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Source: *Journal of Labor Economics*, Vol. 18, No. 1 (January 2000), pp. 1-19

Published by: The University of Chicago Press on behalf of the Society of Labor Economists and the NORC at the University of Chicago

Stable URL: http://www.jstor.org/stable/10.1086/209948

Accessed: 06-04-2018 10:41 UTC

Worker Cooperation and the Ratchet Effect

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Workers paid by the piece should be happy to introduce new techniques that increase output, but firms always seem to reduce the piece rate when workers start earning too much money. Workers respond by restricting output and keeping good new ideas to themselves. We show that this outcome is inevitable in a competitive environment. However, there are noncompetitive situations where firms can use piece rates to get cooperation from their workers. These predictions are consistent with case history evidence from the cotton spinning industry in England in the nineteenth century and the Lincoln Electric Company in the United States even today.

I. Introduction

Workers often know a great deal more than their managers about the way a firm's products are made. At various times they may also come up with ideas that would improve the technology and reduce the cost of production. A firm where workers share their cost saving ideas with coworkers and managers will in the long term earn higher profits. Firms should therefore be striving for cooperative relations with workers in the area of technical change.

In principle, cooperation and involvement should not be difficult to

We would like to thank Yoshi Kanemoto, Ed Nosal, and Michael Huberman for helpful comments. The financial support of the Social Sciences and Humanities Research Council of Canada and NSF grant SBR-9709333 is gratefully acknowledged.

[*Journal of Labor Economics*, 2000, vol. 18, no. 1]

0734-306X/2000/1801-0002$02.50

obtain, at least in jobs where output is observable. If workers are paid a fixed piece rate, then any improvement they make will be reflected in increased output and thus in their own salaries. Workers should cooperate with technical change and be willing to initiate the process themselves. However, there is now a long history in Western manufacturing to suggest that this does not happen. The problem is that firms never seem to allow their workers to start earning more money. Every innovation just leads to a cut in the piece rate. Workers respond by restricting output and keeping their good ideas to themselves.

This phenomenon has been called the "ratchet effect," and it has been studied by several authors. Descriptions of the practice are in Dore (1973) and Clawson (1980), while the theoretical issues are examined by Stiglitz (1975), Frexias, Guesnerie, and Tirole (1985), Lazear (1986), Gibbons (1987), and Kanemoto and MacLeod (1992). The theoretical models are set in a two-period framework. If firms can commit themselves legally to keep the rate fixed in each of the two periods, then workers can be induced to innovate. However, in practice, firms seem to have many ways of avoiding these commitments, even if they are part of an explicit legal contract.[1] The models therefore assume that the firm's promises must be self-enforcing in the second period. Gibbons shows that if workers cannot be prevented from quitting in the second period, then there is no way to prevent them from concealing the true difficulty of the job. Lazear shows that if workers can be bound to the firm, then a scheme where the piece rate is high in the first period and a decreasing function of first period output in the second period will induce efficient behavior. Kanemoto and MacLeod show that if the hidden information is the ability of the worker rather than the difficulty of the task (e.g., as in commission sales), then the existence of an outside market for workers can force firms to keep the rates fixed.

To some observers, these results, although rich and suggestive, remain unsatisfying. The two-period structure forces firms to be completely myopic. In reality, the worker-firm relationship is long term and repeated, and the benefits of cooperation seem substantial. Surely firms are aware that technical change is a continuing process and surely they understand the benefits of worker cooperation in the process. Managers often complain about the costs of output restriction. Do they not understand that cutting a piece rate, however deviously it is accomplished,

[1] Clawson (1980), after discussing several case histories, states on p. 170: "New workers could be assigned to the job at a lower rate while the old workers were transferred elsewhere, information about output on one job could be used to lower the initial price on new work, and any sort of minor change could be made the excuse for large price cuts."

means no more cooperation forever? What can explain this shortsighted managerial attitude?

We argue here that there is much to be learned about the feasibility of piece rates from a more detailed study of the dynamics of the compensation patterns they create. A key factor in our model is the extent to which the gains from worker-sponsored improvements to the technology can be made specific to the firm. Formally, we show that a classic piece rate scheme with fixed rates and worker cooperation is impossible to achieve in a dynamic competitive context, even when the firm has essentially unlimited commitment power. There is a problem with piece rates, but it has nothing to do with shortsighted managers.

The reason is simple. Suppose that a firm could make its piece rate part of an enforceable explicit contract. Its workers begin to innovate, and wages and profits start to increase. Eventually, the ideas developed at this firm will spread to others, and what was a worker-sponsored idea at this firm may become a management-sponsored idea at another. Outside firms, perhaps started by former employees of the first, will eventually undercut the innovating firm by teaching the new techniques to their own employees and setting a lower piece rate. This effect by itself will drive out firms that are committed to maintaining a constant piece rate.

We are also able to establish a converse to this theorem. If the entry of "parasite" firms is sufficiently difficult, then worker cooperation can be sustained with the use of piece rates. Any sustainable piece rate system will involve periodic renegotiation of the rate, but this can be accomplished without the loss of worker trust.

Since previous work has already argued (for different reasons) that piece rates will not survive, it is important that we establish some empirical distance between our results and those in the literature. We do this by studying two cases where firms were able to resist the ratchet effect— one from the history of cotton spinning in nineteenth-century England and the other from the experience of the Lincoln Electric Company, an American manufacturing firm that continues to use piece rates. These two cases make it clear that it is possible, with periodic renegotiation, to use piece rates over long periods of time without losing worker cooperation.

In Lancashire, cotton spinning firms were geographically very close,[2] and there was no way to prevent the diffusion of new ideas. In spite of this, piece rates were stable and worker-initiated technical change was rapid. Piece rates were set according to public "lists," which were maintained and enforced by a collusive agreement among the firms in the area. The firms kept each other, and in particular new entrants, from reducing

[2] Often several firms would rent space in the same building.

the rate by supporting and encouraging the workers at defecting firms to go out on strike. This case suggests quite strongly that it is competitive pressure from other firms that makes rate cuts inevitable. At Lincoln Electric, turnover rates are very low, and production techniques have remained largely proprietary; for these reasons, competitive pressure has been weak.

While lack of competition is necessary for sustainable piece rates, it is clearly not sufficient to guarantee them. Indeed, there are many other payment schemes, such as contingent bonus payments, that will get cooperation and be less costly to firms. In our study of these cases, we attempt to identify the other factors (largely historical in nature) that we believe led to the use of piece rates.

The model is set up and analyzed in the next two sections of this article. The section after that presents details of the two cases used to support the model. The last section concludes.

II. The Model

We develop our ideas with a very simple model of an infinitely lived firm hiring a stream of workers, each of whom lives for two periods only. Periodically the firm will also upgrade its technology by buying new machinery. We denote the current period by τ and the period in which a new machine is bought by t. Output per worker in period τ is given by

$$Q_\tau = A_t + K_{t,\tau}, \tag{1}$$

where A_t is the contribution of the machine bought at time t, and $K_{t,\tau}$ is the stock of knowledge about this machine accumulated at time τ. Knowledge is freely transferrable among workers within the firm, so that old and young workers are equally productive in any period.

The firm exists among a local group of similar firms. The group is small in relation to its input and output markets, and, for simplicity, the price of output is set to unity. In any long-term equilibrium, all of the firms in this group must earn the same level of profits.

Knowledge can be produced internally, through learning by the worker, or it can be obtained from other firms in the local area. Internal knowledge is generated by the efforts of young workers. The benefits show up in the following period, according to

$$K_{t,\tau} = K_{t,\tau-1} + \sigma_{\tau-i}\gamma, \tag{2}$$

where $\sigma \in \{0, 1\}$ is unity if the worker has invested in improving the technology and zero otherwise, and γ is the benefit of investment in learning by the worker. In general, worker knowledge is specific to the vintage of machine, so that knowledge is lost when machines are replaced. For simplicity, however, we assume that worker investments in the last period of a machine's life are valuable for the next vintage of machine. Thus if a young worker invests in period $t - 1$, $Q_t = A_t + \gamma$. If the workers invest each period from time $t - 1$ to time τ, $K_{t,\tau} = \gamma(\tau - t + 1)$.

We denote the cost of investing to the worker by υ. Thus the discounted lifetime utility of a worker born in period $\tau - 1$ is given by

$$U_{\tau-1} = w_{\tau-1} - \sigma_{\tau-1}\upsilon + \delta w_{\tau}, \quad (3)$$

where w is earnings, and δ is the common discount factor. There is also an alternative job that asks for no investments and pays w_0.

Note that knowledge does not decay within the lifetime of a machine, though it is lost when the machine is replaced. The benefits of investing therefore fall as the replacement date gets nearer. For simplicity, we assume throughout that

$$\upsilon < \delta\gamma, \quad (4)$$

so that it is always optimal for workers to invest, even when the current machine is about to be replaced. There is also ongoing technical change in the design of the machines, such that $A_t = A_0 + gt$. Firms can replace their machine at the cost R.

We consider first the question of machine replacement. Let $\Pi = \{\Delta^1, \Delta^2, \ldots\}$ denote a replacement policy, where Δ^s is the length of time machine s is used before being replaced by machine $s + 1$. The value of production at time t when a new machine of productivity A_t is installed using replacement policy Π from this period forward and assuming that workers invest is given by

$$V(\Pi, t) = \frac{A_0 + gt - \upsilon}{1 - \delta} + \sum_{s=0}^{\infty} \left[\Theta^s g \frac{1 - \delta^{\Delta^s}}{1 - \delta} - R + \sum_{\tau=1}^{\Delta^s} \tau\gamma\delta^{\tau-1} \right] \delta^{\Theta^s}, \quad (5)$$

where

$$\Theta^s = \left(\sum_{k=1}^{s} \Delta^k \right) \quad \text{and} \quad \Theta^0 \equiv 0. \quad (6)$$

Notice that we can write $V(\Pi, t) = V(\Pi, 0) + gt/(1 - \delta)$; hence the optimal policy does not depend on the current productivity of a new machine. Therefore the optimal replacement is time independent, though it depends upon γ, R, and g; it is denoted $\Delta^*(\gamma, R, g)$. The value of production at time t will be denoted by V_t^I.

PROPOSITION 1. Optimal machine lifetime $\Delta^*(\gamma, R, g)$ is increasing in γ and R and decreasing in g.

Proof. The value of replacing a machine at date Δ^* is $V(\Delta^*) + g\Delta^*/(1 - \delta)$. From the dynamic programming algorithm, we know that it is not optimal to delay or advance the date of replacement given that an optimal policy is followed after that; hence we have the following two inequalities:

$$V(\Delta^*) + g\Delta^*/(1 - \delta) \geq \gamma(\Delta^* + 1) + \delta[V(\Delta^*) + g(\Delta^* + 1)/(1 - \delta)], \quad (7)$$

and

$$V(\Delta^*) + g(\Delta^* - 1)/(1 - \delta) \leq \gamma\Delta^* + \delta[V(\Delta^*) + g\Delta^*/(1 - \delta)]. \quad (8)$$

This implies that

$$\frac{g}{1 - \delta} \geq (1 - \delta)V(\Delta^*) + (g - \gamma)\Delta^* \geq \gamma + \frac{\delta g}{1 - \delta}, \quad (9)$$

from which the result follows after some algebraic manipulation. Q.E.D.

Notice that machines are replaced in finite time only when $g/(1 - \delta) > \gamma + \delta g/(1 - \delta)$. This requires that $g > \gamma$, that is, that the rate of internal learning be less than the rate of external improvement. In what follows, we assume that $g > \gamma$. Machines will be replaced most rapidly if internal learning does not occur, that is, if $\gamma = 0$. If R, the cost of replacing machines, is zero, then it is also easy to show that machines will be replaced every period.

We now introduce the possibility that a firm can be a "parasite," that is, that it may do no investment internally and that it will take its knowledge from other firms. To keep things as simple as possible, we assume that the cost of copying is β and that a payment of this amount will buy last period's level of knowledge. A parasite firm will have to mimic the machine replacement strategy of the firm it is copying. If there is another firm in the local group whose workers are investing, the present value of production to a parasite entering in period t with a new machine is therefore

$$V_t^P = \frac{A_0 + gt - \beta}{1 - \delta} + \sum_{s=0}^{\infty} \left[(\Delta s) g \frac{1 - \delta^{\Delta}}{1 - \delta} - R + \sum_{\tau=1}^{\Delta} (\tau - 1)\gamma\delta^{\tau-1} \right] \delta^{\Delta s}, \tag{10}$$

where we note that $\Theta^s = \Delta s$, since the machine replacement rate is constant.

If the parasite option is available, for a firm to innovate on its own, we must have $V_t^I > V_t^P$. After some algebraic manipulation, we have

$$V_t^I - V_t^P = \frac{\gamma + \beta - \upsilon}{1 - \delta}. \tag{11}$$

We have assumed above that $\delta\gamma > \upsilon$. It follows that (11) will always be positive, that is, in this model it will never be optimal for a firm and its workers to become parasites, even if the cost of copying is zero. Nonetheless, we shall see that when firms use piece rates to induce innovation, the possibility of entry by parasites cannot be ignored.

Consider a simple linear piece rate contract designed to bring about worker cooperation in every period:

$$w_\tau = \alpha Q_\tau + \underline{w} \ \forall \tau. \tag{12}$$

To be consistent with the history of rate busting and with the case histories to follow, the level of α is treated as an unenforceable promise made by the firm. Workers promise to provide cooperative effort in return. If either party reneges on its promise, the other is assumed to play a grim strategy—workers (including all future workers at the firm) put in their time but provide no inputs into the growth of knowledge, and the firm pays the worker the alternative wage, w^0. These threats form a Nash equilibrium and are therefore credible.[3]

The question is whether the promise to keep the piece rate constant is credible. This model differs from past work in that there is no final period to the relationship. At every point in time, there is a large surplus to be had from future improvements in knowledge and, too, a fixed piece rate gives each party a positive share of this surplus. The conditions seem ideal for piece rates to support cooperation.

[3] Clearly the market may be kinder to the participants than we are assuming here. Since our main result is negative, however, nothing is lost by assuming these grim strategies are available.

Cooperation is optimal for the worker if the future benefit is warranted by the current cost, which, given (12), is satisfied if and only if

$$\alpha\gamma\delta \geq \upsilon. \tag{13}$$

Since the inequality in (4) is strict, we know that there exists an $\alpha \in (0, 1)$ such that the inequality in (13) holds. Note that in this simple framework the incentive constraint does not depend on the level of knowledge,[4] though of course total compensation will depend on total firm productivity. At time zero, the rate $\underline{w}$ is set to ensure that the worker's default utility is given by the market level.

Suppose that all the firms in the local group are using a fixed piece rate that satisfies (13). The discounted future profits of firms at time t is given by

$$\Pi_t^I = (1-\alpha)\left(\frac{A_0 + gt}{1-\delta} + \sum_{s=0}^{\infty}\left[(\Delta s)g\,\frac{1-\delta^{\Delta}}{1-\delta} + \sum_{\tau=1}^{\Delta}\tau\gamma\delta^{\tau-1}\right]\delta^{\Delta s}\right) - \frac{R}{1-\delta^{\Delta}} - \frac{\underline{w}}{1-\delta}. \tag{14}$$

Note that these profits grow over time as innovation continues. Workers also do better over time, that is, their wages increase as does the present value of future wages.

Firms following a parasitic strategy do not need to provide incentives for knowledge accumulation, and therefore they pay the default wage w^0 each period. The discounted future profits of such a firm, assuming it enters at time t with new machinery, is given by

$$\Pi_t^P = \frac{A_0 + gt - \beta}{1-\delta} + \sum_{s=0}^{\infty}\left[(\Delta s)g\,\frac{1-\delta^{\Delta}}{1-\delta} - R + \sum_{\tau=1}^{\Delta}(\tau-1)\gamma\delta^{\tau-1}\right]\delta^{\Delta s} - \frac{w^0}{1-\delta}. \tag{15}$$

Comparing equations (14) and (15), notice that the profits of the parasite firm grow at a faster rate than those of the innovating firm. The difference in profits is given by

[4] This is due to the linearity of K_t in the worker's investment.

$$\Pi_t^P - \Pi_t^I = \alpha \frac{gt}{1-\delta} - C^P, \tag{16}$$

where $C^P > 0$ is a constant that does not depend on t. Thus there will eventually come a time when it is profitable for parasite firms to enter and the situation where all firms in the local group use piece rates cannot be an equilibrium.

The argument assumes that Δ is finite. If not (i.e., if the firm never replaces its machinery), then so long as $g > \gamma$, a similar argument shows that it will eventually be profitable for a firm to enter with new machinery and no worker investments. Thus we have the following proposition.

Proposition 2. When workers invest in knowledge, there is competition in the output market, and firms have the option of stealing ideas from other firms, a fixed piece rate contract is unsustainable.

The intuition behind this result is clear. As workers continue to invest under the piece rate contract, they produce more and more, and they earn higher and higher wages. But it is knowledge, rather than skills,[5] that is the source of this wealth. Another firm (perhaps one started up by a former employee) can always enter with nearly current knowledge and hire employees at the alternative wage. This firm, and others like it, will earn higher profits. A promise to maintain the piece rate forever cannot be kept.

It is perhaps worth reemphasizing that firms are infinitely lived in this model. There is no final period when the firm can cheat on its workers with impunity. The benefits of cooperation to both the firm and its workers are evident and ongoing, and the internal investment strategy continues to be efficient even as wages grow. Nonetheless, there comes a time when the potential entry of new firms forces the piece rate to be adjusted.

Proposition 2 emphasizes the role of competition within the local group. Suppose instead that there is only one firm in the local market, although it remains a price taker, and suppose that this firm is using the fixed piece rate contract (see eq. [12]). As before, if the firm reneges on its promise and cuts the piece rate, workers will not cooperate forever. The firm will thenceforth pay the minimum wage required to retain them. The overall profit to the firm from reneging at time t is given by

$$\Pi_t^R = \frac{A_0 + gt}{1-\delta} + \sum_{s=0}^{\infty} \left[(\Delta^R s) g \frac{1-\delta^{\Delta R}}{1-\delta} - R \right] \delta^{\Delta^R s} - \frac{w^0}{1-\delta}, \tag{17}$$

[5] Knowledge is immediately transferrable, while skills take time to learn and go with the worker. See Kanemoto and MacLeod (1992).

where we note that the optimal time to replace machines in the future has changed. Again, the difference in profits from the two strategies can be expressed as

$$\Pi_t^R - \Pi_t^I = \alpha \frac{gt}{1 - \delta} - C^R, \tag{18}$$

which increases without bound over time. Even a firm with no competitors will eventually find it profitable to renege on a fixed piece rate contract. Of course, a firm with no competitors need not choose strategies to maximize profits, but the costs of not doing so will increase over time.[6]

III. Renegotiation

In this model, there is a surplus to the internal generation of knowledge, even in the presence of parasites. It follows from MacLeod and Malcomson (1989) that there should exist a self-enforcing contract that will support cooperation. Suppose, for example, that the firm explicitly promises to pay the workers the wage w^* each period and makes the legally unenforceable promise to pay them an additional amount B if they contribute, where $B\delta = \upsilon$. The worker (and any of his potential replacements) makes the promise to cooperate and to stop cooperating forever if they have invested and the bonus is not forthcoming. This promise will be credible if $w^* = w^0$, since the worker will then be indifferent between cooperating, not cooperating, and being in an alternative job. A firm that follows this strategy will pay older workers higher wages than a parasite firm by the amount υ/δ. It follows that its profits will be higher if and only if internal investment is optimal, that is, if condition (4) is satisfied. In this case, since continuing to pay the bonus will support these profits, the promise to pay the bonus will be credible as well.[7]

Given proposition 2, and given that other contracts were and are available that can support cooperation, one wonders why piece rates were ever observed. Piece rates have advantages, however, if they can be made to work.[8] They are simple to set up and to implement. They attract energetic workers to the firm. Other measures to increase worker involvement that are not linked to output may distort incentives. For example, basing reward on the number of suggestions received will

[6] The assumption that the firm is a price taker is also very favorable to the prospects for cooperation. If increases in output reduced the market price, the surplus to cooperation would be lower.

[7] MacLeod and Malcomson (1989) show that there are, in fact, a whole range of similar contracts that will sustain cooperation. Our point is simply that a fixed piece rate contract is not one of them.

[8] Many of these are discussed by Stiglitz (1975).

maximize the number of suggestions, but it will not ensure that the suggestions are useful. Basing reward on the number of suggestions actually used gives the firm the incentive to disguise the true source of any innovation. Pure profit sharing is more difficult to implement because the determination of profits is much more costly than the determination of output. The great advantage of piece rates is that anything leading to higher output directly and immediately rewards the worker in proportion to the value of his contribution.

Too, one cannot ignore the role of history. During the Industrial Revolution, a whole generation of workers moved out of their farms and cottages, where the technology was relatively stagnant and piece work was the norm, to the factories. It is not surprising that piece rates were initially the wage system of choice, even if ultimately they were not well suited to the new industrial structure. If the technology in the new industry had been stagnant, there would have been no reason to use a different system. However, if worker inputs were valuable in making improvements, then the piece rate system would come under stress.

This brings up the issue of renegotiation. Suppose that a firm is committed to the use of piece rates, perhaps for reasons related to those just mentioned. The problem with a fixed piece rate is that worker compensation grows without bound over time, while firm profits eventually must be shared with other firms or consumers. The firm may be able to maintain the system if it can reduce the rate from time to time.

This can be achieved if two conditions are satisfied. First, after the rate has been renegotiated, there must be gains to both parties from continued cooperation. Second, the parties must anticipate and accept the process of renegotiation. A convenient focal point for renegotiation occurs when the firm purchases new machinery. Suppose that each time a firm introduces new machinery, it readjusts wages down. In order to ensure worker cooperation in the final period of the previous machine's lifetime, the firm promises to set

$$w_t = \alpha_t Q_t + \underline{w}_t = w_0 + \upsilon/\delta \tag{19}$$

for the first period with the new machine, so long as the worker has cooperated. (As above, the credible threat is to set $w_t = w_0$ and to shift to a no-cooperation regime.) These rates are set for the life of the new machine.

Due to the additive structure on the productivity gains in this model, the optimal piece rate is independent of overall productivity and is given by $\alpha = \upsilon/\gamma\delta$. Thus the renegotiation focuses on the rate $\underline{w}_t$. Firm profits over the lifetime of this machine are given by

$$\Pi_t^I = (1-\alpha)\left[(A_0 + gt)\frac{(1-\delta^\Delta)}{1-\delta} + \sum_{\tau=1}^{\Delta} \tau\gamma\delta^{\tau-1}\right] - R - \underline{w}_t \frac{(1-\delta^\Delta)}{1-\delta}. \tag{20}$$

A parasite firm that enters with the same vintage of machinery and continues to steal ideas will make profits over the same period of

$$\Pi_t^P = \left[(A_0 + gt - \beta)\frac{(1-\delta^\Delta)}{1-\delta} + \sum_{\tau=1}^{\Delta} (\tau-1)\gamma\delta^{\tau-1}\right] - R - w^0 \frac{(1-\delta^\Delta)}{1-\delta}. \tag{21}$$

After some algebraic manipulation using (19), we see that the difference in profits is given by

$$\Pi_t^I - \Pi_t^P = (\beta + \gamma - \upsilon/\delta)\frac{(1-\delta^\Delta)}{1-\delta} - \alpha \sum_{\tau=1}^{\Delta} (\tau-1)\gamma\delta^{\tau-1}. \tag{22}$$

The first term is the difference in the overall value of the two firms over the life of the machine, and it has been assumed to be positive. The second term is the extra wage earned by the workers at the piece rate firm over the same period. So long as the overall expression is positive, parasites will not find it profitable to enter. Workers are paid piece rates, but their wages do not grow without bound, since the time rate is renegotiated with the introduction of new machines. So long as the benefits of worker cooperation are sufficiently large, a calculation similar to (18) will show that the firm will not be tempted to renege in the absence of parasites. Under these conditions, a periodically renegotiated piece rate system can sustain worker cooperation.

Inspection of (22) gives us the following proposition.

Proposition 3. Suppose that a firm wishes to use piece rates, which are to be renegotiated at the time machines are replaced. The firm is more likely to avoid attracting parasites (and thus be able to maintain worker cooperation) if the cost of being a parasite is high, the net benefits of cooperation are high, the piece rate is low, and renegotiation occurs more frequently.

For the calculations above, it is the time rate $\underline{w}_t$ that is being renegotiated, but this is due entirely to the additive structure we have chosen for our model. A lowering of the time rate can be interpreted as an increase in the quota of output required before the piece rate is paid, although to examine this formally one has to consider the possibility of multiple equilibria in the worker's choice problem.[9] Another approach would be to assume that worker ideas become more valuable as the technology improves.[10] In this case, a lower piece rate can maintain incentives. It is also possible in a pure piece rate system (i.e., $\underline{w}_t \equiv 0$) that the piece rate initially is set above the level required to maintain incentives in order to satisfy the participation constraint. In this case, renegotiation of the piece rate with the introduction of a new machine presents no difficulties apart from those outlined above.

This proposition, along with proposition 1, form the basis for the empirical implications of our model.[11] To begin, it is clear that no model of the ratchet effect can explain why so many manufacturing firms were using piece rates at the beginning of the Industrial Revolution. We simply take this as a historical fact. However, some firms managed to maintain a piece rate system quite successfully over many decades, while others could not. Our model provides some rationale for the different histories.

We focus on two cases where piece rates have coexisted with, and have perhaps been instrumental in, worker-sponsored technical improvements. The first is the case of English cotton spinning in the nineteenth century. Here there seems to have been a strong historical commitment to piece rates, and the way in which the industry adapted to them is fascinating. The second is the celebrated case of the Lincoln Electric Company. The founder of this company had a strong ideological preference for the piece rate system. More important from our perspective, the firm has largely managed to keep its production techniques proprietary. Even though piece rates are renegotiated from time to time, its workers earn high wages, and the firm remains profitable.

These two cases show that there is some empirical distance between our approach and standard models of the ratchet effect, which emphasize the short-term profits available to firms that bust the rate. The standard approach is unable to suggest any reason why the firms we are studying

[9] Let Q_t^* be the quota. Compensation is given by $w_\tau = \alpha(Q_\tau - Q_t^*)$. When machines are replaced, the quota is reset to ensure $w_t \geq w_0 + \upsilon/\delta$, as above.

[10] For example, let $Q_\tau = (A_0 + gt)K_{t,\tau}$, where $K_{t,\tau} = K_t + \gamma(\tau - t)$. The marginal benefit of worker effort rises with the vintage of machine, so that the piece rate can fall. Optimal machine replacement becomes more difficult to analyze in this framework.

[11] Proposition 1 suggests that where workers cooperate, machine lifetimes will be long. Proposition 3 suggests that cooperation may require more frequent replacement. This tension cannot be resolved at a theoretical level. It will depend on the degree to which the worker's stock of knowledge is specific to a particular vintage of machine.

could maintain the piece rate system, while others could not. In our model, which is more evolutionary in character, a commitment to piece rates, periodically renegotiated, can be sustained so long as worker investments in knowledge are efficient and so long as the entry of parasite firms is restricted.

IV. Case Histories

A. Nineteenth-Century British Cotton Spinning

British cotton spinning in the nineteenth century provides a good example of a pure piece rate system in operation. The regional centers of Bolton and Oldham in Lancashire have been particularly well studied.[12] Firms in Bolton specialized in spinning finer threads for a largely local market, while those in Oldham spun coarser threads and competed on world markets.

The most important employees at a spinning firm were the "spinners," or "minders," who operated the spinning machines, or "mules," with the help of a number of "piecers." The spinners were paid entirely by the piece, and they in turn paid their piecers (usually children) a time wage out of their own receipts. Spinners came to be responsible for the upkeep of their own machines, which, as a result, became somewhat idiosyncratic in their operation (Lazonick 1981).

The conditions were ideal for rate busting and the associated restriction of output by workers. In Bolton particularly, firms were large—a staff of 200 workers was not uncommon (Huberman 1991*a*, p. 8)—and firm owners seemed to have little direct knowledge of potential output. "The sheer size of large firms enabled workers to keep their employers 'ignorant of what [was] passing in the . . . room'."[13] As well, information about the technology could flow freely from firm to firm. In some cases, different firms shared the same building, using a common power source. Older, experienced piecers, who would have learned a great deal about the technology, were in excess supply and could be hired by other firms. Thus the entry of parasite firms would have been very easy.

In spite of this, the piece rate system remained in place for over a century, and the pace of technical change was rapid.[14] Workers shared in the gains from new techniques. This was due to a remarkable collusion among the firms in each region.

[12] Lucid accounts are provided in Lazonick (1979, 1981) and Huberman (1986, 1991*a*, 1991*b*).

[13] See Huberman 1991*b*, p. 91. The included quote is from Sutcliffe (1816, p. 10).

[14] Lazonick (1979) reports that in Bolton the number of spindles per mule increased from about 144 in 1790 to 1,200 by the 1830s.

Firms established a public list of piece rates for each vintage of machinery by which all firms in the region were supposed to abide. New firms that tried to cut rates were opposed by the incumbents. "To maintain rates of pay, large and medium firms encouraged and financially supported spinners at smaller concerns who struck for payment by the list" (Huberman 1991*a*, p. 14). Firms fearful that a large stock of unemployed spinners would make it too easy for new firms to cut wages, also organized and encouraged the emigration of trained workers to the United States. It seems remarkable that firms would collude to increase the price of an input. But given their commitment to the use of piece rates, it makes sense as a method of ensuring that firms could keep the rates high enough to reward workers for their improvements to the technology.

The first of these lists seems to have been instituted at Bolton in 1813. Firms in Bolton were larger than and the pace of technical change in fine spinning faster than in coarse spinning early in the century. Lists were introduced in Oldham after the introduction of the self-acting mule (in midcentury) made larger firms more efficient. By the end of the century, the Bolton and Oldham lists governed rates of pay in 85% of the English industry. They were the subject of industry-wide bargaining, with the most contentious issue being the cyclical adjustment of rates to market conditions, as indexed by the price of cotton thread.

The lists also had to be modified from time to time as technical change continued. The first Bolton list was the subject of a protracted dispute in 1822–23. "Pressured by competitive forces, . . . firms were adamant that if rates were not cut on . . . [the latest, firm introduced technology] . . . there would be little incentive for further investment" (Huberman 1991*a*, p. 15). Later, disputes of this kind were more common in Oldham, which faced more severe foreign competition. The Bolton list was adjusted in this way 10 times from 1850 to 1900, while in Oldham, rates were adjusted eight times from 1872 to 1900. Nonetheless, contemporary accounts make it clear that firms believed it important that workers be rewarded for their contributions to technical progress. Wages over the latter half of the century rose by 25% in Oldham and 50% in Bolton, eventually making spinners among the best paid manual laborers in Britain (Huberman 1991*a*, p. 23).

There has been some debate among economic historians about the divergent paths taken by the British and North American spinning industries.[15] In North America, firms using similar technologies regularly reduced piece rates to keep worker earnings low. Part of the reason may have been that turnover rates were much higher (Lazonick 1981, p. 496), and firms more geographically dispersed, making piece rate "lists" more

[15] Cohen (1990) covers this debate and much of the evidence in great detail.

difficult to enforce. American firms certainly knew of the British lists and their effects, since many of their employees were former spinners and piecers from England. In any case, workers restricted output, and American firms were quick to abandon the spinning mule in favor of the "ring," an alternate technology that could be run with unskilled labor. In Britain, workers responded to the challenge of American competition by consulting with management on ways to get more output from their mules (Lazonick 1981, p. 514). As it turned out, the ring technology was ultimately more efficient, and the British industry declined in importance in the early twentieth century. Ironically, the large stock of knowledge about an existing technology may have induced firms to make the wrong decision about investing in a new one.

B. Lincoln Electric Company

The Lincoln Electric Company was founded in 1895 to manufacture electric motors and generators. In 1911, it moved into the manufacture of welding equipment. It is now one of the most successful manufacturing companies in the world.

The incentive system at Lincoln Electric has basically been unchanged since 1934. Normal wages for most factory jobs are based purely on piece rates. In addition, there is a year-end bonus based on a merit-determined share of a pool, the size of which depends on company performance. Merit rankings are made by foremen according to the dependability, quality, output, ideas, and cooperation of the workers. Finally, there is guaranteed employment for all workers. This means that in slack times workers' wages can fall precipitously as output and company earnings fall. Management instituted the employment guarantee because it felt that without it "employees would be more likely to resist improved production and efficiency for fear of losing their jobs" (Berg and Fast 1975, p. 6). In return for the employment guarantee, workers had to agree to become multiskilled and to accept any job that was assigned them.

The founder of Lincoln Electric, James F. Lincoln, was a self-described "rugged individualist" who believed that pay for performance and competition were essential if individuals were to realize their true potential. Lincoln Electric has never cut a piece rate. In the words of a past chairman, William Irrgang, "when we set a piecework price, the price cannot be changed just because, in management's opinion, the worker is making too much money. Whether he makes two or three times his normal amount makes no difference. Piece work prices can only be changed when management has made a change in the method of doing that particular job. . . . If this is not carried out 100%, piecework cannot work" (Berg and Fast 1975, p. 4).

Average wages at Lincoln are roughly twice the going rates for similar production work. In good years, they go even higher. The company's competitive advantage has been sustained by significantly lower costs of production. During World War II, the demand for welding equipment was so great that the U.S. Government asked all of the welding equipment manufacturers to add capacity. The president of Lincoln Electric went to Washington and explained that there was plenty of capacity, but that it was being inefficiently used. As told by a former president, George Willis, "he offered to share proprietary manufacturing methods and equipment designs with the rest of the industry. . . . [T]hat solved the problem. As a result, . . . our competitors had costs which were close to ours for a short period after the war, but we soon were out performing them like before" (Berg and Fast 1975, p. 2).

Proprietary manufacturing methods (and not just the extra effort of workers) are a major source of Lincoln Electric's cost advantage. These methods are the result of incremental, worker-sponsored improvements and are known to the workers. How can they be a secret? Part of the answer lies in turnover rates. After the first 6 months, when many workers might decide that they do not like working under a piece rate system, workers at Lincoln Electric have been very reluctant to leave. Turnover rates averaged .5% throughout the 1960s, as compared to around 4% in all manufacturing. This is not surprising given the salaries being earned and given that the workforce is a self-selected group that likes working under a piece rate system.[16]

Visitors to the Lincoln plant often report that the machines being used seem very old (Milgrom and Roberts 1995, p. 201). This is also consistent with our story. Workers have learned a great deal over the years about their machines, and this knowledge would be lost if wholesale reinvestment took place. The Lincoln Electric case illustrates clearly the basic message of this article. Managers are quite able to make and keep a promise to keep a piece rate fixed and to share the rewards of cooperation with workers if they can be sure that these rewards will not be appropriated by competitors and then consumers. On their part, workers will be happy to cooperate with a firm that can make credible promises.

V. Conclusions

Theoretical work has identified several situations where piece rates might be expected to arise. An overall condition, of course, is that all relevant aspects of output must be observable. Given this, piece rates can

[16] Milgrom and Roberts (1995) argue that complementarities among all of the practices at Lincoln mean that a rival firm, to match its performance, would have to match the whole package. The wartime experience outlined above would seem to believe this, but Milgrom and Roberts are not talking about "proprietary manufacturing methods" so much as the organizational practices that led to the discovery of those methods.

work if the technology of production is known and unchanging (as in agricultural sharecropping or low-skill manufacturing) or if such learning as takes place is embodied in the form of worker skills (as in sales). Previous work has argued that when worker inputs create productive knowledge, the inability of firms to commit to a constant piece rate leads inexorably to the ratchet effect and to a bad outcome where no workers invest.

This inability to commit is a puzzle given the long-term nature of the worker-firm relationship and the obvious benefits that accrue to firms whose workers are cooperative. However, a fixed piece rate generates an inexorable increase in the wage bill that eventually forces firms to bust the rate. The leakage of knowledge to other firms will hasten the day when this must occur. Even an entrepreneur who is morally committed to the maintenance of piece rates, if faced with serious competition, will either renege or be driven out of business by firms that steal his workers' good ideas.

Our argument is consistent with two cases where firms have managed to avoid the ratchet effect. In one (Lincoln Electric Company), the firm is without rivals in its use of the manufacturing technology. In the other (the nineteenth-century cotton spinning industry in England), firms actually colluded with each other to keep the price of inputs high, so as to prevent rival firms from exploiting the public nature of worker-sponsored advances.

Piece rates are not the least expensive way to obtain the cooperation of workers. A bonus system does better. Thus we must invoke some other factors to account for our two cases. With Lincoln Electric, the idiosyncratic beliefs of the founder seem sufficient.[17] With English cotton spinning, the widespread use of piece rates in agriculture and in the cottage industry of the time may have made piece rates the obvious choice. Indeed, the most remarkable aspect of this case may be the amount of effort it took to make piece rates a workable system.

References

Berg, N., and Fast, N. *The Lincoln Electric Company,* case 376-028, HBS Case Services. Boston: Harvard Business School, 1975.

Carmichael, H. Lorne, and MacLeod, W. Bentley. "Multiskilling, Technical Change, and the Japanese Firm." *Economic Journal* 103 (January 1993): 142–60.

Clawson, Daniel. *Bureaucracy and the Labor Process.* New York: Monthly Review, 1980.

[17] The payment scheme at Lincoln relies more on bonuses and less on piece rates than it did in the early 1900s.

Cohen, I. *American Management and British Labor: A Comparative Study of the Cotton Spinning Industry.* London: Greenwood, 1990.

Dore, Ronald P. *British Factory–Japanese Factory.* Berkeley: University of California Press, 1973.

Frexias, Xavier; Guesnerie, Roger; and Tirole, Jean. "Planning under Incomplete Information and the Ratchet Effect." *Review of Economic Studies* 52 (April 1985): 173–191.

Gibbons, Robert. "Piece Rate Incentive Schemes." *Journal of Labor Economics* 5 (October 1987): 413–29.

Huberman, Michael. "Invisible Handshakes in Lancashire: Cotton Spinning in the First Half of the Nineteenth Century." *Journal of Economic History* 46 (December 1986): 987–98.

———. "Cotton Spinning Lists in Lancashire: A Case Study of Efficiency Wages." Photocopied. Peterborough: Trent University, Department of Economics, February 1991. (*a*)

———. "How Did Labor Markets Work in Lancashire? More Evidence on Prices and Quantities in Cotton Spinning." *Explorations in Economic History* 28 (January 1991): 94–98. (*b*)

Kanemoto, Yoshi, and MacLeod, W. Bentley. "The Ratchet Effect and the Market for Secondhand Workers." *Journal of Labor Economics* 10 (January 1992): 85–98.

Lazear, Edward. "Salaries and Piece Rates." *Journal of Business* 59 (July 1986): 405–31.

Lazonick, William. "Industrial Relations and Technical Change: The Case of the Self-Acting Mule." *Cambridge Journal of Economics* 3 (September 1979): 1–33.

———. "Production Relations, Labor Productivity, and Choice of Technique: British and U.S. Cotton Spinning." *Journal of Economic History* 41 (September 1981): 491–516.

MacLeod, W. Bentley, and Malcomson, James. "Implicit Contracts, Incentive Compatability, and Involuntary Unemployment." *Econometrica* 57 (April 1989): 447–80.

Milgrom, Paul, and Roberts, John. "Complementarities and Fit: Strategy, Structure, and Organizational Change in Manufacturing." *Journal of Accounting and Economics* 19 (March–May 1995): 179–208.

Stiglitz, Joseph. "Incentives, Risk, and Information: Notes toward a Theory of Hierarchy." *Bell Journal of Economics and Management Science* 6 (August 1975): 552–79.

Sutcliffe, J. *A Treatise on Canals and Reservoirs.* Rochdale: Hartley, 1816.