

**DYNAMIC CONTRACTUAL ENFORCEMENT:
A MODEL OF STRIKES***

BY JAMES A. ROBINSON^{†1}

University of Southern California, U.S.A.

This paper provides a theory of strikes as part of a constrained efficient enforcement mechanism for an implicit contractual agreement. A firm possessing contemporaneously private information about demand engages in an enduring relationship with its workforce. If the information becomes perfectly observable subsequently, then, modulo discounting, the first-best is implementable, but strikes are always off the equilibrium path. If the observations of the workforce are imperfect strikes occur in equilibrium. The dynamic contracting problem is modeled as a repeated game with imperfect monitoring. The equilibrium exhibits production inefficiency and incomplete insurance to mitigate the inefficiencies caused by strikes.

1. INTRODUCTION

This paper uses the theory of repeated games to provide a dynamic model of strikes as part of a constrained efficient enforcement mechanism of a labor contract under asymmetric information. I argue that both the rationale for contracts, and the empirical evidence suggest that strikes be modelled in a dynamic environment. The framework I provide allows an integration of the literature and results on strikes and contracting.

There is much evidence that the employment nexus is not amenable to analysis within a simple competitive framework. Rents can be generated by a firm and a group of workers committing to relationship-specific investments and engaging in nonanonymous repeated interactions. While there may be competitive elements in the initial matching process the ex post situation has important noncompetitive facets (Williamson 1985). In such cases it is often assumed that wage and employment decisions are mediated by some form of contract. This influential approach stems from the contributions of Azariadis (1975), Baily (1974), and Gordon (1974).

A contractual mechanism solves the problem of wage and employment determination in the case of perfect, symmetric, and verifiable information. In this case explicit contracts can be written, verified, and enforced by third parties. However, many relationships feature intrinsically differential information which may be pertinent to

* Manuscript submitted April 1993; revised December 1995.

[†] E-mail: jarobins@almaak.usc.edu

¹ I would like to thank Truman Bewley, Peter Cramton, Stephen Morris, David Pearce, Ennio Stacchetti, Canice Prendergast, and two anonymous referees for their helpful comments and advice. None of the above are responsible in any way for the paper.

the implementation of the contract. In the work of Grossman and Hart (1981, 1983), and Hart (1983), the firm possesses private information about product demand which it has an incentive to misrepresent. There is a nontrivial enforcement problem. The solution proposed by Grossman and Hart was to distort the contract away from the first-best to remove the incentive for the firm to lie.

The asymmetric information models of strikes can be viewed from this perspective. Hayes (1984) modeled strikes as a constrained efficient sorting mechanism used by the workforce to elicit private information from a firm. Low profitability firms must endure a strike to credibly communicate this information. Cramton and Tracy (1992) model strikes as resulting from strategic delay between wage offers. Delay is used as a credible mechanism to signal private information. These models are alternative mechanisms to deal with the same fundamental problem as that studied by Grossman and Hart (1981, 1983).

The motivation for considering contractual relationships is however, a dynamic one. The contractants interaction is not one-shot but enduring. An intertemporal perspective changes the characterization of incentive compatibility since the signing of a single contract cannot be divorced from the previous history or the anticipated future (this was first stressed in the contracting literature by Rogerson 1985). It is also plausible that contemporaneously private information will accrue over time. In this paper I exploit these observations to provide a dynamic theory of strikes as a punishment mechanism enforcing a contract under asymmetric information.

The empirical evidence on strikes indicates the importance of taking a dynamic viewpoint. There are systematic features of the data that are impossible to reconcile with a static model. Card (1990) finds that a short strike increases the probability of there being a strike at the next contract negotiation, while a long strike significantly reduces the probability of a strike next time. There are also wage effects inherited from previous contracts. Card finds that a higher relative wage at the end of an expiring contract reduces the probability of a strike.

I embed a contracting model in a repeated game and consider two classes of assumptions about the dissemination of information. Firstly, I consider perfect monitoring. In this case private information at any date becomes observable to all contractants in the next period. Secondly, imperfect monitoring. In this case a noisy signal of the true information becomes observable in the subsequent period. I assume that whatever information becomes observable it is not verifiable to third parties and so the contract must be enforced by the firm and the workforce themselves.

A firm and a pool of workers sign a contract in each period that is conditional on the state of nature. I interpret this as a demand variable that is observable only to firms. Following Hart (1983), firm risk aversion implies that when there is production, there is an incentive for the firm to under-report the state of nature since this increases profits. The assumption of firm risk aversion is inessential to the results of the paper and only determines the direction in which incentive constraints bind and the form of inefficiency in equilibrium. For example, in Section 3, I show that in equilibrium there may be inefficiently low employment in the low state of nature. If, as in Azariadis (1975) for example, it was the workers who were risk averse and the firm risk neutral, then the incentive constraint would bind in the other direction and

the firm would have an incentive to over-report the value of the state. In Section 3 this would lead to inefficiently high employment in the high state of nature. The assumption of firm risk aversion therefore, while inessential in developing the idea that strikes can enforce contracts under asymmetric information, generates a possibly more attractive form of inefficiency. Moreover, the assumption seems plausible. The idea that firms are risk neutral really rests on implausibly strong assumptions about the perfection of the capital markets. Even if the firm had a linear utility for profits with imperfect capital markets and bankruptcy the indirect utility function would exhibit risk aversion. Indeed, Bewley (1996) argues in his field study of firm behavior that firms act in a very risk-averse manner.

Unlike Hart's static model, the workforce gets future observations on the contemporaneously unobserved demand conditions. In the perfect monitoring case the intuition behind the Folk Theorem (Fudenberg and Maskin 1986) suggests that punishment strategies may exist for the workers which support honesty by the firm as an equilibrium of the repeated game. I establish the exact sense in which this is true in Section 2. Now imagine (following Green and Porter 1984, and Porter 1983) that the state is observed in the next period with noise. It is plausible that firm profits become observable in the next period. However, realized profit statistics will not reveal perfectly the true state of demand at the time when firms made production and employment decisions. The motivation for strikes then comes from the fact that workers cannot perfectly monitor the state of nature. In effect, I assume that ex post published profit figures are an imperfect source of information about the firm's demand price for labor at the time when production takes place. In a large, diversified corporation, where bargaining takes place with heterogeneous pools of workers, this seems a plausible assumption. Indeed, Kennan and Wilson (1993) recently defend the more extreme position (implicit in much of the literature on dynamic contracting, for example Dewatripont 1989, and Laffont and Tirole 1988), that workers never get any direct evidence on relevant state variables.

When announcing the state, the firm knows that even if it lies it will not necessarily have to face punishment. Instead of ensuring incentive compatibility by distorting employment in each period, incentive compatibility is now guaranteed by an intertemporal calculation which includes the increased probability and cost of facing punishment.

Repeated games inherently have a plethora of equilibria. My approach to this is normative. I restrict attention to a class of strategies that use strikes as punishments and within this class calculate the most efficient way for the firm and workforce to enforce the contract. Such a restriction precludes global efficiency in the case of imperfect monitoring.

There are many ways in which a workforce may punish a firm for noncompliance. Apart from striking, they may initiate 'slowdowns,' cause contract delay, or withhold information valuable for efficient production. With perfect monitoring any credible punishment strategy that forces the firm to its minimum payoff and stipulates that the first-best contract be played along the equilibrium path of play can be regarded as optimal. Since all such punishments never arise in equilibrium, their relative cost to the contractants is irrelevant. With imperfect monitoring, however, the nature of efficient punishment becomes more critical since punishment will occur in equilib-

rium. Although firms always tell the truth, bad realizations of the noise trigger a strike. As I show in Section 3, this distorts the contract played in equilibrium away from the first-best in order to ameliorate the cost of using the strike weapon. Within the set of strategies considered in the present paper imperfect monitoring introduces interesting trade-offs between the use of the strike weapon and the nature of the contract which is played in equilibrium.

Recent theoretical work on repeated games with imperfect monitoring by Abreu et al. (1986, 1990), and Fudenberg et al. (1994) has cast the analysis supergames into a recursive setting. Many of the simplifications that I adopt to analyze the model are without loss of generality once this transformation can be established. If a game is recursive, a given history of the game can be captured by the expected discounted values of the firm and workforce. Thus the value of playing a particular equilibrium is a notional 'state variable' that plays the same role as the capital stock at any date in a growth model. This allows the analysis to abstract from the use of complex history dependent strategies, since every aspect of past play relevant to current play is factored into the value. The vector of values acts as a coordination device so that, given current values actions and observed outcomes, all players know what equilibrium actions are induced in the next period.

The value function approach can be justified under very general conditions with perfect monitoring. Much subtler issues are involved when I introduce imperfect monitoring. In Section 3, I define the class of equilibria for which the reduction is valid.

An important theoretical issue is the perfection of the strike threat. In Green and Porter (1984), collusion is supported by trigger strategy reversion to the Cournot-Nash equilibrium of the game. Since this is an equilibrium of the stage game, the threat is self-enforcing. In Abreu (1988) and (implicitly) in Abreu et al. (1986, 1990), punishments worse than such equilibrium reversion are made credible by constructing more complex punishments. A deviant firm that fails to submit only succeeds in re-starting the punishment, and a designated punisher which fails to punish is itself punished.

In the present paper, striking is credible because if the workers fail to strike then the workers and firm revert to an equilibrium in which the strike threat is never credible, hence never believed, and the workers are forced down to the minimum level of expected utility that they will accept without exercising their outside option. Proposition 1 establishes that this behavior is a subgame-perfect equilibrium of the repeated game. An interpretation of this equilibrium is that it represents a break-up of any coalition between the workforce if the strike fails to materialize. Workers then engage in a Bertrand game in wages, driving the labor market equilibrium down to the competitive one. The Bertrand equilibrium is used as a threat point to sustain collusion (see Weibull 1987, and Sabourian 1988).

The results of this paper are not closely tied to the specifics of the Grossman and Hart model. The issues could equally well have been analyzed in other asymmetric information contracting models (e.g. Green and Kahn 1983, and Chari 1983), or by reformulating the model as a risk-neutral Nash bargaining problem. The reason that I did not couch the main body of the analysis in a bargaining framework is that I am interested in the issue of implicit contractual enforcement. The idea of using strikes

to enforce contracts has been widely discussed verbally (e.g., Malcolmson 1983, Reder 1983, Horn and Svensson 1986, and Newberry and Stiglitz 1987), but no formal development has been presented to my knowledge.

The main result of the paper is Proposition 6, which characterizes the most desirable equilibrium of the repeated game with imperfect monitoring. This equilibrium exhibits the presence of strikes. I begin in Section 2 by examining the game with perfect monitoring. Section 3 then considers the case of imperfect monitoring. In Section 4 I provide a discussion of the model and the results. Section 5 concludes.

2. THE MODEL: PERFECT MONITORING

In this section, I show that the first-best Pareto optimal contract can be enforced by a strike for a nontrivial range of the discount rate when ex post information is perfect. The main restrictions on the enforceability of the contract are that the cost to the firm of replacing the workforce be large enough, and the value of the outside option of the workforce be sufficiently low.

2.1. The Stage Game. I start by specifying the details of the stage game, denoted G . I assume that the structure of G is common knowledge. There are N identical workers and one firm. The firm is risk averse, and has a twice differentiable utility function for profits, $V: \mathfrak{R}_+ \rightarrow \mathfrak{R}$, where $V(0) = 0$, $V' > 0$, and $V'' < 0$. The firm possesses a twice differentiable revenue function, $\theta f(L)$, where θ is a random variable and, $f: \mathfrak{R}_+ \rightarrow \mathfrak{R}_+$, where, $f(0) = 0$, $f' > 0$, and $f'' < 0$. The parameter θ takes on two values, h and l , with $h > l > 0$. The values h and l occur with probabilities p and $(1 - p)$, respectively.

Each worker is endowed with a twice differentiable utility function, $U: \mathfrak{R}_+ \times [0, 1] \rightarrow \mathfrak{R}$, for consumption, c , and hours worked, H , with $\partial U(c, H)/\partial c > 0$, and $\partial U(c, H)/\partial H < 0$. Hours are bounded above by one. I assume that the workers are risk neutral and that $U(c, H) = c - RH$, where $R > 0$. I assume that there are no layoffs and that employment is shared equally among the N employees. $L = NH$ denotes the total labor input to the firm.

The sequence of play in G is as follows. At the start of each period, the realization of θ in the previous period, denoted θ_{-1} , becomes common knowledge. The workforce then goes on strike for some length of time T . T may be greater or less than one. I assume that the time scale for contracts is shifted by a strike, so that production never takes place for less than one period. If T is noninteger I assume that the firm observes a new realization of θ whenever production recommences. If $T = 0$ then the firm makes an offer of a one-period contract. A contract is a pair of functions, $(w(\hat{\theta}), L(\hat{\theta}))$, where w is the wage and L the labor input as a function of the firm's announcement, $\hat{\theta}$, of the state. Labor input is constrained by $L(\hat{\theta}) \leq N$. The workforce then accepts or rejects this offer. If the workforce rejects the offer, it can strike for some length of time T' or quit the firm. The firm then observes θ , announces a value for it, and the contract is implemented on the basis of the announcement. The firm decides whether to replace the workforce, which it can do at a cost of $C > 0$. If the firm replaces the workforce, then no production takes place in that period. The new workforce begins work in the following period. All these

decisions occur at the beginning of the period. If the firm does not replace the workforce and a contract is accepted, production takes place and wages are paid as specified in the contract. The workforce does not observe the contemporaneous value of θ . (When the game is repeated, the current θ becomes observable at the start of the next period.)

For the workforce, the set of actions in G consists of the following: strike for some length of time T , accept contract offer, reject contract offer and quit, or reject contract offer and strike for some length T' . I denote this set of actions \mathcal{A}_w . For the firm, the set of actions, denoted \mathcal{A}_f , consists of the following: the possible contract offers, announcements of the state and the decision whether to replace the workforce. A strategy is a contingent action plan. The strategy of the workforce specifies the strike decision as a function of the observed value of θ_{-1} , and specifies an accept, quit, or strike decision as a function of θ_{-1} and the firm's contract offer. The set of such strategies is denoted S_w . For the firm, a strategy in G specifies a contract offer as a function of the workforce's strike decision and specifies an announced value of θ as a function of the true value of θ and the workforce's decision to strike, quit or accept the contract. Denote the set of strategies of the firm S_f . One play of G according to the strategy profile $s = (s_w, s_f) \in S_w \times S_f$ generates actions $(a_w(s), a_f(s)) \in \mathcal{A}_w \times \mathcal{A}_f$.

The expected utility to the firm of a one-period contract $(w(\hat{\theta}), L(\hat{\theta}))$ is

$$(1) \quad \tilde{V} = pV(hf(L(\hat{\theta}^h)) - w(\hat{\theta}^h)L(\hat{\theta}^h)) + (1-p)V(lf(L(\hat{\theta}^l)) - w(\hat{\theta}^l)L(\hat{\theta}^l)),$$

where $\hat{\theta}^i$ is the firm's announcement of the state when the true state is i . The expected utility to the workforce of this contract is,

$$(2) \quad \tilde{U} = p(w(\hat{\theta}^h) - R)L(\hat{\theta}^h) + (1-p)(w(\hat{\theta}^l) - R)L(\hat{\theta}^l).$$

The utility of this contract to one worker would be $1/N$ th of this quantity.

I assume that each worker always has an outside option which gives him or her utility of $U^m/N > 0$, for one period.

A one-period Pareto-optimal contract between the firm and the workforce maximizes \tilde{V} , subject to the expected utility constraint $\tilde{U} \geq U$, for some U . This contract is characterized by production efficiency and full insurance. Full insurance implies $V'(\pi^h) = V'(\pi^l)$, where π^h and π^l are profits in states h and l , respectively. From this equation, it follows that $\pi^h = \pi^l$. Production efficiency implies $hf'(L(\hat{\theta}^h)) = R = lf'(L(\hat{\theta}^l))$. Let L^{*h} and L^{*l} denote the state contingent efficient levels of labor which solve these last two equations. If the firm offers an efficient contract, it has an incentive to announce l when it observes h . In order to see why this is so, let $(w^h, w^l, L^{*h}, L^{*l})$ be an efficient contract, where w^h and w^l are the wages offered for states h and l , respectively. Then $hf(L^{*h}) - w^h L^{*h} = \pi^h = \pi^l = lf(L^{*l}) - w^l L^{*l} < hf(L^{*l}) - w^l L^{*l}$.

2.2. The Repeated Game. I now define the discounted infinitely repeated game, $G^\infty(\delta)$, consisting of an infinite sequence of repetitions of G . Firms and workers each discount the future by the constant discount factor $\delta \in (0, 1)$. Their intertempo-

ral objective functions in $G^\infty(\delta)$ are the discounted sums of their objective functions in the game G , these being, respectively,

$$(3) \quad v(\delta) = (1 - \delta) \sum_{t=0}^{\infty} \delta^t \tilde{V}_t$$

$$u(\delta) = (1 - \delta) \sum_{t=0}^{\infty} \delta^t \tilde{U}_t$$

where \tilde{V}_t is the expected utility of profits to the firm in period t , and \tilde{U}_t the expected utility of the workforce in t .

The set of one-period histories in $G^\infty(\delta)$ is, $\mathcal{H} = \mathcal{A}_w \times \mathcal{A}_f \times \{h, l\}$, where h and l refer to nature's choice of the true state. The set of t -period histories is $\mathcal{H}^t = \times_{s=0}^{t-1} \mathcal{H}$. A typical element of \mathcal{H}^t is denoted h^t . I restrict attention to pure strategies. Strategies in $G^\infty(\delta)$ for the workforce and the firm are sequences of mappings, $\sigma_w^1, \sigma_w^2, \dots, \sigma_w^t, \dots$ and, $\sigma_f^1, \sigma_f^2, \dots, \sigma_f^t, \dots$, respectively, from the history of the game to the set of strategies in G . Thus, $\sigma_f^t : \mathcal{H}^t \rightarrow S_f$, and $\sigma_w^t : \mathcal{H}^t \rightarrow S_w$, for all t . Define $\sigma_f = \{\sigma_f^t\}_{t=0}^\infty$, and $\sigma_w = \{\sigma_w^t\}_{t=0}^\infty$. Let Σ_w be the set of possible σ_w and Σ_f the set of possible σ_f and let $\Sigma = \Sigma_w \times \Sigma_f$ denote the set of strategy profiles, with $\sigma = (\sigma_w, \sigma_f)$ denoting a typical element of Σ . Let $v(\delta, \sigma)$ and $u(\delta, \sigma)$ be the discounted expected total payoffs to the firm and workforce, respectively, induced by the strategy profile σ .

The analysis focuses on the construction of a subgame-perfect equilibrium, σ^p , which supports a Pareto-optimal contract. The expected payoffs per period of playing σ^p from a particular point in the game onwards are $U^p > U^m$ and π^p to the workforce and firm, respectively.

Firstly, I define an equilibrium, σ^w , which punishes the workforce by giving it an expected discounted total payoff of U^m . Corresponding to this level of expected utility is the level of expected discounted total profits π^m . In this equilibrium, no strike ever occurs and so no Pareto-efficient contract can be enforced. It follows that the contract must give the workforce the same utility in each state. Therefore, the state contingent wages, denoted \underline{w}^h and \underline{w}^l , respectively, are $\underline{w}^h = U^m/L^h + R$ and $\underline{w}^l = U^m/L^l + R$. If the firm maximizes profits subject to these constraints, then the state contingent levels of labor input solve the problems, $\underline{L}^h = \arg \max [hf(L) - U^m - RL]$, and $\underline{L}^l = \arg \max [lf(L) - U^m - RL]$. Hence, $hf'(\underline{L}^h) = R = lf'(\underline{L}^l)$, which implies $\underline{L}^h = \underline{L}^{*h}$, and $\underline{L}^l = \underline{L}^{*l}$, where L^{*h} and L^{*l} are the efficient levels of labor input.

The strategy profile σ^w is constructed as follows. The workforce never strikes, accepts contracts offering it expected utility of at least U^m , and quits if the firm offers a contract with expected utility less than U^m . The firm offers the contract $(\underline{w}^h, \underline{w}^l, L^{*h}, L^{*l})$, in every period, and always announces the state truthfully, irrespective of whether the workforce strikes. It replaces the workforce only if it quits.

I assume that if the firm replaces the workforce at any date t then the equilibrium played by the firm and the new workforce from $t + 1$ on is σ^w . The expected discounted total payoff to the firm from replacing its workforce is $\delta\pi^m - (1 - \delta)C$. Let $\underline{\delta} = C/(\pi^m + C)$.

PROPOSITION 1. For any $\delta \in (\underline{\delta}, 1)$, the strategy profile σ^w is a subgame-perfect equilibrium of $G^z(\delta)$.

PROOF. There is no profitable deviation for the firm. Given the constraint of offering utility U^m to the workforce in each state, the firm maximizes profits by announcing the true realization of θ , and offering efficient employment L^{*h} and L^{*l} at wages \underline{w}^h and \underline{w}^l . If it ever offers a contract with a lower utility level, then the workforce quits and takes its outside option. If the firm replaces its workers, its payoff is $\delta\pi^m - (1 - \delta)C$, which is less than the π^m it gets in σ^w , so that the firm never replaces the workforce unless it quits. Since $\delta > \underline{\delta}$, $\delta\pi^m - (1 - \delta)C > 0$, so that it is profitable for the firm to replace the workforce if it quits. It is not profitable to replace the workforce otherwise, since the payoff from replacement is $\delta\pi^m - (1 - \delta)C$, which is no more than the payoff, π^m , received in the equilibrium.

There is also no advantageous deviation for the workforce. Given σ_f^w , a strike at any date reduces the utility of the workforce below U^m . Quitting at any time gives the workforce a payoff of U^m , which is identical to its payoff in σ^w . The strategy profile σ^w is therefore 'unimprovable' (Abreu 1988) and the strategies of σ^w are perfect best responses to each other. \square

I now construct the equilibrium, σ^p , supporting a Pareto-optimal contract, $(w^{ph}, w^{pl}, L^{*h}, L^{*l})$ (given efficient employment the wage levels are implied by the values (π^p, U^p)). Suppose a strike length T occurs, the number $T = T(\delta)$ is defined by the equation

$$(4) \quad \delta^{T+1}\pi^p = \delta\pi^m - (1 - \delta)C.$$

It would be profitable for the firm to replace its workforce rather than face a strike of length exceeding $T(\delta)$.

ASSUMPTION 1. $\pi^p < \pi^m$.

Let $X = V(hf(L^{*l}) - w^{pl}L^{*l}) - V(hf(L^{*h}) - w^{ph}L^{*h})$.

ASSUMPTION 2. $C > \pi^m X / \pi^p$.

Let $\bar{\delta} = (C - X) / (\pi^m - \pi^p + C - X)$.

ASSUMPTION 3. $U^m \leq \bar{\delta}^{T(\bar{\delta})+2} U^p$.

Assumption 1 stipulates that profits are higher for the firm in σ^w than in σ^p . Assumption 2 is a restriction on the cost of replacing the workforce. If $\delta \leq \underline{\delta}$, replacement of the workforce would give the firm nonpositive expected total utility, which seems improbable. If δ is too close to one, the possibility of replacing the workforce becomes so attractive to the firm that it becomes impossible to enforce the Pareto-optimal contract through the threat of a strike. For these reasons, I restrict attention to δ belonging to the interval $(\underline{\delta}, \bar{\delta})$.

I now describe the equilibrium σ^P . The firm always announces the true value of θ and offers the contract $(w^{Ph}, w^{Pl}, L^{*h}, L^{*l})$, irrespective of whether the workforce strikes. It replaces the workforce only if it quits. The workforce strikes for $T(\delta)$ periods if in the previous period the firm has lied about the true value of θ or currently offers a contract giving expected utility less than U^P . If the firm tells the truth, then the workforce accepts all contracts giving it expected utility at least U^P . The workforce never quits the firm. If the workforce deviates from its strategy, then σ^P coincides with σ^w from that point on.

PROPOSITION 2. *For any $\delta \in (\underline{\delta}, \bar{\delta})$, the strategy profile σ^P is a subgame-perfect equilibrium of $G^z(\delta)$.*

PROOF. By Assumption 2 and equation (4), the following inequality is satisfied for $\delta \in (\underline{\delta}, \bar{\delta})$

$$(5) \quad (1 - \delta) [V(hf(L^{*l}) - w^{Pl}L^{*l}) - V(hf(L^{*h}) - w^{Ph}L^{*h})] \leq (\delta - \delta^{T(\delta)+1})\pi^P.$$

Therefore it is not profitable for the firm to deviate from σ^P by claiming that the state is l when it is in fact h . Offering a contract with expected utility less than U^P is *a fortiori* not profitable. Equation (4) and the restriction to $\delta > \underline{\delta}$ implies that the firm wishes to replace the workforce only if it quits. By Assumption 3 the workforce has an incentive to carry through with its strike, since the assumption implies that, $\delta^{T(\delta)+1}U^P > U^m$, for all $\delta \in (\underline{\delta}, \bar{\delta})$. The workforce never has an incentive to quit because in σ^P it receives total discounted expected utility of $U^P > U^m$. \square

REMARK. The restrictions on the enforceability of the Pareto-optimal contract are very intuitive. As δ rises above $\underline{\delta}$ it becomes more advantageous for the firm to replace its workforce. As δ increases, $T(\delta)$ falls, so that equation (4) holds. As the firm becomes more patient, the value of replacing the workforce rises and the length of the strike needed to reduce the firm to this value decreases. However, if δ becomes too large, then even with $T(\delta) = 0$ the firm will replace since by Assumption 1, $\pi^P < \pi^m$. The critical value of δ where $T(\delta)$ is zero and (4) still holds is $\delta' = C/(\pi^m - \pi^P + C)$. Let $T(\delta)$ satisfy (4) for $\delta \in (\underline{\delta}, \delta')$. It remains to verify that it is not profit maximizing for the firm to lie about the value of θ when faced with the imposition of a strike of length $T(\delta)$. A sufficient condition for (5) to be satisfied at $\delta = \underline{\delta}$ is Assumption 2. However, evaluating (5) at $\delta = \delta'$ and substituting $T(\delta')$ from equation (4) implies $X \leq 0$, a contradiction. Therefore, before $T(\delta)$ falls to zero it becomes profitable for the firm to lie about the realization of θ . Obviously, $T(\delta)$ must be strictly positive to deter cheating. Therefore, there is a $\bar{\delta} < \delta'$ with $T(\bar{\delta})$ such that inequality (5) holds with equality. This condition can be solved for $\bar{\delta}$. Comparing the formulae for $\bar{\delta}$ and δ' establishes that $\bar{\delta} < \delta'$ as required.

Assumption 2 also guarantees that $\underline{\delta} < \bar{\delta}$ and so a nontrivial $T(\delta)$ exists that supports the Pareto-optimal contract.

Notice that if conditions (4) and (5) are satisfied then it is also not profitable for the firm to lie and then replace the workforce in the next period.

Finally, Assumption 3 guarantees that the workforce is prepared to strike for $T(\delta)$ periods rather than have to switch to the equilibrium σ^w . The assumption requires that U^p be sufficiently high relative to U^m . It is in this sense that the workforce needs to have an adequate surplus in σ^p .

REMARK. The equilibrium path of σ^p features production efficiency, full insurance and no strikes. Since the punishment strategies for the firm and workforce both push the respective parties to their reservation utility levels, σ^p supports a first-best contract for the largest possible range of discount factors. This establishes that σ^p is the optimal equilibrium of $G^\infty(\delta)$ for the firm and workforce to play. This result is closely related to those of Abreu (1988). However his formulation is not convenient in the present model since an outcome path would be a function of the realizations of θ , and the structure of the punishment path for the firm does not fit easily within his framework.

3. IMPERFECT MONITORING

In this section, I assume that the workforce receives only imperfect observations of the state. By assuming that the workforce adopts a trigger strategy and strikes when it suspects the firm of lying I show that the firm can be induced to truthfully reveal the state. However, in contrast to Section 2, the contract offered by the firm is distorted by the fact that strikes occur in equilibrium. I characterize the constrained efficient contract for the firm and workforce to use, and prove that it can be supported as an equilibrium of the supergame.

I now describe the stage game with imperfect monitoring, denoted G_I . In G_I the preferences and technology are identical to those in G . The introduction of imperfect monitoring means that instead of θ_{-1} becoming observable at the start of a period a noisy signal of it, denoted s , becomes observable. I assume that the signal has a thrice differentiable conditional probability distribution $M(s | \theta)$ with concave density $m(s | \theta)$ on the unit interval support $[0, 1]$.

The sequence of play in G_I is identical to that of G except that at the start of each period the previous signal realization, s_{-1} , becomes common knowledge. The action sets of the workforce and firm, denoted \mathcal{W} and \mathcal{F} , respectively, are identical to those in G . Strategies of the workforce and firm must now be conditioned on the value of s_{-1} rather than directly on the realization of θ_{-1} . In G_I I denote the strategy sets of the workforce and firm, respectively, as S_{Iw} and S_{If} .

As part of their strategy the workforce must decide when to strike as a function of s_{-1} . I assume that the workforce uses a statistical tail test. The firm has an incentive to announce l when in fact $\theta = h$. Hence if the firm announces l , high signal realizations would tend to suggest that the firm has lied. Assumption 4 provides a sufficient condition under which this intuition is correct and under which a tail test is the optimal statistical criterion for the workforce to adopt (essentially as a corollary of the Neyman-Pearson Lemma (Abreu et al. 1987)). This implies the existence of a critical signal, denoted s^* , such that if $s_{-1} > s^*$ then punishment is triggered.

ASSUMPTION 4. (*Monotone Likelihood Ratio Property*) $m(s|h)/m(s|l)$ is increasing in s on $[0, 1]$

ASSUMPTION 5. The set $\{s \in [0, 1] | m(s|\theta) > 0\}$ is independent of all $(a_w, a_f) \in \mathcal{A}_w \times \mathcal{A}_f$.

Assumption 5 rules out the possibility that some signal realizations will allow the workforce to infer the true state with probability one and thus implement the first-best with a ‘forcing contract.’

The value of the signal is not directly payoff relevant so that the expected utilities of a one-period contract to the firm and workforce, respectively, are given by expressions (1) and (2). The first-best, one-period Pareto-optimal contract between the firm and workforce therefore has an identical form to that of Section II.

The discounted infinitely repeated game with imperfect monitoring, denoted $G^\infty(\delta)_I$, consists of an infinite sequence of repetitions of G_I . The intertemporal objective functions are given by the formulas in (3).

There is now enduring private information in the repeated game and it becomes important to distinguish between private and public histories. The set of one-period public histories in $G^\infty(\delta)_I$ is $\mathcal{H}_p = \mathcal{A}_w \times \mathcal{A}_f \times [0, 1]$, consisting of the actions of the workforce and firm and the signal realization. The set of t -period public histories is $\mathcal{H}_p^t = \times_{s=1}^{t-1} \mathcal{H}_p$, with a typical element being denoted h_p^t . There is also a private history for the firm since the true value of θ is never observed by the workforce. I denote a t -period private history by $\mathcal{P}^t = \{h, l\}^{t-1}$, the $(t - 1)$ -fold Cartesian product of $\{h, l\}$.

Strategies in $G^\infty(\delta)_I$ are sequences of mappings from the history of the game into strategies in G_I . For the workforce the representative element of the sequence is denoted $\sigma_{Iw}^t : \mathcal{H}_p^t \rightarrow S_{Iw}$, and for the firm a representative member is $\sigma_{If}^t : \mathcal{H}_p^t \times \mathcal{P}^t \rightarrow S_{If}$. I define $\sigma_I = (\sigma_{Iw}, \sigma_{If})$ in the natural way.

In order to maintain the recursiveness of the game I restrict attention to pure strategy *perfect public equilibria*. A strategy in $G^\infty(\delta)_I$ is a public strategy if the actions it induces at any point in the game are functions only of the history of public outcomes.

DEFINITION. A strategy profile σ_I is a perfect public equilibrium if (i) each σ_I^i is a public strategy, and (ii) for each date t and public history h_p^t the strategies yield a Nash equilibrium from that point in the game on.

With this restriction I can use a recursive formulation to compute the constrained efficient equilibrium of the supergame (see Fudenberg et al., 1994).

The object of the analysis is to examine the most efficient way of utilizing strikes to support a Pareto-efficient contract. Given the analysis under perfect monitoring, one might imagine that during a production period the first-best contract corresponding to some level of expected utility for the workforce would be offered by the firm. Though in equilibrium the firm will always tell the truth, occasional large realizations of the noise will trigger a strike. In this case some optimal strike length is determined and after this the firm and workforce return to the first-best contract. However, the fact that strikes now occur in equilibrium turns out to falsify this

intuition. To ameliorate the inefficiency caused by striking, the contract which is offered in the constrained efficient equilibrium is distorted. Consider the following argument. Since the firm tells the truth in equilibrium strikes are only triggered when $\theta = l$. When $\theta = h$ the firm announces h , and it is never profitable to do so unless the true state is h . This suggests that employment will be efficient when $\theta = h$. If employment is efficient in l a small reduction in labor input has only a second-order direct effect on welfare, but has a first-order effect on the incentive to deviate. This suggests that reducing employment when $\theta = l$ may reduce the profitability of deviations in such a way that incentives may be provided by a shorter strike length and this may raise total welfare. A similar argument applies to movements away from full insurance. This intuition turns out to be correct, and the constrained efficient contract offered by the firm exhibits inefficient employment in the low state and incomplete insurance.

To formulate the contracting problem I now develop the incentive constraint for the firm. The workforce uses a trigger strategy, so that if the firm announced $\theta = l$ and $s > s^*$ then a strike is triggered, but if $s \leq s^*$ then production commences. If the true value of θ is l then $\text{prob}\{s > s^*\} = 1 - M(s^* | l)$, and $\text{prob}\{s \leq s^*\} = M(s^* | l)$. Denote the expected present discounted total value of playing an equilibrium to the firm and workforce, respectively, by W^f and W^w . Using the fact that the firm tells the truth in equilibrium, these values satisfy the following recursive relationships

$$(6) \quad W^f = (1 - \delta) [pV(hf(L^h) - w^h L^h) + (1 - p)V(lf(L^l) - w^l L^l)] + p\delta W^f \\ + (1 - p) [(1 - M(s^* | l))\delta^{T+1}W^f + M(s^* | l)\delta W^f],$$

$$(7) \quad W^w = (1 - \delta) [p(w^h - R)L^h + (1 - p)(w^l - R)L^l] + p\delta W^w \\ + (1 - p) [(1 - M(s^* | l))\delta^{T+1}W^w + M(s^* | l)\delta W^w].$$

Solving these expressions for W^f and W^w and using the notation $\pi = [pV(hf(L^h) - w^h L^h) + (1 - p)V(lf(L^l) - w^l L^l)]$ and $U = p(w^h - R)L^h + (1 - p)(w^l - R)L^l$, where w^h, w^l, L^h, L^l denote the wages and labor inputs offered by the firm in some contract as functions of the state of nature, gives

$$(8) \quad W^f = (1 - \delta)\pi Z^{-1}$$

$$(9) \quad W^w = (1 - \delta)UZ^{-1},$$

where,

$$Z = [1 - p\delta - (1 - p)\delta^{T+1} - (1 - p)(\delta - \delta^{T+1})M(s^* | l)].$$

Misrepresenting the state of nature will not raise the expected total utility for the firm if,

$$(10) \quad (1 - \delta) [pV(hf(L^h) - w^h L^h) + (1 - p)V(lf(L^l) - w^l L^l)] + p\delta W^f \\ + (1 - p) [(1 - M(s^* | l))\delta^{T+1}W^f + M(s^* | l)\delta W^f]$$

$$\begin{aligned} &\geq (1 - \delta) [pV(hf(L^l) - w^l L^l) + (1 - p)V(lf(L^l) - w^l L^l)] \\ &\quad + p[(1 - M(s^* | h)) \delta^{T+1} W^f + M(s^* | h) \delta W^f] \\ &\quad + (1 - p)[(1 - M(s^* | l)) \delta^{T+1} W^f + M(s^* | l) \delta W^f]. \end{aligned}$$

This expression can be simplified to,

$$(11) \quad \begin{aligned} &(1 - \delta) [V(hf(L^l) - w^l L^l) - V(hf(L^h) - w^h L^h)] \\ &\leq (1 - M(s^* | h)) (\delta - \delta^{T+1}) W^f. \end{aligned}$$

Inequality (11) states that the gains from deviating must be no more than the expected discounted loss from the punishment that such a deviation induces.

The contracting problem is now to choose simultaneously w^h, w^l, L^h, L^l along with the optimal strike length T , and the trigger signal s^* . These are found by solving the following program.

$$(12) \quad \max_{w^h, w^l, L^h, L^l, T, s^*} \alpha W^f + (1 - \alpha) W^w$$

subject to (11). Where $\alpha \in (0, 1)$ is a welfare weight.

A further constraint on the problem is the maximum feasible strike length, which is determined by the ability of the firm to replace the workforce. Let $T_{\max}(\delta)$ be determined by the following equation

$$(13) \quad \delta^{T+1} W^f = \delta \pi^m - (1 - \delta) C.$$

Any strike larger than $T_{\max}(\delta)$ will induce the firm to replace the workforce. The solution to (12) has two cases. In the first the optimal T is set as large as possible and determined by equation (13), and given this T , s^* is chosen optimally along with wages and labor input to satisfy incentive compatibility. In the second case T has an interior solution and s^* is fixed by an equation derived from the first-order conditions of (12) (equation (15) below).

Consider inequality (11) for fixed w^h, w^l, L^h, L^l , and use D to denote the expression,

$$\frac{V(hf(L^l) - w^l L^l) - V(hf(L^h) - w^h L^h)}{pV(hf(L^h) - w^h L^h) + (1 - p)V(lf(L^l) - w^l L^l)}.$$

D is the normalized gain from deviation. Inequality (11) can now be written,

$$(14) \quad (1 - M(s^* | h)) (\delta - \delta^{T+1}) Z^{-1} \geq D,$$

which is just a function of T and s^* . With wages and labor input fixed either s^* or T can be adjusted to ensure that inequality (14) holds.

Forming a Lagrangean in (12) and taking the ratio of the first-order conditions with respect to T and s^* yields the expression,

$$(15) \quad \frac{m(s^* | h)}{m(s^* | l)} = \frac{1 - M(s^* | h)}{1 - M(s^* | l)}$$

That an s^* exists which satisfies this equation is established by the following result, whose proof is relegated to the Appendix.

LEMMA. *There exists an $s^* \in (0, 1)$ which solves equation (15).*

PROPOSITION 3. *In any solution to Program (12) either $T = T_{\max}(\delta)$ and s^* satisfies (14) as an equality, or s^* is determined by equation (15) and T is chosen to satisfy (14) as an equality.*

PROOF. Notice that (15) is independent of all the endogenous variables except s^* . In case 1 the solution to (12) has T determined by (13) and s^* determined by (14) to satisfy incentive compatibility. This implies $m(s^* | h)/m(s^* | l) \neq (1 - M(s^* | h))/(1 - M(s^* | l))$. In case 2 the solution to (12) has s^* determined by (15) and, given this s^* , T determined by (14). \square

I now consider the structure of the second-best contract. Consider the constraint for fixed D . Take case 2 with s^* fixed by (15) and T chosen so that (14) is an equality. A Lagrangean can be formed with the objective function in (12) and this constraint. Setting the gradient to zero provides a set of necessary conditions that the optimizing choices must satisfy, and which define the implicit functions $w^h(T)$, $w^l(T)$, $L^h(T)$, $L^l(T)$. Substitution of these into the objective function defines a maximized value of (12) for fixed T . In case 2 the strike length is then chosen optimally by maximizing this with respect to T . I denote this strike length $T_T(\delta)$. This calculation determines the optimal trade-off between the strike length, employment distortions, and incomplete insurance, while guaranteeing incentive compatibility. If case 1 is appropriate, then the argument is identical except that the second stage optimization is over the critical trigger signal.

PROPOSITION 4. *The solution to (12) is characterized by efficient production when $\theta = h$, inefficiently low labor input when $\theta = l$, and incomplete insurance.*

PROOF. The Lagrangean function is, $\mathcal{L} = [\alpha\pi + (1 - \alpha)U]Z^{-1} + \lambda[(1 - M(s^* | h))(\delta - \delta^{T+1})Z^{-1} - D]$, where λ is a Lagrange multiplier. The gradient with respect to w^h, w^l, L^h, L^l respectively is,

$$(16) \quad \begin{aligned} & [-\alpha pV'(\pi^h) + (1 - \alpha)p]Z^{-1} + \lambda V'(\pi^h) \\ & - \lambda(1 - M(s^* | h))(\delta - \delta^{T+1})Z^{-1}pV'(\pi^h) = 0 \end{aligned}$$

$$(17) \quad \begin{aligned} & [-\alpha(1 - p)V'(\pi^l) + (1 - \alpha)(1 - p)]Z^{-1} + \lambda V'(hf(L^l) - w^lL^l) \\ & - \lambda(1 - M(s^* | h))(\delta - \delta^{T+1})Z^{-1}(1 - p)V'(\pi^l) = 0 \end{aligned}$$

$$(18) \quad V'(\pi^h)(hf'(L^h) - w^h) [\alpha p - \lambda Z + \lambda(1 - M(s^* | h))(\delta - \delta^{T+1})p] \\ + (1 - \alpha)p(w^h - R) = 0$$

$$(19) \quad V'(\pi^l)(lf'(L^l) - w^l) [\alpha(1 - p) + \lambda(1 - M(s^* | h))(\delta - \delta^{T+1})(1 - p)] \\ - \lambda Z V'(hf(L^l) - w^l L^l)(hf'(L^l) - w^l) + (1 - \alpha)(1 - p)(w^l - R) = 0.$$

Substituting (16) into (18) yields $hf'(L^h) = R$, so that production is efficient if $\theta = h$. Substituting (17) into (19) yields,

$$(1 - \alpha)(1 - p)(lf'(L^l) - R) = \lambda Z V'(hf(L^l) - w^l L^l)([h - l]f'(L^l))$$

Since $[h - l]f'(L^l) > 0$ this equation implies $lf'(L^l) > R$, and hence production and labor input are inefficiently low when $\theta = l$. Finally using (16) and (17) one derives the modified insurance condition,

$$\frac{V'(\pi^l)}{V'(\pi^h)} = 1 + \frac{\lambda Z}{p(1 - p)(1 - \alpha)} [pV'(hf(L^l) - w^l L^l) - (1 - p)V'(\pi^l)]$$

so that the marginal utilities of the firm are not constant across states of nature. \square

Denote the wages and labor inputs that solve (12) in case 2 with $T = T_I(\delta)$ for some welfare weight α by, $w_I^h, w_I^l, L_I^h, L_I^l$.

To clarify the nature of the trade-off between the strike length, the trigger signal s^* (and implicitly the probability of inducing punishment), and employment and insurance, I now consider a simpler program than (12). Take case 2 where s^* is fixed by (15) and T satisfies (14). Now $D = X/\pi$. With T fixed so that (14) holds with equality X/π equals a constant. Consider the weighted welfare of the firm and workforce today as a function of D ignoring the future,

$$(20) \quad \max_{w^h, w^l, L^h, L^l} \alpha \pi + (1 - \alpha)U$$

subject to $X/D = \pi$.

The constraint defines a one-to-one relationship between D and T . As D increases the gains to deviating increase and T must rise in order to maintain incentive compatibility. The left-hand-side of (14) is increasing in T . Since the objective function in (20) ignores the future cost of strikes, varying D (and implicitly T) allows me to consider the current trade-off between employment, wages, and the strike length while ensuring that the contract is enforceable. Intuitively, welfare must be increasing in T since L^l and insurance can be increased while at the same time providing sufficient incentives to enforce the contract. Denote the maximized value of (20) as a function of D , $G(D)$.

PROPOSITION 5. $G'(D) > 0$

PROOF. Consider the Lagrangean for problem (20). $\mathcal{L} = \alpha \pi + (1 - \alpha)U + \gamma[D - X/\pi]$, where γ is the Lagrange multiplier. The gradient of this optimization problem defines the implicit functions $w^h(D), w^l(D), L^h(D), L^l(D)$, and $G(D) = \alpha \pi(D) + (1 - \alpha)U(D) + \gamma[D - X(D)/\pi(D)]$. By the envelope theorem, $G'(D) = \gamma > 0$. \square

I now describe a perfect public equilibrium, denoted σ_I^p , that supports the constrained efficient contract. Corresponding to σ_I^p and welfare weight α are the expected payoffs per production period of π_I^p and U_I^p to the firm and workforce, respectively. These payoffs correspond to the vector of wages and labor inputs $(w_I^h, w_I^l, L_I^h, L_I^l)$. The specification depends on whether case 1 or 2 is applicable. I assume that case 2 is appropriate so that $T = T_I(\delta)$ and s^* is determined by equation (15). The extension of the analysis to case 1 is immediate.

ASSUMPTION 6. $(1 - \delta)\pi_I^p Z^{-1} < \pi^m$, and $(1 - \delta)U_I^p Z^{-1} > U^m$

Let $\pi_I^p(T = 0)$ denote the expected utility of profits to the firm when the strike length is zero in the solution to (12), and define, $\delta^* = C / (\pi^m - \pi_I^p(T = 0) + C)$

ASSUMPTION 7. $(\delta^*)^{T(\delta^*)+2}(1 - \delta)U_I^p Z^{-1} \geq U^m$

$T_I(\delta)$ is calculated in such a way that the incentive compatibility constraint is satisfied. Even if $T_I(\delta) = 0$ equation (14) still holds since then $X = 0$. Intuitively, wages and employment are distorted so that there are no deviation profits and we have the static Grossman-Hart solution. As in Section II, I restrict attention to $\delta > \underline{\delta}$ so that the firm wishes to replace the workforce if it quits. If δ is very high then (13) cannot hold. Consider (13) with $T = 0$. Then π_I^p is determined by incentive compatibility and the welfare weight α (again, this is basically the Grossman-Hart solution). I can solve this condition for the largest possible δ for which the contract is enforceable. This is δ^* . The analysis is predicated on C being fixed. If C is very small then the maximum feasible strike length will be short and this makes it more likely that case 1 will apply.

In the equilibrium σ_I^p the firm always announces the true value of θ and offers the contract $(w_I^h, w_I^l, L_I^h, L_I^l)$ irrespective of whether the workforce strikes. It replaces the workforce only if it quits. The workforce strikes for $T_I(\delta)$ periods if $s^{-1} > s^*$ and strikes for $T_{\max}(\delta)$ periods if the firm currently offers a contract offering expected utility less than U_I^p . If it observes $s^{-1} \leq s^*$ then the workforce accepts all contracts giving it expected utility of at least U_I^p . The workforce never quits the firm. If the workforce deviates from its strategy, then σ_I^p coincides with σ^w from that point on.

PROPOSITION 6. For any $\delta \in (\underline{\delta}, \delta^*)$, the strategy profile σ_I^p is a perfect public equilibrium of $G^z(\delta)_I$.

PROOF. By construction it is not profitable for the firm to misrepresent the value of the state when faced with the possibility of a $T_I(\delta)$ period strike. Offering a contract with expected utility of less than U_I^p is also not profitable. Since $\delta > \underline{\delta}$ and (13) is satisfied the firm only wishes to replace the workforce if the workforce quits. Assumption 7 implies that the workforce will carry out a strike of $T_I(\delta)$ or $T_{\max}(\delta)$ periods, and Assumption 6 guarantees that it never has an incentive to quit. \square

4. DISCUSSION OF THE RESULTS

With the objective functions given in (3) the equilibrium of Proposition 2 implements the first-best, long-term contract in one simple case. Define the interest rate in the economy to be ρ . I assume that the economy as a whole is in a stationary equilibrium and this justifies the assumption that $\delta = 1/(1 + \rho)$. The contract is characterized by the program, maximize $v(\delta)$ subject to $u(\delta) \geq U^p$. It features a constant level of profits both across time and states of nature. This implies that neither agent would wish to enter the capital market even under full information. This justifies an implicit assumption in my analysis which is that neither the firm nor the workforce has access to capital markets. In line with the results of Allen (1985), Malcolmson and Spinnewyn (1988), and Fudenberg et al. (1990), if the firm has perfect access to the capital market it could self-insure and the incentive problem would vanish. In some sense capital market imperfections are a sine qua non of an interesting problem in the present model. The assumption is restrictive because it does not allow the firm to borrow during, or save for, a strike. Relaxing this still implies that strikes would be costly in terms of the present discounted stream of profits, but less so in utility terms since the firm could smooth consumption.

The Coase property does not hold in the present model as long as one associates credibility with subgame perfection. Hart (1989) discusses how this affects the equilibria of the screening model of strikes. There is, however, another renegotiation issue which concerns the credibility of supergame equilibria that use inefficient continuation payoffs, see Pearce (1987), Farrell and Maskin (1989), and Bernheim and Ray (1989).

In the equilibrium of Proposition 6 the level of labor input L_l^l is higher, and the difference between $V'(\pi^h)$ and $V'(\pi^l)$ lower than in the standard characterization of incentive compatibility. The presence of an extra instrument in the form of a strike can never reduce the welfare of the contractants, since a possible solution to (12) involves setting $T = 0$ and equating the wage and employment levels to those which solve a standard static problem as in Grossman and Hart.

Intuitively, the type of mechanism that one might wish to adopt depends on the informativeness of the ex post information. If the subsequent information received by the workforce is perfect, then as I have shown, the first-best contract is implementable (subject to discounting). As the signal becomes more garbled the probability of striking inappropriately, and therefore the welfare loss, increases. At some stage it will be optimal to switch to some mechanism which elicits the information of the firm contemporaneously, such as a Grossman and Hart employment-insurance distortion, or a Hayes-type screening strike, rather than trust the firm and wait for ex post information. The results of Mirrlees (1974) suggest that the improvement in the precision of the information need not necessarily be uniform on the signal space.

While this paper focuses on imperfections of information to generate strikes in equilibrium it has been pointed out by Haller and Holden (1990) and Fernandez and Glazer (1991) that the implicit assumption that there cannot be inefficient (from the first-best perspective) strikes or delays with complete information, is incorrect. This intuition, which stems from the seminal work of Rubinstein (1982), is not robust to

changes in the structure of the extensive form of the game. Both papers show that alterations in the symmetry of the move structure allow for multiple equilibria and therefore equilibrium strikes supported by 'repeated game like' punishment strategies. Note also that dropping the restriction to Nash equilibrium can also generate strikes. Strikes (or more generally bargaining delays) are rationalizable (in the sense of Bernheim 1984 and Pearce 1984) even with complete information.

The strategies considered in this paper imply that the full methodology of Abreu et al. (1986, 1990) is inappropriate. To see the connection between my results and theirs, consider respecifying the rules of the game in such a way that the restrictions on strategies become restrictions on the structure of the game. Given this approach their main theorem says that efficient punishments use only extremal points of the equilibrium value set. In my case the risk aversion of the firm implies that a strike of any length generates an extremal value. Proposition 6 picks out the best one for the firm and workers. To place the restrictions on the rules of the game is very unnatural, however.

The optimal strike is not necessarily the longest feasible. In the model of Porter (1983), Abreu et al. (1986, 1990) demonstrate that the optimal punishment is to punish for as long as possible. Intuitively, the welfare loss is the product of the probability of triggering a punishment inappropriately and the severity of the punishment. Think of moving along a contour trading off the trigger probability against the punishment severity, such that the incentive compatibility constraint binds. Provided that the likelihood ratio is increasing, the welfare loss is monotonically decreasing as the severity is increased and the trigger probability reduced. Hence the optimization problem studied by Porter has a corner solution. In the present model the welfare optimization has an interior solution because the contracting problem is of a fundamentally different nature than the cartel maintenance one. In particular, there is not a linear relationship between the punishment severity and the losses in a production phase from distorting the contract due to the curvature of both technology and preferences. The equilibrium value set in the present model is a considerably more complex object than that of Porter's model.

5. CONCLUSION

In this paper I have developed a theory of strikes as an implicit enforcement mechanism in a repeated contractual relationship. I argued that a dynamic perspective seems essential, and the present model seems a natural way to proceed. It is not proposed, however, as a holistic theory of strikes, but rather as an attempt to formalize an important aspect of industrial disputes which has so far been missing from the literature. In particular, the addition of a state variable (such as market share) would be necessary to make a closer connection to the empirical literature. The approach I take does have important implications. For example, it implies that the optimal amount of strike activity is positive. No strikes could imply that workers did not get enough surplus from the contract to credibly mount strikes, and in this case incentive-compatible contracts imply employment distortions in equilibrium which may entail more inefficiency than strikes.

A major drawback is that constrained optimality was only established with respect to a severely restricted set of strategies. In particular, if one allows the workforce to punish using rent sharing, then it is not clear why strikes would ever be observed in equilibrium. Instead, if the signal indicated that the firm had been lying, then it could pay the workforce a punitively high wage. Such an equilibrium clearly represents a Pareto improvement over the equilibria in the present model. Firstly it does not ‘throw away surplus’ during the punishment phase, and secondly it punishes in a way that allows for increased insurance while still maintaining incentives.

The results of Fudenberg et al. (1994) imply that if δ is sufficiently large, the full information first-best can be obtained as an equilibrium of the repeated game with imperfect monitoring when punishment takes place through rent sharing. Nevertheless, such an equilibrium seems implausible for a number of reasons. In practice such variation is not observed (Kennan 1986). Rent sharing is bilateral and subject to ratchet effects and irreversibilities as well as more serious renegotiation problems that undermine its credibility. Striking is a unilateral sanction. If we consider a case where the signal of the firm’s profitability is not public information but rather private information to the workforce, then equilibria emerge where punishment occurs both through striking and rent sharing. The workforce strikes for long enough to credibly signal what it observed, and then the firm accedes to higher wages.

6. APPENDIX

PROOF OF LEMMA. When $s^* = 0$ the left-hand side of (15) is less than one by Assumption 4 and the right-hand side is greater than one. By L’Hôpital’s rule both sides are equal at $s^* = 1$. The left-hand side is monotone increasing. The slope of the right-hand side evaluated at $1 - \epsilon$ is,

$$(21) \quad \frac{(1 - M(1 - \epsilon|h))m(1 - \epsilon|l) - (1 - M(1 - \epsilon|l))m(1 - \epsilon|h)}{(1 - M(1 - \epsilon|l))^2}$$

Taking a Taylor series expansion of (21) around $s^* = 1$ yields,

$$(22) \quad \frac{m'(1|h)m(1|l) - m(1|h)m'(1|l)}{m(1|l)^2}.$$

Now take a Taylor series expansion of the derivative of the left-hand side around $s^* = 1$, and ignore terms in ϵ^2 . This yields,

$$(23) \quad \frac{m'(1|h)m(1|l) - m(1|h)m'(1|l) + m(1|h)m''(1|l)\epsilon - m(1|l)m''(1|h)\epsilon}{m(1|l)^2 - 2m'(1|l)\epsilon}$$

For there to be an s^* which solves (15), equation (22) must be larger than (23) just away from one. Taking the limit as ϵ goes to zero in (23) gives (22), verifying

L'Hôpital's rule. Subtracting (22) from (23) gives,

$$(24) \quad \frac{\epsilon \left[2m'(1|l)m'(1|h)m(1|l) - 2m'(1|l)^2m(1|h) \right]}{m(1|l)^2 \left[m(1|l)^2 - 2m'(1|l)\epsilon \right]} + \frac{\epsilon \left[m(1|h)m''(1|l)m(1|l)^2 - m(1|l)^3m''(1|h) \right]}{m(1|l)^2 \left[m(1|l)^2 - 2m'(1|l)\epsilon \right]}$$

Assumption 4 implies that $m'(s^*|l) < 0$, and $m'(s^*|h) > 0$ for all $s^* \in [0, 1]$, so that the denominator in (24) is positive. The numerator is negative since $m''(s|\theta) \leq 0$ by the concavity of $m(s|\theta)$. Hence (24) is less than zero and (22) is greater than (23) as required. This establishes the existence of an s^* that solves (15), although it is not necessarily unique.

REFERENCES

- ABREU, D., "On the Theory of Infinitely Repeated Games with Discounting," *Econometrica* 56 (1988), 383-396.
- , D.G. PEARCE, AND E. STACCHETTI, "Optimal Cartel Equilibrium with Imperfect Monitoring," *Journal of Economic Theory* 39 (1986), 251-269.
- , ———, AND ———, "Toward a Theory of Discounted Repeated Games with Imperfect Monitoring," Cowles Foundation Discussion Paper No. 791, Revised September 1987.
- , ———, AND ———, "Toward a Theory of Discounted Repeated Games with Imperfect Monitoring," *Econometrica* 58 (1990), 1041-1063.
- ALLEN, F., "Repeated Principal-Agent Relationships with Lending and Borrowing," *Economic Letters* 17 (1985), 27-31.
- AZARIADIS, C., "Implicit Contracts and Underemployment Equilibria," *Journal of Political Economy* 83 (1975), 1183-1202.
- BAILY, M.N., "Wages and Employment under Uncertain Demand," *Review of Economic Studies* 41 (1974), 37-50.
- BERNHEIM, B.D., "Rationalizable Strategic Behavior," *Econometrica* 52 (1984), 1007-1028.
- , AND D. RAY, "Collective Dynamic Consistency in Repeated Games," *Games and Economic Behavior* 1 (1989), 295-326.
- BEWLEY, T.F., "Why Don't Wages Fall During Recessions?" Harvard University Press, forthcoming.
- CARD, D., "Strikes and Wages: A Test of an Asymmetric Information Model," *Quarterly Journal of Economics* 105 (1990), 625-659.
- CHARI, V.V., "Involuntary Unemployment and Implicit Contracts," *Quarterly Journal of Economics* 98 (1983), 107-122.
- CRAMTON, P.C. AND J.S. TRACY, "Strikes and Holdouts in Wage Bargaining: Theory and Data," *American Economic Review* 82 (1992), 100-121.
- DEWATRIPONT, M., "Renegotiation and Information Revelation Over Time: The case of Optimal Labor Contracts," *Quarterly Journal of Economics* 104 (1989), 589-620.
- FARRELL, J. AND E. MASKIN, "Renegotiation in Repeated Games," *Games and Economic Behavior* 1 (1989), 327-360.
- FERNANDEZ, R. AND J. GLAZER, "Striking for a Bargain Between Two Completely Informed Agents," *American Economic Review* 81 (1991), 240-252.
- FUDENBERG, D., B. HOLMSTROM, AND P. MILGROM, "Short-Term Contracts and Long-Term Agency Relationships," *Journal of Economic Theory* 51 (1990), 1-31.
- AND E. MASKIN, "The Folk Theorem for Repeated Games with Discounting or with Incomplete Information," *Econometrica* 54 (1986), 533-554.

- , D.K. LEVINE, AND E. MASKIN, "The Folk Theorem with Imperfect Public Information," *Econometrica* 62 (1991), 997–1040.
- GORDON, D.F., "A Neo-Classical Theory of Keynesian Unemployment," *Economic Inquiry* 12 (1974), 431–459.
- GREEN, E.J. AND R.M. PORTER, "Noncooperative Collusion under Imperfect Price Information," *Econometrica* 52 (1984), 87–100.
- GREEN, J.R. AND C.M. KAHN, "Wage-Employment Contracts," *Quarterly Journal of Economics* 98 (1983), 173–188.
- GROSSMAN, S.J. AND O.D. HART, "Implicit Contracts, Moral Hazard, and Unemployment," *American Economic Review* 71 (1981), 301–307.
- AND ———, "Implicit Contracts under Asymmetric Information," *Quarterly Journal of Economics* 98 (1983), 123–156.
- HALLER, H. AND S. HOLDEN, "A Letter to the Editor on Wage Bargaining," *Journal of Economic Theory* 52 (1990), 232–236.
- HART, O.D., "Optimal Labour Contracts under Asymmetric Information: An Introduction," *Review of Economic Studies* 50 (1983), 3–36.
- , "Bargaining and Strikes," *Quarterly Journal of Economics* 104 (1989), 25–44.
- HAYES, B., "Unions and Strikes with Asymmetric Information," *Journal of Labor Economics* 1 (1984), 57–83.
- HORN, H. AND L.E.O. SVENSSON, "Trade Unions and Optimal Labour Contracts," *Economic Journal* 96 (1986), 323–341.
- KENNAN, J., "The Economics of Strikes," in O. Ashenfelter and R. Layard, eds., *Handbook of Labor Economics* (Amsterdam: North-Holland, 1986).
- AND R. WILSON, "Bargaining with Private Information," *Journal of Economic Literature* 31 (1993), 45–104.
- LAFFONT, J-J. AND J. TIROLE, "The Dynamics of Incentive Contracts," *Econometrica* 56 (1988), 1153–1176.
- MALCOLMSON, J.M., "Trade Unions and Economic Efficiency," *Economic Journal* 93 (1983), 50–64.
- MALCOLMSON, J.M. AND F. SPINNEWYN, "The Multiperiod Principal-Agent Problem," *Review of Economic Studies* 55 (1988), 391–407.
- MIRRELES, J., "Notes on Welfare Economics, Information and Uncertainty," in M. Balch, D. McFadden, and S. Wu, eds., *Essays in Economic Behavior Under Uncertainty* (Amsterdam: North-Holland, 1974).
- NEWBERRY, D.M.G. AND J.E. STIGLITZ, "Wage Rigidity, Implicit Contracts, Unemployment and Economic Efficiency," *Economic Journal* 97 (1987), 416–430.
- PEARCE, D.G., "Rationalizable Strategic Behavior and the Problem of Perfection," *Econometrica*, 52 (1984), 1029–1050.
- , "Renegotiation-Proof Equilibria: Collective Rationality and Intertemporal Cooperation," Cowles Foundation Discussion Paper No. 855, Yale University, 1987.
- PORTER, R.M., "Optimal Cartel Trigger-Price Strategies," *Journal of Economic Theory* 29 (1983), 313–338.
- REDER, M.W., "Unionism, Wages, and Contract Enforcement," in J.D. Reid Jr., ed., *New Approaches to Labor Unions* (London: JAI Press, 1983).
- ROGERSON, W.P., "Repeated Moral Hazard," *Econometrica* 53 (1985), 69–76.
- RUBINSTEIN, A., "Perfect Equilibria in a Bargaining Model," *Econometrica* 50 (1982), 97–110.
- SABOURIAN, H., "Wage Norms and Involuntary Unemployment," *Economic Journal* 98 (1988), 177–188.
- WEIBULL, J.W., "Persistent Unemployment in Subgame Perfect Equilibrium," Institute for International Economics, Stockholm, Seminar Paper No. 381, 1987.
- WILLIAMSON, O., *The Economic Institutions of Capitalism* (New York: Free Press, 1985).