The Coevolution of Technology and Organization in the Transition to the Factory System

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FIRST DRAFT

Introduction.

Within the last two decades, the question of the origin and nature of the factory system has leapt from obscurity to fill thousands of pages. The seminal article was, of course, Marglin's "radical" interpretation of factory organization, a paper now 20 twenty years old. But Marglin's broadside arguably aroused as much interest as it did because the questions it addressed were quite congenial to those in which the larger profession was becoming increasingly interested, namely, questions of institutions and organization. As exemplified in the work of Douglass North in economic history and Oliver Williamson in the economics of organization, this New Institutional Economics, as it was coming to be called, offered a fresh viewpoint on the nature of capitalist organization during the Industrial Revolution. Economic historians like David Landes and S. R. H. Jones also took up the cudgels, adding historical insight and a perspective typically rather different from either the "radicals" or the New Institutionalists.

Despite the complexity and subtlety of the conversation, it might nonetheless be helpful to summarize the arguments in a simple schema. First of all, the questions, it seems to me, move along two different dimensions. The first dimension is what we may call that of origins: what *caused* the factory system to emerge? The second dimension is what we make call that of *raisons d'être:* what is the nature or essence of the factory system, and how do we characterize its cause? Figure 1 summarizes the possibilities.

	Organization	Technology
Efficiency	Williamson (1980)	Landes (1986)
Exploitation	Marglin (1974)	Marx (1867)

Figure 1

Along the horizontal dimension lies the issue of origins: did the factory system emerge because of its organizational form, or did it spring from new technology, notably centralized motive power? Along the vertical dimension is the issue of *raison d'être*: did the factory system emerge because it was more efficient than what went before, or did it emerge because capitalists found themselves able to use factory organization as a mechanism for worker exploitation?

The traditional Marxian view is that the essence of capitalism is, well, capital. What characterizes the capitalist system is the mode of production — the technology — and it is technology that enables the capitalist to create and appropriate surplus value.[1] What was remarkable about Marglin's assault on capitalist work organization was his rejection of the Marxian insistence on machinery as the engine of exploitation. For Marglin, it was the organization of work, not the technology, that mattered. By subdividing tasks in the manner Smith advocated in the *Wealth of Nations*, capitalists could *deskill* work, rendering

[1] For an excellent account of the Marxian system, see Roberts and Stephenson (1973).

each task so simple that an undifferentiated and untrained proletariat could replace skilled artisans. But the capitalists divided labor not because this process is more efficient than crafts production but because deskilling allows the capitalist to control workers more effectively — and therefore to reap a larger fraction of the joint surplus of production.[2]

Writers like Williamson (1980) and North (1981) also view the arrival of the factory system as a matter of organization. But they see that system as emerging because of greater efficiency, which they understand largely in terms of the minimization of transaction costs, especially the costs of material lost to embezzlement, the costs of coordinating a finely subdivided process, and the costs of monitoring product quality. Economic historians like Jones (1982, 1987, 1993) and Landes (1986) have criticized both Marglin and the transaction-cost theorists for a comparative lack of attention to history. And, despite all the arguments of *a priori* theory, history demonstrates, they assert, that it was the superior technology associated with centralized power sources that triggered the factory system.[3] "No," writes Landes (1986, p. 606), "what made the factory successful in Britain was the muscle: the machines and the engines. We do not have factories until these were available, because nothing less would have overcome the cost advantage of dispersed manufacture."

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[2] In addition to Marglin (1974), see Marglin (1984, 1991).

[3] We might in fact call this the "traditional" view among economic historians. See for example Mantoux (1961).

This essay argues that, although proponents of the "efficient technology" argument are certainly closest to the truth, none of these alternatives has it completely right. In the end, the explanation for the rise of the factory system does in fact lie in the realm of organization, but not in the qualities of organization envisaged by either the "radical" view or the transaction-cost view. The factory system arose because growth in the extent of the market (for textiles principally, but eventually most other goods as well) opened up entrepreneurial possibilities for high-volume throughput. This meant not only an extended division of labor but also investment in new capabilities (including, but not limited to, capital equipment) that, by making production more routine, permitted lower unit costs. For reasons that we will see, these new capabilities implied high fixed costs, at least initially, and it was these fixed costs that called for the "factory" mode of organization.

Was this efficiency or exploitation? Efficiency, without doubt. But the problem of explanation is a subtle one, and this essay closes with some musings on the logic of both efficiency and exploitation.

What is a factory?

We need to begin by establishing the meanings of terms. First and foremost: what is a factory and what is the factory system? There are a number of characteristics, operating both singly and in conjunction, that one might offer as distinctive of the factory. Principal among these are

- expensive or indivisible technology;
- the concentration of workers in a singly location; and
- close monitoring or supervision of work.

As Fang (1978, p. 16) suggests, the archetypal factory had all three. Does any of these by itself define a factory?

The idea that large-scale central-power technology defines the factory is an idea that goes back at least to Ure (1861, p. 13). From the point of view of this essay, however, defining the factory by the use of large-scale, expensive, or indivisible technology rather begs the question. Moreover, there are at least some examples — notably the famous cottage factories in the silk industry (Jones 1987, p. 90) — suggesting that it is possible, if perhaps just barely possible, that indivisible central power could coexist with the putting-out system. (There are plenty of examples, however, in which indivisible central power is fully compatible with *inside* contracting, a point to which I will return.) Conversely, as Axel Leijonhufvud (1986, p. 205) has noted, if centralized power defines the factory system, are we not compelled to wonder why the factory system remained alive and well in the era of small electric motors?

The agglomeration of workers in a single facility is also not a definition of the factory. Here too there are plenty of examples, going back at least to the Arsenal of Venice (Lane 1973), of clusters of workers that we would not want to classify as factories, at least not in the sense of the British factory system of the Industrial Revolution. Indeed, to the extent that the workers act as independent

contractors, the resulting inside contracting system (Buttrick 1952) is in many ways closer to the putting-out system than it is to the factory system. There is, of course, the issue of whether the contractor or the capitalist owns the tools of production. In the former case, one might want to say that labor (the contractor) hires capital (buys his or her own tools), whereas in the other case capital hires labor. Inside contracting when the capitalist owns the machinery, as in the case of mule spinning in Lancashire in the late eighteenth and early nineteenth century (Lazonick 1990, p. 80-85), obviously comes closer to a full-fledged factory than does inside contracting when the contractor supplies the tools.

Indeed, one often hears the Marx-inspired criterion of capital hiring labor touted as *the* defining characteristic of the factory system (not to say of capitalism as such). And we might well want to describe as a factory a Lancashire mule-spinning establishment in which master spinners use the capitalist's machines, power, and material to produce yarn on a piece-rate basis. Yet, there is also arguably something more to the factory system. An equally strong tradition holds that what is essential about the firm, if not necessarily the factory, is that the contract between worker and capitalist within a firm is not a simple contract over output. For Coase (1937) and his followers, there is an essential difference between a spot-contract for product and an employment contract. In the former, it is relative prices that matter; in the latter, it is authority — or so many have interpreted it — that matters: "If a workman moves from department Y to department X, he does not go because of a change in relative prices, but because

he is ordered to do so" (Coase 1937, p. 387). It is for this reason that Williamson (1975, pp. 71-72), following Simon (1957), characterizes the employment contract as an "authority relation" — a loaded term[4] — and the capitalist firm as a "hierarchy." In much of the literature on the emergence of the factory system, indeed, "capitalist hierarchy" is assumed to be the *explanandum* (*e.g.*, Berg 1991).

There is both truth here and confusion. One wouldn't want to dispute that the capitalist firm is a hierarchy, in one or more senses. Surely the boss "tells the worker what to do," and this is crucial. But also crucial is the difference between entrepreneurship and supervision.[5] In Simon's formulation of the "authority relation," the capitalist pays a wage for the right to choose which action $x \in \Omega$ the worker will perform at any time, where Ω is the "job description" or set of allowable actions to which the worker agrees. As in Coase, the accent here is on the flexible assignment of workers to tasks. As Langlois and Robertson (1995) argue, economic change, which necessitates the flexible redeployment of economic capabilities in order to capture entrepreneurial

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[4] Many other followers of Coase would insist that, in the end, a contract is a contract, and "authority" is not involved. "To speak of managing, directing, or assigning workers to various tasks is a deceptive way of noting that the employer continually is involved in renegotiation of contracts on terms that must be acceptable to both parties. Telling an employee to type this letter rather than to file that document is like my telling a grocer to sell me this brand of tuna rather than that brand of bread." (Alchian and Demsetz 1972, p. 778.) The final station for this train of thought — a *reductio,* but by no means *ad absurdum* — is that the firm is nothing but a "nexus of contracts" (Cheung 1983).

[5] As Temin (1991) points out, there is a difference between entrepreneurs, who engage in non-routine command behavior, and managers, who engage in routine or customary behavior, including the exertion of factory discipline. "Managers, in short, were the workers' bosses, but entrepreneurs were the managers' bosses" (Temin 1991, p. 350). On the distinction between command and customary behavior, see Temin (1980).

opportunities, is a vital and neglected aspect of the theory of vertical integration and disintegration. And, as Peter Temin (1991) has emphasized, the neglect of this function of entrepreneurial coordination accounts in large measure for the inability of the "radical" critics of capitalism to detect a non-exploitive function for those they indiscriminately call "bosses."

But this understanding of "capitalist hierarchy" as flexible redeployment is also far from the experience of workers in the early factories of the industrial revolution. The key point — and here we come finally to the essence of the definition — is that the factory system consists in a change (relative to the putting-out system or the inside-contracting system) in the nature of the *supervision* the capitalist exercises. Rather than monitoring output, as the putter-out or merchant capitalist does with a contractor, the factory capitalist (or, more likely, his hired supervisor) monitors the work process itself. That is to say, the crucial difference between the merchant capitalist and the factory capitalist is that the latter exerts *factory discipline* (Pollard 1963), supervisory measures aimed at keeping up the workers' pace and level of effort.

Now, one can argue that factory discipline also does not by itself define the factory system. There was plenty of "factory discipline" under the putting-out system. The discipline — the monitoring of the work process itself — was the province of the master of the cottage, whose charges were typically members

of his own family as well as some casual laborers.[6] A putting-out cottage or artisan workshop was thus a factory by this definition. So the transition to the factory *system* represented not a shift away from supervision of the work process *per se* but a shift in the locus of that supervision from the subcontracting cottage master to the factory owner (Cohen 1981). Figure 2 summarizes the possibilities.

	Concentrated	**Dispersed**
Process supervision	Factory system	___
Product monitoring	Inside contracting	Putting out

Figure 2

Division of labor, routine, and technology.

We can think of the putting-out system and the factory system as alternative institutional trajectories;[7] and the problem of explaining the rise of the factory system as a problem of explaining Britain's transition from one trajectory to the other.

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[6] This was also true of inside contractors like the master spinners in Lancashire. These masters, who hired and disciplined their own "scavengers" and "piecers," were far more likely to use and abuse child labor than were capitalists directly employing labor, and they accounted for a significant fraction of the child labor in the industry (Ure 1861, pp. 290 ff; Pollard 1965, p. 43).

[7] In the sense of Langlois and Robertson (1995, chapter 6).

As an institutional structure, the putting-out system offered a number of advantages. Principal among these was low labor cost. Apart, in the early years, from evading urban guild regulations, the merchant capitalist or putter out could take advantage in the countryside of surplus labor time made available by the seasonal nature of agriculture, a pool of labor soon augmented by the enclosure movement.[8] The rural location of work also meant that cottagers could keep to some agricultural pursuits, thus lowering their subsistence needs from outside sources and further reducing labor costs relative to urban areas. Moreover, as the cottager owned his or her own tools, and capital requirements were low in any case, putting-out was a strategy that offered the advantage of flexibility: in times of low demand, the capitalist had little in the way of fixed costs to cover.

The transaction-cost theorists, however, point to some of the short-comings of this system. The very dispersion of work made monitoring difficult, encouraging, in particular, embezzlement of materials, which the domestic worker could then either resell or work up on his or her own account. The embezzlement was typically covered up by reducing the quality rather than the quantity (which could be more easily measured) of the finished product. As we saw, North and Williamson see the superiority of the factory in light of the easier

[8] The relationship of the putting-out system to the enclosure movement was not, of course, a matter of one-way causality. Since the majority of enclosures in Britain were for pasturage of sheep, the demand for wool from the cottage textile industry reinforced enclosure, just as the release of labor from enclosure reinforced cottage woolens. This is an instance of institutional coevolution, in the sense discussed below.

monitoring of "inside" production. But Jones (1982, 1993), among others, has disputed the importance of embezzlement, noting that the merchants compensated for expected embezzlement with lower prices and certain other tricks like the truck system, which required the workers to take their compensation in kind. Moreover, it is not clear that the benefits of avoiding embezzlement and shoddy work outweighed the advantages of putting out. When it was worth it — when the material, such as Spanish wool, was especially valuable, or when problems of quality-control were especially serious — workshops did indeed spring up (Pollard 1965, p. 33). That there were few examples of this in the heyday of the putting-out system suggests that, for the most part, embezzlement costs didn't outweigh the benefits of low labor costs and flexibility. There is a message here. Although transaction-cost theorists understand in principle that evaluating relative efficiency is a matter of counting up both transaction costs and production costs (Williamson 1985, p. 103), in practice analysts often forget the production-cost part — and production costs frequently turn out to be decisive (Langlois and Robertson 1995, chapter 3).

There is a more important point. This process of evaluating the relative efficiency of institutions — comparative-institutional analysis, as it is called in the Coasean tradition — is almost always conceived of as a static exercise. Seldom do the evaluators consider the rates of change of the relevant variables along with their magnitudes. (Put less neoclassically: they don't seriously consider history.) What is significant about the transaction costs of the putting

out system is not so much the costs of embezzlement but the rate of change in those costs. Before the second half of the eighteenth century, embezzlement and deteriorating quality were not serious problems. What made them problems — or, more correctly, symptoms of a far larger problem — was the increasing demand for the products of the outworkers, especially spun yarn,[9] as final demand for fabric accelerated. As Landes (1969, pp. 57ff.) makes clear, by the fourth quarter of the eighteenth century, the putting-out system was reaching its limits. Although flexible in downturns, the system was difficult to crank up in the face of predictable, secularly increasing demand. The possibilities for geographical expansion had been exhausted, and pressure at the intrinsic margin — output per worker — was met, Landes tells us, with a backward-bending supply-of-effort curve. Indeed, embezzlement was largely a reaction by the outworkers to the capitalists' attempt to lower real piece rates through indirect means as diminishing returns set in (Landes 1969, p. 59).

Ultimately, then, as Landes (but few others) emphasize, the ultimate driver of the factory system — I will postpone using the word "cause" — was the increase in demand for low-cost manufactured goods. This was nowhere more significant than in cotton fabrics, the industry that became the avatar both of British manufacturing and of the factory system itself (Fang 1978). But the

[9] In the era before major mechanical innovations in cotton machinery, spinning was the bottleneck, as it took the output of upwards of five spinners to supply one hand loom (Landes 1969, p. 57).

mechanism by which increases in demand led to or triggered the move to the factory system remain obscure — or at any rate subtle.

With the geographic margin of the putting-out system reaching a point of sharply diminishing returns, there remained two other margins on which to push: the workers' level of effort and the organization of production. (What about technology? I'll come back to that.) And here Marglin enters the picture. One aspect of his argument is to draw our attention to the usefulness of factory organization in pushing along the effort margin. Factory discipline can get more effort out of a given labor force, and in that way break the bottleneck of the putting-out system to the owners' (but not, of course, the workers') advantage. We will look at this argument more closely in the next section. Notice here, however, that Marglin neglects the organizational margin. That is, he does not see the reorganization of production in the factory (of which factory discipline may play a part) as another way of attacking the cost bottleneck of the putting-out system. Organization, for Marglin, is merely a stratagem that allows the capitalists to exert pressure on worker effort, and it conveys no efficiency benefits in its own right. Needless to say, there is reason to think that capitalists pushed on all margins simultaneously, and that the organization margin yielded considerably.

In what way did organization change? By Adam Smith's famous theorem (or its converse, at any rate), the increasing demand for textiles in the late eighteenth century should have called for increasing division of labor. And this,

in turn, should have led to a more intricate sequencing of tasks. In the pinshop model, the time-sequencing of tasks becomes crucial, as one worker's output is the input to the next worker. By monitoring the work process, the capitalist can make the workers work at the system's pace rather than at their own, assuring that intermediate product flows smoothly between stages. Thus does Williamson (1980) argue the superiority of the factory system in part on the grounds that it economizes on work-in-process inventories relative to an (inside or outside) contracting system. This is not implausible. Buttrick (1952), for example, lays the demise of inside contracting in the American small-arms industry of the nineteenth century largely to inefficient inventory systems.[10] On the other hand, Clark (1994) has calculated that the cost of work-in-process inventories would in fact have been unimportant in the factories of the industrial revolution.

Leijonhufvud (1986) suggests another reason why the division of labor may have led to the factory system. In the pinshop model, all the workers become complementary to one another, in contrast to crafts artisans, who are substitutes in production. This complementarity means that, if the workers owned their own tools, they could individually threaten to withdraw their capital from the production process in order to capture a larger share of the joint

[10] On the other hand, the just-in-time inventory system, invented in the early American automobile industry as "hand-to-mouth buying" (Flugge 1929, p. 163), suggests that contractors can also in principle regulate product flow carefully. Indeed, hand-to-mouth buying is itself an instance of the division of labor, for it decouples the function of speculation in inventories from the manufacturing function (Stillman 1927, p. 3).

rents of production.[11] This is the phenomenon of "hold up" familiar in the transaction-cost literature (Klein, Crawford, and Alchian 1978). If, however, the physical capital were pooled under common ownership — and capital hired labor instead of the other way around — this problem would disappear (or be replaced, at any rate, with the problem of bargaining with a labor union). This does not explain, however, the existence of process monitoring in Fang's archetypal factory, since, as we saw, the fact of capital hiring labor does not speak to the nature of the *contract* between capital and labor, and is perfectly consistent with inside contracting.

Does this mean that organizational advantages do not explain the factory system? If we take organizational advantages to mean the transaction-cost problems of the division of labor, as those terms are usually understood, the answer is probably negative. If, however, we broaden our field to mean by organizational advantages an imperative of which the division of labor is itself only derivative, then organization does indeed matter. To see what this means, let's consider the process of production more carefully.

Under crafts production, labor is undivided in the sense that each artisan performs a wide range of tasks. This requires a relatively large investment in human capital, since, to be proficient, the artisan must be accomplished in a wide variety of skills or subskills. Crafts production also implies a certain kind

[11] This also depends, however, on the worker's capital being firm specific as well as process specific. If there is a thick market for, say, weavers, a weaver who threatens to withdraw his looms from a firm might be easily replaced by less-recalcitrant alternates.

of flexibility and a lack of standardization, since the artisan controls the "interfaces" between tasks and the connections between parts. If, with Nelson and Winter (1982), we think of production as a matter of exercising and choosing among certain "routines,"[12] then crafts production requires the possession of and ability to choose among a wide range of possible routines (Stinchcombe 1990, chapter 2). Crafts production thus obviously has advantages when production runs are small, for reasons of both demand and supply. On the demand side, as Smith reminds us, the division of labor is limited by the extent of the market, and, if "the number of potential buyers of a commodity were too small, it would not be possible to dispose of the increased output which differentiation permits, forcing a worker to perform several activities in order to earn enough to fend off starvation" (Robertson and Alston 1992, p. 331). On the supply side, crafts production may be necessary or advantageous when the production process involves uncertainty, in the sense that the choice of routines must be fitted interactively to changing particular circumstances (Stinchcombe 1990, pp. 66-70).

We can think of a spectrum of skill levels.[13] At one end of the spectrum are deskilled — or, at any rate, unskilled —factory workers. These operatives have a small repertoire of routines, and they engage in a restricted range of

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[12] See also Ames and Rosenberg (1965), who talk about the activities performed in production as instances of rule-following behavior.

[13] Following Ames and Rosenberg (1965), I am here taking "skill level" to be a measure of the size of the workers repertoire of routines. In fact, we can also think of being skillful as meaning skill deepening, that is, a highly developed ability to perform one or a few routines.

active choice within that repertoire. In other words, unskilled workers perform routine activities (in the less-technical sense of the term). At the other extreme are the professions — physicians, architects, attorneys, academics — who must have large repertoires of routines and who must be able to choose deftly among routines to fit changing particular circumstances. In addition, professionals also engage in innovation, the introduction of new routines (Savage 1994). In between are the semiskilled occupations, like tradesmen — carpenters, plumbers, drywallers, electricians — or the crafts artisans of the eighteenth century. These workers must also choose among routines flexibly, but both the size of the repertoire and the range of application of the routines is more restricted. Semiskilled workers also are less likely to innovate routines.

Obviously, artisans in crafts production are more difficult to monitor directly than are factory operatives. Indeed, as Minkler (1993) argues, workers — especially skilled ones — may possess knowledge that is qualitatively different from that of supervisors, making monitoring costly even in the absence of principal-agent problems of the standard neoclassical sort.[14] It is not surprising, therefore, that, as skill level increases, workers are less likely to be employees (supervised in process) and are more likely to interact with the

[14] Minkler (1992) uses this idea of specialized knowledge as an explanation for the franchising contract, the modern-day analogue of the putting-out system.

market through subcontracting relations (monitored in product by relative prices).[15]

We saw that the key fact about the putting-out system, especially in textiles, was that, by the middle of the eighteenth century, it was beginning to strain under the pressure of predictable, secularly increasing demand. What is significant here, however, is not only the *extent* of the market but also the *predictability* of the market. When the extent of the market for a product increases, especially if it does so without much fluctuation, the production process becomes less uncertain, in the sense that the selection of productive routines requires less interactive tailoring to particular circumstances.[16] This reduction in uncertainty leads to two distinct effects, only one of which is captured in the traditional notion of the division of labor. I will call these the *division-of-labor effect* and the *volume effect*.

The former is much discussed if not always well understood. As we have seen, it is only when flexible interactive selection among routines is no longer necessary that labor can be divided in the manner Smith advocated. Each worker can concentrate narrowly and deeply on a smaller subset of the routines necessary for production precisely because the function of selection among the

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[15] Professionals, indeed, are autonomous not only in the sense that they are seldom employees but also in that "no one except another professional is able to challenge the day-to-day decisions of a professional" (Savage 1994, p.). And professionals are monitored not only by relative prices but by a complex set of institutions, including peer monitoring.

[16] In more technical terms, predictability reduces the behavioral entropy of the choice among routines. For an analysis of the effect of uncertainty and predictability on the selection of actions from a repertoire, see Langlois (1986).

routines becomes effectively hard-wired into the system. Variability in the pace of the individual workers can introduce a mild kind of uncertainty, but one, as we have also seen, that can be "buffered" (in Stinchcombe's terms) by work-in-process — or *buffer* — inventories, the cost of which may or may not be significant to the choice of monitoring system.

In the Smithian story, labor starts out skilled (crafts production) but tools are specialized; with the division of labor, labor specializes (tools remaining specialized) and, through differentiation spurred by innovation, perhaps increases its level of specialization. This does not exhaust the possibilities, however. It is also possible, through mechanical innovation, for tools to integrate previously separate tasks (Robertson and Alston 1992) and, in general, for machines to become more "skilled," that is, to have a larger repertoire of routines (Ames and Rosenberg 1965). For example, to the extent that the advent of the self-acting mule after the 1830s "deskilled" the spinner (that is, required less skill in our sense than the common mule), it did so not because it subdivided labor more finely but because the machine itself became more skilled.[17]

Notice that, like the subdivision of tasks, the introduction of more-skilled machinery requires both increased volume of output and predictability of output. Consider the simple jig. With a reduction in uncertainty — permitting

[17] The acquisition of skill by a machine does not, however, imply deskilling of labor. Consider the backhoe, which integrates a number of ditch-digging functions. It requires an operator more skilled than any manual ditch-digger (Robertson and Alston 1992).

an increase in standardization — the sequencing of choice among routines can be hard-wired into a machine.[18]

> In drilling the plate A without the jig the skilled mechanic must expend *thought* as well as skill in properly locating the holes. The unskilled operator need expend no thought regarding the location of the holes. That part of the mental labor has been done once for all by the tool maker. It appears, therefore, that a "*transfer of thought*" or *intelligence* can also be made from a person to a machine. If the quantity of parts to be made is sufficiently large to justify the expenditure, it is possible to make machines to which all the required skill and thought have been transferred and the machine does not require even an attendant, except to make adjustments. Such machines are known as *full automatic* machines. (Kimball 1929, p. 26, emphasis original.)

This transfer of skill to machines is another manifestation of the process that motivates the division of labor, namely, the increasing routine and standardization of production. It is also an aspect of what I have called the volume effect. It is not, however, the only aspect. As the quote above suggests, the transfer to a machine of "intelligence" — that is, the ability to select among operational routines — often takes the form of a jig, pattern, or die. And, as Alchian (1959) points out, the "method of production is a function of the volume of output, especially when output is produced from basic dies — *and there are few, if any, methods of production that do not involve 'dies'*" (Alchian 1959 [1977, p 282], emphasis added). Why? Because, with increased volume, it pays to invest in *more durable* dies.

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[18] Machines, of course, can deal with some kinds of uncertainty. The prime example is the Jacquard loom, the ancestor of modern numerical-control techniques. But even in modern computer-aided manufacturing, the degree and type of uncertainty with which machines can deal is limited to what I call parametric uncertainty (Langlois 1984).

Consider the example of printing. If one is going to run off a few copies of memo, a photocopy machine will do the trick. If one needs several hundred copies of documents on an ongoing basis, I might be worth investing in a small offset press. For even larger predictable production runs, it would pay to have a more serious printing press. As volume and predictability allow greater "durability of dies," unit costs decline. This is an effect of growth in the extent of the market distinct from the division of labor narrowly understood.

In the case of cotton textiles during the Industrial Revolution, it is arguable that the volume effect was more important than increases in the division of labor. For one thing, as Pollard (1965, p. 34) and others have noted, the division of labor was one of the benefits that originally recommended the putting out system. And, although there was surely room for further division of labor in factories, most of the change in technology and organization in cotton was in fact arguably of a sort that increased the skill of machines rather than more finely sibdividing tasks. Moreover, the history of technological change in cotton textiles is one directed very much toward what we could call greater durability of "dies." The spinning jenny, waterframe, and later the mule were ways of multiplying for many bobbins simultaneously the routines of the spinning wheel. Innovations in weaving, printing,[19] and other departments could be described in a similar way.

[19] Indeed, the case of calico printing is an example almost literally analogous to the printing example cited above: cylinder printing was invented in 1783 not for books but for the printing of calicoes, moving Baines (1966, p. 265, cited in Mokyr 1990, p. 99) to compare the

"Durability," fixed costs, and supervision.

Obviously, if increasing extent of the market led to what I have called the volume effect — more highly skilled machines embodying more durable "dies" — then there is likely some connection between the extent of the market and the factory system. The precise nature of that connection, however, requires some elucidation.

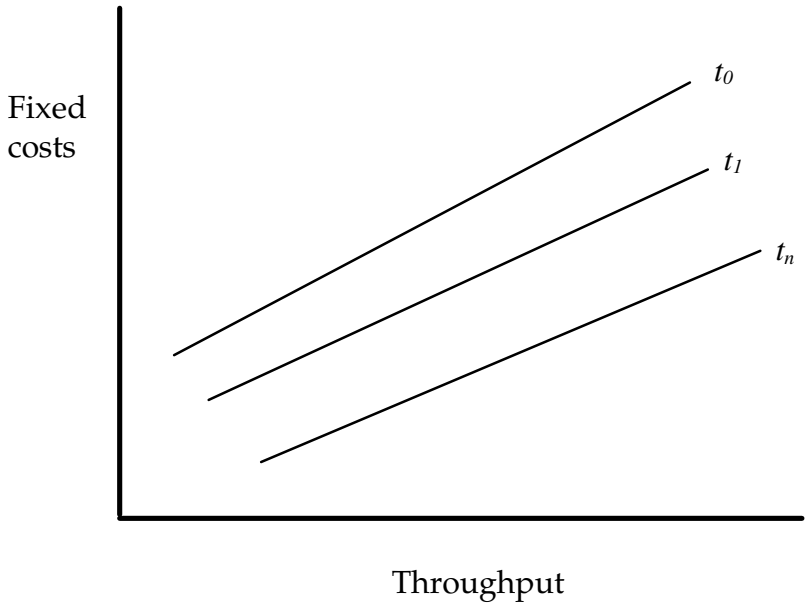

Figure 3: throughput and fixed costs.

The first missing link in the argument is the relationship between the volume effect and fixed costs. It is far from implausible to postulate that, *ceteris paribus*, as the skill and durability-as-die of machines increases, so do fixed costs. For graphic simplicity, Figure 3 displays the relationship between throughput (which I will use as a shorthand for the volume effect) and fixed costs as linear,

advancement of this machine over block printing to the advancement of mechanical spinning over the spinning wheel.

but the second derivative of the relationship will likely depend in fact on the particular technology and industry under consideration. The upward-sloping relationship holds at any particular planning date *t*. Over, time, however, the curve is likely to shift down. That is, with innovation and learning in the production process and the machinery industries that supply it, the costs of providing any particular level of durability will decline. Only in an atemporal sense, then, does increased throughput imply higher fixed costs.[20]

Recall that factory organization means not only workers concentrated in a single location but also the direct supervision of work. By elaborating on a couple of recent models of worker effort and organization (Lazonick 1990, Clark 1994), we can generate several different arguments for why increased fixed costs might lead to factory organization.

Consider Figure 4. MP_0 is the marginal productivity of effort, assumed linear for convenience, to the representative firm with fixed costs F_0. If the labor market is competitive, and each worker's marginal product can be costlessly monitored, then the firm will offer a piece-rate contract that rewards workers according to their marginal product (and is thus identical to MP_0), and the representative worker with utility function U(*e*,*w*) will supply effort e_0 and receive payment w_0. In this world, there is no need for monitoring of the work process, and fixed costs don't change that. A firm with fixed costs F_1 (and,

[20] Whether the observed expansion path is upward or downward sloping (that is, whether we observe increased throughput and higher fixed costs in a particular industry) will depend on the relative strengths of the volume effect and the rate of innovation in machinery.

plausibly, a steeper marginal product of effort) can keep the worker on the same indifference curve by offering wage w_1, which elicits effort e_1. The worker works harder and receives a higher wage, but there is no need for discipline.

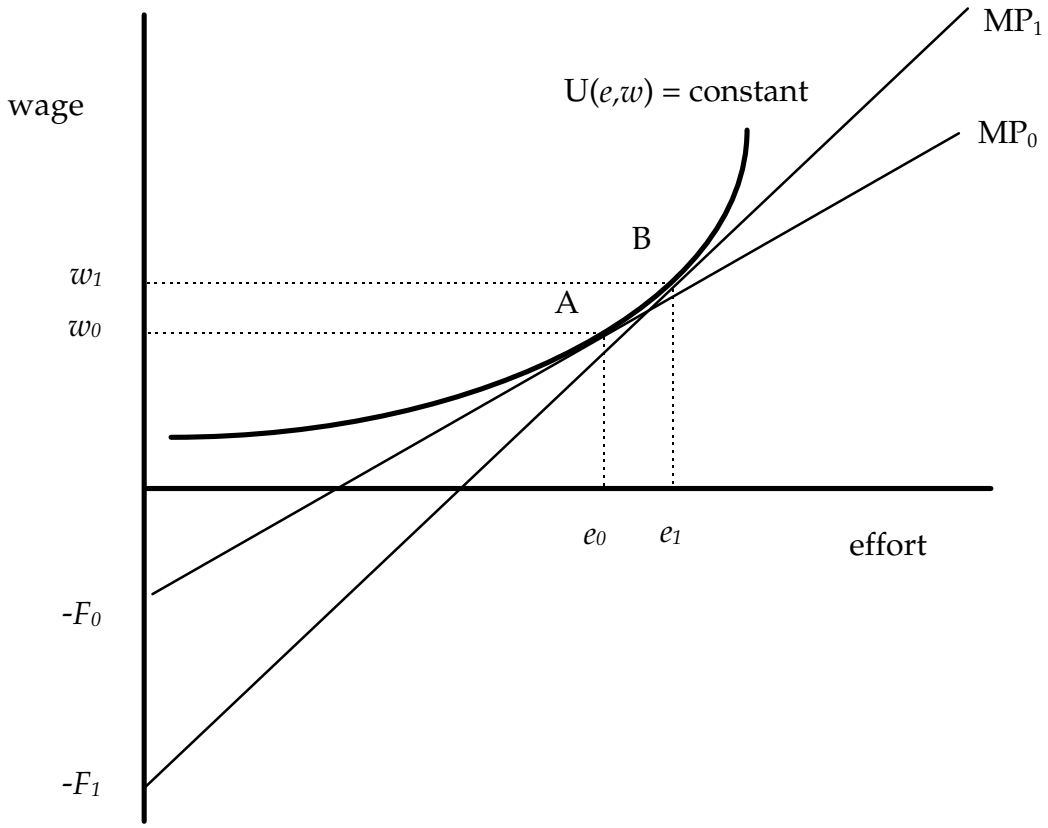

Figure 4.
(After Clark (1994).)

Obviously, this could change if marginal product were costly to determine. In that case, a piece-rate contract might be infeasible, and the capitalist would have to contract for an hourly wage. The worker would agree

to supply (to firm 0) effort level e_0 in exchange for wage w_0. But, to the extent that monitoring of output is costly, the worker could reach a higher indifference curve by shirking and supplying less than e_0. Direct monitoring of work in such a case may be less costly than the productivity foregone. Indeed, for firm 1, the marginal cost of shirking (the marginal productivity foregone) is greater because of the steeper slope of MP_1. This qualifies as an explanation for the transition to the factory system, since it explains why process supervision (which requires centralized location) would eventually become economical as the extent of the market (and with it throughput and fixed costs) grew. It is a transaction-cost explanation, but one rather different from those offered by Williamson, North, or Leijonhufvud. It comes closest, in fact, to the story told by Alchian and Demsetz (1972), in which the inability separately to meter individual marginal products leads to process monitoring by a specialist monitor, who, as residual claimant, is in turn monitored by market prices.

The problem with the shirking explanation is that it relies on a specific kind of monitoring difficulty, namely indivisibilities in team production. In the textile industry, however, individual marginal products were arguably quite distinguishable, and, indeed, the success of the putting-out system in this and other important industries suggests that there was no general monitoring-cost problem in offering piece rates.

An exploitation explanation is in many ways the flip-side of the shirking story. Instead of the worker reducing effort below what was contracted for, in

the simplest version of an exploitation story, the capitalist squeezes more effort out of the worker than was contracted for. This is essentially Marx's idea: the capitalist pays the going (subsistence) wage for abstract labor power, but then must apply discipline to get the concrete labor out of the worker, the labor value of which concrete labor is more than the wage.

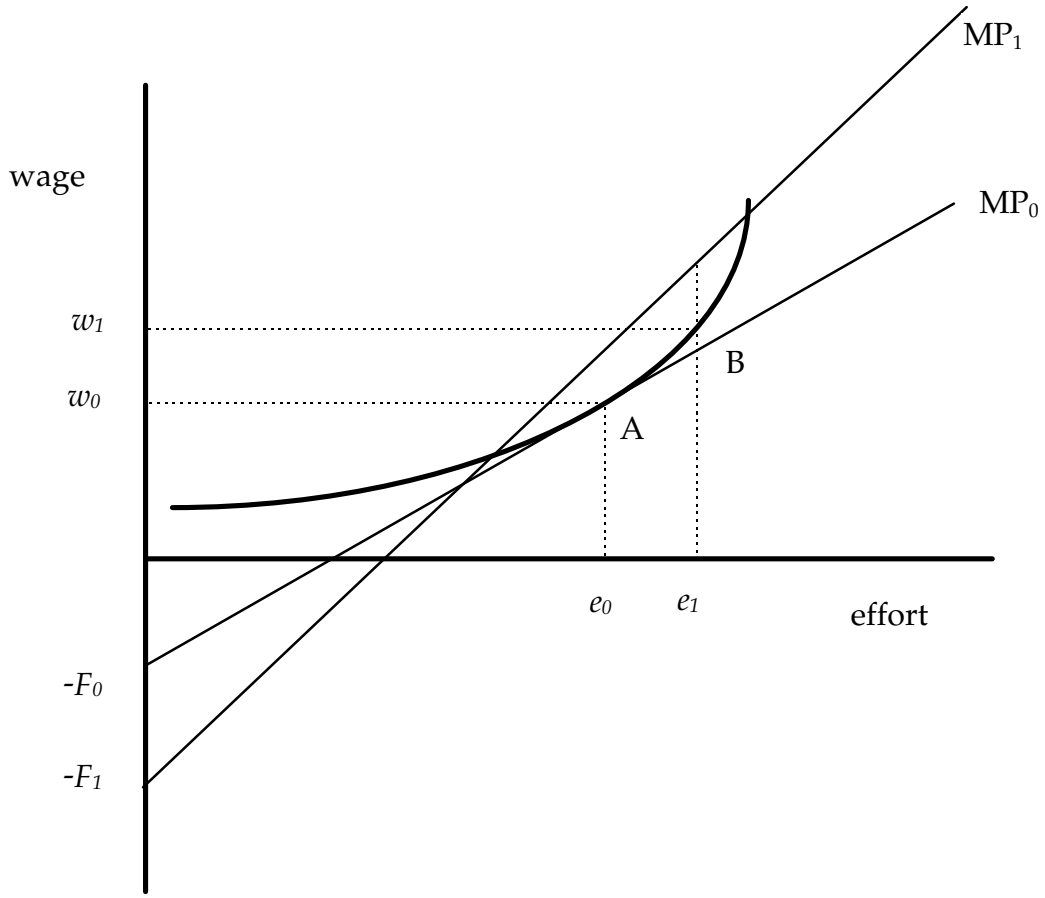

Figure 5: an exploitation explanation.

Clark (1994) offers a slightly different interpretation of what he calls a "coercion" account of factory discipline.[21] See figure 5. Firm 0 (perhaps the putting-out system) is in initial equilibrium at point A. By increasing fixed costs, the capitalist shifts the marginal productivity of effort to MP_1. It now pays to increase worker effort, which the capitalist does by introducing discipline. But the workers must be compensated by a higher wage w_1, and the difference between w_1 and w_0 is a "disgust premium" for submitting to discipline. This is exploitation in one sense, since the worker is not paid at marginal product and the capitalist pockets the surplus. Since point B is not a competitive equilibrium, however, one has to introduce a mechanism to keep wages from being bid up (and effort bid down) to marginal product. "Radicals" (*e.g.*, Marglin 1991, p. 243) find it easy to assert that the worker "has no choice"; neoclassicals find it less easy to do so. (I return to this issue below.)

Why is factory discipline necessary at point B? Obviously, if the capitalist announces a wage contract of (w_1, e_1), the worker will have an incentive to accept but then to supply effort less than e_1. But, as we saw, unless we introduce transaction costs that prevent cheap monitoring of worker output, there exists a piece-rate contract that will elicit effort e_1 for payment of w_1. (It would be given by the slope of a line tangent to the indifference curve at B.) Clark's account, however, is more interesting. Before we turn to it, consider a broader class of

[21] As we will see, Clark's account is not in fact a "coercion" account, since his argument is ultimately that the contract (w_1, e_1) plus discipline is Pareto optimal.

explanations (to which Clark's belongs) in which the worker's preferences do not appear as fully formed and given over the entire relevant space.

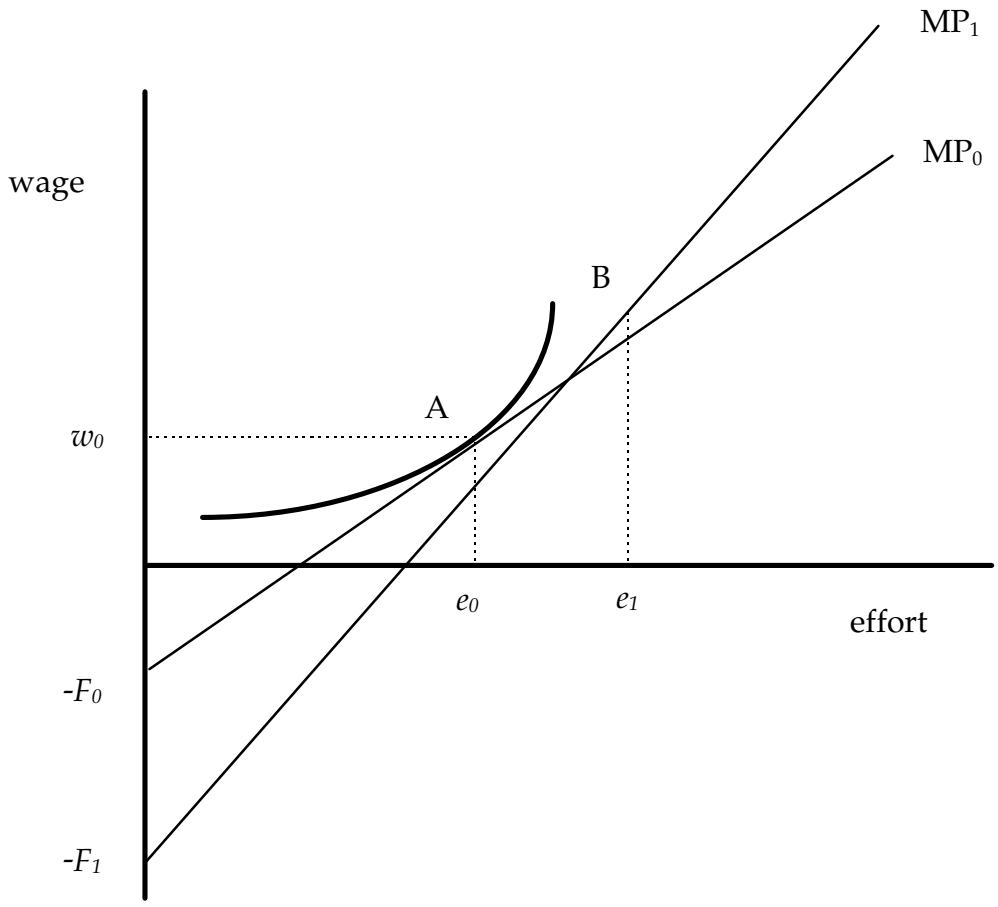

Figure 6: backward-bending effort supply.

In a model that is similar in many ways to that of Clark, Lazonick (1990) formalizes an explanation of factory discipline hinted at by both "radicals" and economic historians: a backward-bending supply curve of effort. Put in terms of the story we have been telling, the representative worker may have a utility function such that the capitalist will not be able to elicit higher levels of effort

with pecuniary incentives. For example, in Figure 6, there is no wage less than marginal product, and therefore no piece-rate contract, that will elicit an effort level, such as e_1, that makes the higher-throughput technology (MP_1) economical. Lazonick does not think of these preferences as immutable standards of economic welfare, however, but as "customary effort norms" (1990, p. 348) that should not be allowed to impede the adoption of higher-throughput technology. And it is clear that Lazonick, like many others, doesn't see tastes as immutable. He agrees with Marglin, he says, that "the success of the factory system depended not on technology but on the creation of a social environment conducive to the imposition of work discipline"[22] (1990, p. 52). That is to say, the capitalists had to teach the workers a different set of effort norms: they had to change the workers's utility functions. Factory discipline served this function.

[22] As I have suggested, however, Lazonick's high-fixed-cost model does in fact suggest that technology was indeed in part responsible for the factory system, in that it was fixed costs that made discipline desirable. In Lazonick's defense, however, fixed costs do not always mean physical capital; they can also mean human-capital investments and fixed investments in organizational capabilities. How important these latter were compared with physical capital during the Industrial Revolution is an open question. Despite his inclination to heap praise on Marglin (*e.g.*, Lazonick 1991, pp. 291-294), Lazonick's account is on the whole quite at variance with that of Marglin. For Lazonick, changes in favor of high-throughput production (during the Industrial Revolution and at other times) do in fact reflect efficiency, and are moreover the principal engine of economic growth and competitive advantage. In addition, the imposition of these technologies is not typically exploitation, in that the most successful episodes of rapid economic growth have occurred when institutions permitted capitalists and workers to share the gains of new technology so that neither would have an incentive to impede those changes. Indeed, the failure of economic growth and competitiveness has often been a matter of laborers standing in the way of the efforts of capitalists to impose more-efficient high-throughput methods.

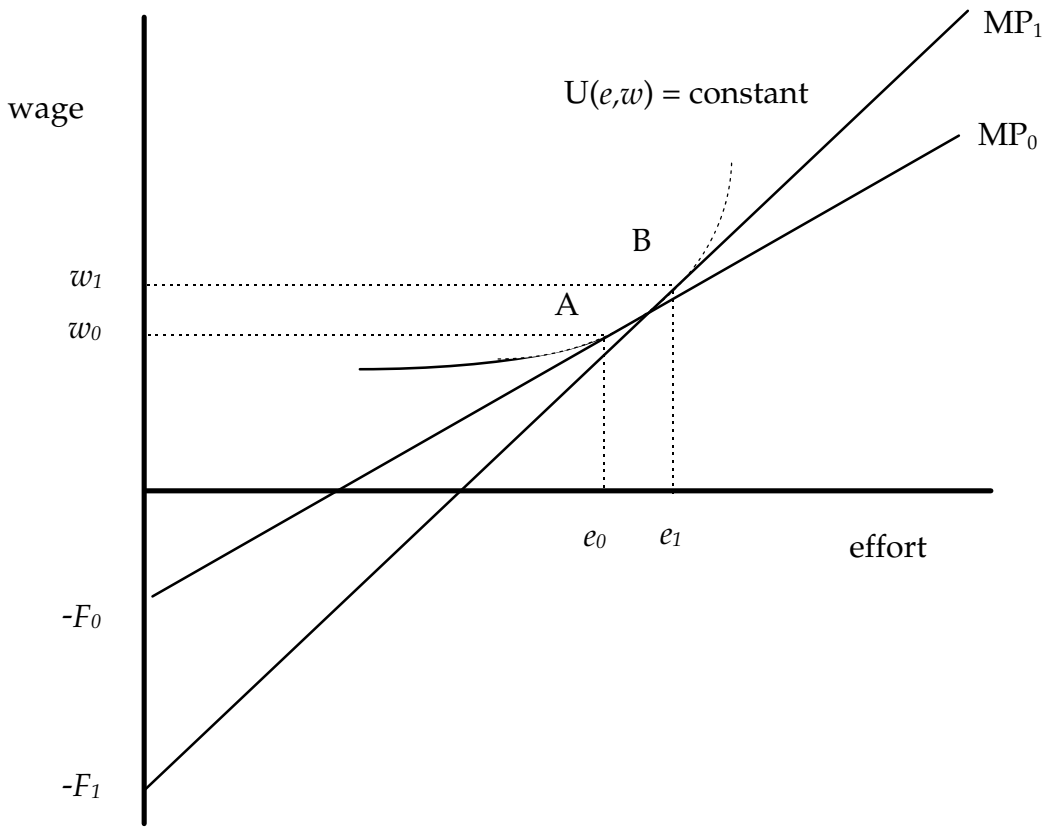

Figure 7: Discontinuous indifference curve.

Clark places a somewhat different twist on this account. He notes that, although workers complained about the pace of work, and although they would have chosen both lower *e* and lower *w* if allowed to choose their own effort/wage tradeoff, workers nonetheless voluntarily chose the high wages and hard work of the factories. This suggests a problem of marginal incentives: effectively, the worker's indifference curves are either discontinuous (they exist only locally around specific points (as suggested in Figure 7) or they are not

convex. In either case, workers cannot traverse the space from point A to point B along the same indifference curve when technology changes; given a choice on the margin, they will take leisure over higher wages. Yet, if they are "coerced" into working at point B, they will accept the non-marginal tradeoff between B and the lower-wage, lower-effort alternatives. "The workers dislike discipline, but they stay in the factory because at the end of the week their wage is 60 percent greater than that they can achieve without discipline" (Clark 1994, p. 160). Thus the workers are not "coerced" into doing what the capitalist wants them to do — that is, they are not exploited; rather, the workers are "coerced" into doing what they themselves would like to do but can't bring themselves to do on the margin.

In the end, we might say that Clark's explanation builds a bridge between the Alchian-and-Demsetz account of shirking and Lazonick's account of preference change. Like Lazonick (and many others), Clark sees factory discipline — like discipline in other areas of life — as aimed at a problem of individual preference. But, like Alchian and Demsetz, he sees discipline as correcting a problem of externality rather than as changing preferences. As with the shirking workers in the Alchian-and-Demsetz story, monitoring here solves a problem of divergence between marginal incentives and the global optimum. In this case, however, it is a "shirking" externality that occurs within each worker's individual psyche. Like a dieter faced with a piece of cake, the worker sees a bit of leisure on the margin as far more enticing than higher wages, even though,

like a more svelte figure to the dieter, the longer-range goal of income is ultimately more desirable —by the individual's own lights. Just as teams of bargemen in pre-Revolutionary China hired an overseer to whip them,[23] workers in the industrial revolution acceded willingly, though not happily, to the "coercion" of their capitalist masters.

Whether it is possible to disentangle shirking externalities (whether within the group or within the psyche) from changes in preferences is an empirical question I leave in the hands of historians.

Evolution, explanation, and the inevitable.

[Section to be written.]

[23] Or so Steven Cheung (1983) claims.

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