ is the part time fraction that workers devote to spinning cotton with the spinning wheel. It follows that the profitability formula becomes

$$K_J = \sum_{t=1}^{T} \frac{w \cdot Y \cdot D \left(\frac{\alpha_S - \alpha_J}{\alpha_S}\right) - m_J}{(1+r)^t} \ . \tag{6}$$

Equation (6) is exactly the one used by Allen to assess the profitability of the spinning jenny across different countries, which are characterized by a different value of K_J and w. Crucially, the value of r as obtained with (3)–(6) is flawed in two distinct regards.

First, the assumption of fixed output is implausible when discussing the adoption of a new technology. In fact, a reduction of marginal costs would lead any profit-maximizer producer to *increase* output. Not surprisingly, this is what happened also to cotton spinners during the Industrial Revolution: as Allen him self recalls, "producers were paid by [...] the pound that they spun, and they bought jennies to *increase* their production and thus their earnings" ([3], p.915, Italic added).

Second, and regardless of whichever assumption on output, (3)–(6) provide a downward biased estimate of profitability. Cash flows are computed assuming that utilization rate of capital drops after adoption, so that spinners buy more capital than they will ever use: this reduces the profitability of the jenny by inflating capital costs. An example clarifies the point. Suppose, like Allen does, that a cotton spinner worked 100 full working days in a year ([3], p.916), and set this level of capital utilization to be 100%. According to (3)–(6), what would the spinner do if the jenny turned out profitable with $P = 3$? She would substitute her one spinning wheel with one jenny to end up producing the same fixed output in *one third* of the time. Hence, the adoption of the jenny would lead her to devote to spinning only 33.3 full working days per year! In parallel, the utilization rate of capital would drop to 33.3%, while for the remaining 66.6% of the time the jenny would be left idle. Hence, Allen's computation shows how profitable it is to buy a jenny that is kept it in the closet for 332 days a year while being used in the remaining 33 days.

2.2 Scenario 2: Fixed labor and increased output

It is possible to carry out a profitability computation that does not suffer from the limitations discussed above. To begin with, an analysis of the profitability of the jenny relative to the spinning wheel is relevant only if $p \geq w\alpha_S$. Otherwise, if $p < w\alpha_S$, spinning wheels would be out of business since the variable cost $w\alpha_S$ would exceed the marginal revenue p. Then, if price must be such that $p \geq w\alpha_S$, it is clear that $p > w\alpha_S$ would guarantee higher revenues as compared to $p = w\alpha_S$ for any technique in use; therefore, if the jenny is profitable under the assumption that $p = w\alpha_S$, it would also be profitable for any higher price. For this reason setting $p = w\alpha_S$ is a "safe" assumption since it could never overestimate the profitability of the jenny. By setting $p = w\alpha_S$, equation (2) can be rewritten as

$$\begin{aligned} K_J &= \sum_{t=1}^{T} \frac{w \cdot \alpha_S \left(\frac{L_J}{\alpha_J} - \frac{L_S}{\alpha_S}\right) - w(L_J - L_S) - m_J}{(1+r)^t} \\ &= \sum_{t=1}^{T} \frac{w \left(\frac{\alpha_S - \alpha_J}{\alpha_J}\right) L_J - m_J}{(1+r)^t} \, . \end{aligned} \tag{7}$$

Notice that the value of r as determined with (7) is increasing in L_J: the more the spinner works with the jenny the more she will find it profitable relative to the spinning wheel. In this perspective, it would not be surprising if cotton spinners during the Industrial Revolution decided to substitute labor for leisure, as argued by De Vries [6]. Nonetheless, labor supply will be here assumed to remain constant after adoption in order to make results especially robust. Assuming

$$L_J = L_S = L = Y \cdot D \tag{8}$$

allows to restate equation (7) as

$$K_J = \sum_{t=1}^{T} \frac{w \left(\frac{\alpha_S - \alpha_J}{\alpha_J}\right) Y \cdot D - m_J}{(1+r)^t} \, . \tag{9}$$

Notably, (9) differs from (6) by the term $P = \frac{\alpha_S}{\alpha_J}$, which is the labor productivity of the jenny relative to the spinning wheel. More precisely, multiplying w in (6) by P yields exactly (9). It must also be noticed that equation (9) could be obtained even without any specific assumption on the value of p. In particular, equation (9) can be recovered expressing *per unit of output* both inflows and outflows of equation (2). This is equivalent to imputing exactly as much capital services as those actually enjoyed by the adopter, contrarily to what happens with (3)–(6).

2.3 Results

The profitability of the jenny relative to the spinning wheel is computed here according to the two different scenarios discussed above. The necessary data are taken directly from Allen, as summarized by Table 1. Given these data, the values of r as computed with equations (6) and (9) are reported in Table 2. The results are exposed for varying values of the part time fraction D and of the productivity of the jenny relative to the spinning wheel P, identically to what Allen does in his work. Moreover, Table 2 shows explicitly the level of L_J implied by the assumptions on labor supply specific to each scenario.

The values of r obtained under SCENARIO 1 are systematically lower than those under SCENARIO 2. The third and fourth column of Table 2 report the downward biased values of r obtained by Allen using equation (6), while the sixth and seventh column report those obtained with equation (9). Notice that the results in SCENARIO 1 are based on implausibly low levels of yearly working days (fifth column of Table 2), which imply unreasonably low utilization rates of

ENGLAND	FRANCE	[Ref.]:Page
$w = 6.25$ *d.* per day	$w = 9$ *st.* per day	[3]:916
$Y = 250$ days	$Y = 250$ days	[3]:916
$K_J = 840$ *d.*	$K_J = 2800$ *st.*	[3]:916
$\mu = \frac{1}{10}$	$\mu = \frac{1}{10}$	[3]:916
$m_J = K_J \cdot \mu = 84$ *d.*	$m_J = 2800 \cdot \frac{1}{10} = 280$ *st.*	[3]:916
$K_S = 12$ *d.* ≈ 0	$K_S = 24$ *st.* ≈ 0	[3]:908
$m_S = K_S \cdot \mu = 1.2$ *d.* ≈ 0	$m_S = 24 \cdot \frac{1}{10} = 2.4$ *st.* ≈ 0	[3]:916
$T = 10$ years	$T = 10$ years	[3]:916
$\delta = \frac{1}{T} = \frac{1}{10}$	$\delta = \frac{1}{T} = \frac{1}{10}$	[3]:911
$d = \mu + \delta = \frac{1}{5}$	$d = \mu + \delta = \frac{1}{5}$	[1]: 9
$i = 5\%$	$i = 15\%$	[2]:188

Table 1: Data for England and France. Money values are expressed in pence *(d.)* and sous tournois *(st.)*. VARIABLES: w, daily wage; Y, working days in a year; K_J purchase price of the jenny; μ, yearly maintenance rate; m_J, yearly maintenance cost of the jenny; K_S purchase price of the spinning wheel; m_J, yearly maintenance cost of the spinning wheel; T, years of life of the jenny; δ, linear yearly depreciation rate net of maintenance; d, total depreciation rate; i interest rate.

		SCENARIO 1			SCENARIO 2		
P	D	r_{UK}	r_{FR}	L_J	r_{UK}	r_{FR}	L_J
2	0.3	12.3	-21.7	37.5	44.6	6.8	75.0
2	0.4	24.0	-8.2	50.0	63.9	17.9	100.0
2	0.5	34.6	0.2	62.5	82.8	27.5	125.0
3	0.3	24.0	-8.2	25.0	101.5	36.5	75.0
3	0.4	38.0	2.5	33.3	138.8	53.5	100.0
3	0.5	51.2	10.7	41.7	176.0	70.0	125.0
4	0.3	29.4	-3.7	18.7	157.4	61.8	75.0
4	0.4	44.7	6.8	25.0	213.2	86.2	100.0
4	0.5	59.2	15.3	31.2	269.0	110.2	125.0

Table 2: Values of r (%) and L_J (full working days per year) in England and France . The values of r in the third and fourth column (SCENARIO 1) are computed with equation (6). The values of r in the sixth and seventh column (SCENARIO 2) are computed with equation (9). The values of L_J in the fifth and eighth column are computed respectively with equations (5) and (8).

the jenny. As soon as SCENARIO 1 is abandoned and SCENARIO 2 is considered, the jenny becomes always profitable both in England and France. In particular, under SCENARIO 2 r exceeds the expected rate of return on alternative activities, which Allen deems to be 15% ([3], p.917). This is always true in both countries but in the totally unlikely case of $P = 2$ and $D < 0.4$. To realize how remote this case is, consider that other authors suggest much higher ranges of P compared to the one investigated by Allen; for instance, Landes estimates the productivity of the jenny relative to the spinning wheel to be "anywhere from six up to twenty-four to one for the jenny" ([9], p.85). Notice that also a third scenario would be economically reasonable: one in which spinners decided to work more with the jenny than they did with the spinning wheel precisely to increase the profitability of adopting the former. In that case profitabilities would be even higher since r is increasing in L_J.

Alternatively, the adoption of the jenny can be shown to be viable both in England and in France via a graphical representation of the adoption choice. Figure 1 does precisely this using the data from Table 1 adopting pence as the common money value at the exchange rate 1 *d.* = 2 *st.* This *quantitative* exercise is carried out here as a response to Allen's *qualitative* argument. His claim is that, being capital-intensive and labor-saving, the inventions which characterized the Industrial Revolution fell typically in Region I of Figure 1; hence, their adoption was viable only in those countries with a sufficiently steep isocost, indicating a high price of labor relative to capital (see [2], pp.151–55, [3], p.909 and [4]). In contrast with Allen's argument, Figure 1 shows that the jenny did not fall in Region I. Labor relative to capital was dearer in England than in France, and the jenny was indeed more capital intensive than the the spinning wheel: yet, none of these two conditions was sufficient to have the jenny falling in Region I. To the contrary, the jenny fell in Region II thus being cost-effective both in England and in France:

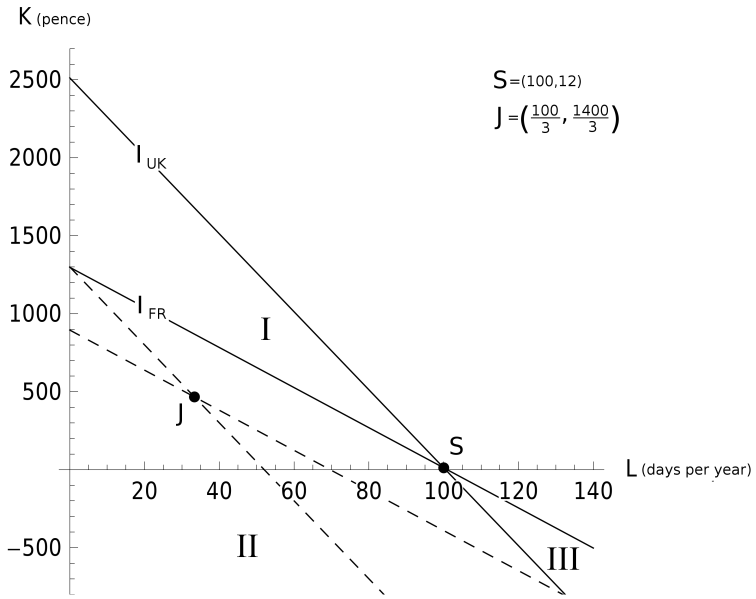

Figure 1: England, France and the spinning jenny

The isocosts I_{UK} and I_{FR} in Figure 1 refer respectively to England and France. Each of them constitutes simply the level curves of the unit cost function of the spinning wheel, whose price $K_S = 12\ d$ is not neglected in this case. The unit cost function of the spinning wheel reads

$$C_{S,h} = w_h \cdot L_S + \rho_h \cdot K_{S,h} \ , \tag{10}$$

where h indexes countries. The unit isoquants in Figure 1 are identified with the usual Leontief coefficients $S = (L_S, K_{S,h})$ and $J = (L_S/P, K_{J,h}/P)$, respectively for the spinning wheel and the jenny. Crucially, such coefficients are obtained setting both the part time fraction D and the relative productivity of the jenny P to the values that Allen deems most likely ([3], p.916). More precisely, $D = 0.4$ so that $L_S = Y \cdot D$ amounts to $250 \cdot 0.4 = 100$ working days per year; while $P = 3$, so that $J = (100/3, 1400/3)$.[1] The slope of the isocosts is given by the relative price of labor to capital $-w/\rho$, where $\rho = (i + d)$ amounts to $\rho_{UK} = 0.25$ and $\rho_{FR} = 0.35$ respectively

[1] Normally, Figure 1 should show two coefficients of the spinning jenny: one for England having as coordinates $J_{UK} = (100/3, 840/3)$, and one for France with coordinates $J_{FR} = (100/3, 1400/3)$. This is simply due to the fact that the jenny had a different purchase price in the two countries, equal to 840 and 1400 pence respectively in England and France. However, Figure 1 reports only the French coefficient (labeled as J) to avoid unnecessary confusion. The French coefficient is preferred for graphical representation because the purchase price of the jenny was higher in France; therefore, if adoption could take place at the French purchase price, it could certainly also take place at the British one.

in England and France. As for what concerns the value of i, Allen uses a value of $i_{UK} = 5\%$ for England ([2], Figure 8.1, p.188), but he never explicits the value of the French interest rate, i_{FR}. To make the present result particularly robust, Figure 1 was drawn taking from the literature the estimate of i_{FR} that was most favorable to Allen's argument and most *un*favorable to ours: that is $i_{FR} = 15\%$, which is the highest estimate found in the literature ([5], p.306–09; [7], p.302; [8], p.169–73). Notice also that, more generally, the essential message of Figure 1 is extremely robust to variations of ρ_{FR}: holding other things constant, J would fall in Region I only if $\rho_{FR} \geq 0.66$. Hence, one can reliably claim that switching from technique S to J would have led both England and France on the lower isocots represented by the dashed lines of Figure 1.

3 Conclusion

Differentials in the price of labor relative to capital are insufficient to explain why the spinning jenny spread in England but not in France. The quantitative assessments carried out in the present work reveal that the jenny was profitably adoptable in both countries, despite their difference in terms of relative prices. Nonetheless, it was Hargraeves and not some French inventor to develop the jenny. This implies that the potential *demand* for innovation might be necessary but non sufficient to generate a corresponding *supply* of inventions. The riddle of the different fortunes of the spinning jenny in England and in France during the Industrial Revolution remains open.

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