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THE STRATEGIC ASPECTS OF PROFIT SHARING IN [illegible] INDUSTRY

by

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Abstract

A three-stage partial equilibrium oligopoly model is studied in order to investigate the strategic effects of profit-sharing in an industry. In the first stage, firms propose a profit-sharing contract to their workers. In the second stage, the workers accept or refuse the proposed contract. There is an exogenously given market wage, and the traditional wage system is implemented in the firm if the contract is rejected by its workers. The last stage is a standard Cournot oligopoly. It is shown that perfect equilibria of this game involve profit-sharing on the part of all firms. A single firm always has incentives to adopt a profit-sharing scheme if its competitors pay their workers according to the usual wage system. The structure of the game is that of the 'Prisoner's Dilemma'.

1. Introduction

In the recent years, there has been some debate concerning Martin Weitzman's (1983, 1985, 1987) claim that a 'profit-sharing' or 'share' economy has a better macroeconomic performance than a standard 'wage-economy', especially with respect to employment levels (see for example Nordhaus (1988), Nuti (1987)).

A number of authors have discussed the problem in purely macroeconomic terms. On the other hand, the idea that profit-sharing schemes might constitute a good internal incentive system for the firm has been studied further, but from the point of view of labour economics, organization and management theory. By contrast, we focus here on a much less studied topic: the relationships between profit-sharing and the behaviour of an oligopolistic market. More specifically, profit-sharing will be viewed here as an additional strategic tool in the process of imperfect competition. In what follows, the scope of the analysis is that of the industry. This approach seems to be relevant to the task of providing firm microeconomic foundations for Weitzman's proposals.

In the context of a simple general equilibrium model with imperfect competition and downwardly rigid nominal wages, Weitzman has shown that the introduction of profit-sharing increases aggregate labour demand and thus reduces unemployment. Since new hirings always cause a decline in workers' <u>per capita</u> income under profit-sharing contracts, a shift from the wage system to the 'share' system will be Pareto-improving only if the induced macroeconomic feed-back effects on the level of the firms' demand functions are taken into consideration. Weitzman thus claims that such an improvement will be achieved if a share contract is adopted by a sufficiently large proportion of the firms in the economy.

These ideas have been attacked using partial equilibrium microeconomic reasoning. Since workers would resist a decline of their income levels, it has been argued that a monopolistic firm must guarantee a <u>per capita</u> compensation at least as great as the prevailing market wage. In this situation, a monopolist's profits cannot be increased, and the firm has no incentive to propose a profit-sharing contract to its employees.

However, it can be shown that tax incentives can be profitably introduced to encourage profit sharing in Weitzman's macro model (e.g. Zylberberg (1988)), but Wadhwani (1988) argues that they could easily be misused and dissipated, since firms and unions would have an incentive to construct a merely 'cosmetic' scheme.

These negative results and the subsequent discussion on the appropriateness of public intervention have been developed in the framework of a simple model with a single monopolist. In the following, our goal is to discuss these problems in a model which allows for explicit consideration of the strategic interdependence of firms.

In the context of a Cournot oligopoly model, we show that a firm always has an incentive to introduce profit-related pay unilaterally, even if subject to the constraint that workers will reject any contract yielding less than the prevailing market wage at the (Cournot) equilibrium. Furthermore, the adoption of a profit-sharing scheme by each firm in the industry constitutes a non-cooperative equilibrium.

These results have strong implications. They clearly say that public intervention is not necessary in order to trigger the introduction of share systems.

The closely related idea that contracts can be used as a means of strategic commitment, or the more general idea that the organization of product markets is not independent of the strategy used by firms on the labour and input markets have been expressed and studied in some recent papers (for example: Aghion and Bolton (1987), Dewatripont (1987, 1988), Dixit (1982), Stewart (1987)). We provide here a completely rigorous derivation of the above-mentioned results on the properties of profit-sharing, using a game-theoretic framework.

In the model's first stage, firms propose a profit-sharing contract to their workers (or to the workers' union). In the second stage, the workers accept or refuse the proposed contract. There is an exogenously given market wage, and the traditional wage system is implemented in the firm if its workers refuse the contract. This amounts to assuming that a firm can always hire its work-force at the prevailing wage rate. The last stage is a Cournot oligopoly with standard properties. The game's second stage can easily be disposed of, since workers will simply reject any contract leading to an equilibrium for which their payoff is less than the market wage. Instead of explicitly modelling this second stage, we substitute an equivalent "individual rationality" constraint, imposing bounds on the firm's first-stage choice of a contract. To summarize this discussion, in the following model firms choose a profit-sharing scheme subject to the constraint that the induced last-stage Cournot equilibrium profits will be sufficient to pay at least the market wage to the workers.

It turns out that this game has the structure of a 'Prisoner's Dilemma'. If all firms pay their workers according to the wage system, a single firm's best response is always to adopt some profit-sharing contract. Therefore, the traditional wage system cannot be a perfect equilibrium of this game. Any perfect equilibrium of the game involves profit sharing on the part of all firms. In this latter situation, profit levels are shown to be less than the case in which each firm uses the wage system.

In addition, the employment level increases and the equilibrium market price decreases in the profit-sharing perfect equilibrium, as compared to the traditional wage-system oligopoly outcome.

This paper is organized as follows. In Section 2, the model is described and a few technical lemmata are stated. Section 3 examines individual incentives to adopt profit sharing in the industry. Finally, perfect equilibria in contracts are studied in Section 4, and Section 5 contains our concluding remarks.

2. The Model

Consider an industry comprising n identical firms indexed by $i = 1, \ldots, n$. Let $w > 0$ be the prevailing market wage (an exogenous parameter here). Let q_i be the quantity produced by firm i. Firms produce a single homogeneous good whose price is given by an inverse demand function P. Define q as the n-tuple of firms' decisions $q = (q_1, \ldots, q_n)$ and further define Q as $Q = \sum_i q_i$. It must be understood that $q_i \geqq 0$. Labour is the sole input of the industry and there are constant returns to scale: one unit of labour gives one unit of product in each firm. Each firm i may choose a profit-sharing scheme, or 'contract', which can be formally represented as a couple of real numbers (α_i, β_i), firm i's profit function being defined as:

$$\Pi_i(q, \alpha_i, \beta_i) = (1 - \alpha_i)\left(P(Q) - \beta_i\right)q_i$$

and workers' <u>per capita</u> income being defined as:

$$t(q, \alpha_i, \beta_i) = \alpha_i\left(P(Q) - \beta_i\right) + \beta_i.$$

Clearly, the wage system is a particular contract obtained when $(\alpha_i, \beta_i) = (o, w)$. In the following, for all i, we restrict (α_i, β_i) to lie in the set $[0, 1)\times[o, w]$. Clearly, α_i is a share and belongs to $[0, 1)$, and β_i must be interpreted as a base wage. Negative values of β_i would thus be meaningless. Finally, no interesting aspect of the problem is lost by restricting β_i to remaining below w.

Let $\alpha = (\alpha_1, \ldots, \alpha_n)$ and $\beta = (\beta_1, \ldots, \beta_n)$. We define the subgame $\Gamma(\alpha, \beta)$ as the n-person Cournot oligopoly obtained for fixed (α, β). The pay-off for each firm i is $\Pi_i(q, \alpha_i, \beta_i)$ and q_i is firm i's strategic variable.

We introduce here a set of standard assumptions.

Assumptions

(A1) $P : \mathbf{R}_{++} \to \mathbf{R}_{+}$; $P \varepsilon C^{k}(\mathbf{R}_{++})$, $k \geq 2$; $P'(Q) < 0$ if $P(Q) > 0$;

$w < \lim_{Q\to 0} P(Q)$ and $\lim_{Q\to 0} P(Q)Q = 0$.

(A2) There exists $Q_0 > 0$ such that $P(Q) = 0$ for all $Q \geq Q_0$

and $P(Q) > 0$ for all $Q < Q_0$.

(A3) For all $q, q^0 \geq 0$ such that $0 < q + q^0 < Q_0$, if $P(q^0+q) + qP'(q^0+q) \geq 0$, then $P'(q^0+q) + qP''(q^0+q) < 0$.

The first two assumptions do not need any comment. Only A3 deserves our attention. It is slightly stronger than the strict quasi-concavity of Π_i with respect to q_i. Note that strict quasi-concavity of Π_i is characterized by: $P(q^0+q) + qP'(q^0+q) = \beta_i$ implies $2P'(q^0+q) + qP''(q^0+q) < 0$.

We now state a few preliminary results which ensure that the equilibria of $\Gamma(\alpha, \beta)$ are well-behaved in the relevant domain. All the proofs are in the Appendix.

Lemma 1 (Existence of subgame equilibria)

Under A1-A3, for all $(\alpha, \beta) \in [0, 1)^n \times [0, w]^n$, $\Gamma(\alpha, \beta)$ possesses a Cournot-Nash equilibrium.

It is clear that the equilibria of $\Gamma(\alpha, \beta)$ do not depend on $\alpha < 1$. Let $q(\beta) = (q_1(\beta), \ldots, q_n(\beta))$ denote an equilibrium, and let $Q(\beta) = \sum_i q_i(\beta)$ denote the corresponding total production.

We also have:

Lemma 2 (Symmetry)

Under A1-A3, if $\beta = (b, b, \ldots, b)$, $b \varepsilon [0, w]$, then $q_1(\beta) = q_2(\beta) = \ldots = q_n(\beta) > 0$. Any diagonal set of base wage parameters leads to a symmetric and interior equilibrium of $\Gamma(\alpha, \beta)$ for all $\alpha \varepsilon [0, 1)^n$.

Lemma 3 (Global Uniqueness)

Under A1-A3, for all $\beta \varepsilon [0, w]^n$, interior equilibria of $\Gamma(\alpha, \beta)$ are globally unique.

For all values of the parameter β for which an interior equilibrium of $\Gamma(\alpha, \beta)$ exists, we denote $q(\beta)$ this unique equilibrium. In addition:

Lemma 4 (Comparative Statics)

Under A1-A3, if $q(\beta)$ is interior, then $\beta \rightarrow q(\beta)$ is a C^1 function on a neighbourhood of β and

$$q'_{ii} = \frac{\partial q_i(\beta)}{\partial \beta_i} = \frac{nP'(Q)+Q_{-i}P''(Q)}{P'(Q)\left[(n+1)P'(Q)+QP''(Q)\right]} < 0;$$

$$q'_{ij} = \frac{\partial q_i(\beta)}{\partial \beta_j} = \frac{-\left[P'(Q)+q_iP''(Q)\right]}{P'(Q)\left[(n+1)P'(Q)+QP''(Q)\right]} > 0 \text{ if } i \neq j;$$

$$Q'_i = \frac{\partial Q(\beta)}{\partial \beta_i} = \frac{P'(Q)}{P'(Q)\left[(n+1)P'(Q)+QP''(Q)\right]} < 0;$$

where $Q = Q(\beta)$ and $Q_{-i} = Q(\beta) - q_i(\beta)$ for all i.

In addition, $Q'_i - q'_{ii} > 0$.

Lemma 4 shows that the model's comparative statics do not contradict economic intuitions.

3. Individual Firms' Incentives to Adopt a Profit-sharing Scheme

We consider here the following problem. Given that all firms other than firm 1 pay their workers according to the wage system $[$i.e.: $(\alpha_i, \beta_i) = (0, w)$ for all $i = 2, \ldots, n]$, does there exist a non-trivial $[$i.e. $(\alpha_1, \beta_1) \neq (0, w)]$ profit-sharing contract such that both firm 1 and its employees are better off in Cournot equilibrium? In other words, would an oligopolist firm unilaterally adopt some profit-sharing scheme subject to the constraint that a worker's contractual payment must be greater than w? A positive answer is provided here.

Define $q^S(b) = q(b, b, \ldots, b)$ for all $b \varepsilon [0, w]$. To simplify notation, $\Pi_i(q^S(w), 0, w)$ is simply denoted $\Pi^0(w)$.

<u>Definition 3-1</u>. A contract $(\alpha, \beta) \varepsilon [0, 1) \times [0, w]$ is implementable by firm 1 if and only if for all Cournot equilibria q of $\Gamma(\alpha, 0, \ldots, 0; \beta, w, \ldots, w)$ one has

(S) $t(q, \alpha, \beta) \geq w$
(F) $\Pi_1(q, \alpha, \beta) \geq \Pi^0(w)$.

Let C denote the set of implementable contracts.

<u>Definition 3-2</u>. A contract $(\alpha, \beta) \varepsilon C$ is Pareto-improving if and only if (S) and/or (F) in Definition 3-1 are satisfied as strict inequalities.

Then we have:

<u>Lemma 5</u>

Under A1-A3,

(i) $(0, w) \varepsilon C$;
$(\alpha, \beta) \varepsilon C$ and $\alpha = 0$ implies $\beta = w$;

(ii) $(\alpha, \beta) \varepsilon C$ implies $\Gamma(\alpha, 0, \ldots, 0, \beta, w, \ldots, w)$ has a unique interior equilibrium $q(\beta, w, \ldots, w)$;

(iii) C is compact (in $\mathbf{R}^2$).

In other words, the set of implementable contracts is non-empty and no implementable contract can deter the entry of any firm which pays its workers according to the wage system. Thus, the implementable set of contracts leads to subgames which possess a unique interior equilibrium.

Note however that entry deterrence would be possible if potential entrants (say the firms $i = 2, \ldots, n$) had sufficiently high fixed costs.

It is now possible to study the existence of a Pareto-improving contract in the sense of Definition 3-2.

Define the functions s and f as follows. For every $\beta \varepsilon [0, w]$,

$$s(\beta) = \frac{(w-\beta)}{[P[Q(\beta, w, \ldots, w)] - \beta]} \varepsilon [0, 1]$$

$$f(\beta) = 1 - \frac{\Pi^0(w)}{[P[Q(\beta, w, \ldots, w)] - \beta]q_1(\beta, w, \ldots, w)} \varepsilon [0, 1),$$

where $Q(\beta, w, \ldots, w) = \sum_i q_i(\beta, q, \ldots, w)$.

With these definitions $(\alpha, \beta)\varepsilon C$ is equivalent to $\alpha \varepsilon [0, 1)$, $\beta \varepsilon [0, w]$ and $s(\beta) \leqq \alpha \leqq f(\beta)$.

These functions are well-defined, since $(\alpha, \beta)\varepsilon C$ implies $q(\beta, w, \ldots, w) >> 0$ and $P[Q(\beta, w, \ldots, w)] > w \geq \beta$. Lemmata 3 and 4 thus show that $q(\cdot)$ is continuously differentiable when $(\alpha, \beta)\varepsilon C$. It follows that s and f are differentiable.

<u>Theorem 1</u>: Under A1-A3, if $n > 1$, there exists a contract (α^0, β^0) which is Pareto-improving (in the sense of Definition 3-2). Formally, C has a non-empty interior.

Before the proof of Theorem 1, it is useful to show why the result is not true in the case of a monopoly (i.e.: $n = 1$). Suppose that there exists a Pareto-improving contract (α, β), then

$$(F) \quad (1-\alpha)\left(P\left(q_1(\beta)\right)-\beta\right)q_1(\beta) \geqq \Pi^0(w) \quad \text{and}$$

$$(S) \qquad \alpha\left(P\left(q_1(\beta)\right)-\beta\right) \geqq (w-\beta)$$

with at least one strict inequality.

Multiplying (S) by $q_1(\beta) > 0$ and adding (S) to (F) yields

$$\left(P\left(q_1(\beta)\right) - w\right) q_1(\beta) > \Pi^0(w) = \Pi_1\left(q_1(w),\ 0,\ w\right),$$

but by definition of $q_1(w)$ (the monopolist's output at w) one has

$$\Pi^0(w) \geqq \left(P(q) - w\right) q \quad \text{for all} \quad q \geqq 0.$$

In particular, this last inequality is true for $q = q_1(\beta)$, a contradiction.

Proof of Theorem 1:

First note that if there exists a β^0 such that $s(\beta^0) < f(\beta^0)$, then C has a non-empty interior. Consider $\Phi(\beta) = f(\beta) - s(\beta)$. To prove the existence of such a β^0, it is sufficient to show that when β^0 is close to w, with $\beta^0 < w$, one has $\Phi(\beta^0) > 0$.

To shorten notation, we write everywhere $q(\beta)$ instead of $q(\beta, w, \ldots, w)$ and so on. Define $p(\beta) = P\left(Q(\beta)\right)$ and $\pi(\beta) = \left(p(\beta) - \beta\right)q_1(\beta)$. Then, simple algebra yields

$$\Phi(\beta) = \pi(\beta)^{-1} \left(\pi(\beta) - \Pi^0(w) - (w-\beta)q_1(\beta)\right),$$

and differentiation with respect to β yields:

$$\Phi'(\beta) = \pi(\beta)^{-1} \left(q_1(\beta) - (w-\beta)q'_{11}(\beta) + \pi'(\beta)\right) - \pi(\beta)^{-1}\, \Phi(\beta)\pi'(\beta).$$

Since $\pi(w) = \Pi^0(w)$ and $\Phi(w) = 0$, at $\beta = w$, this expression reduces to $\Phi'(w) = \pi(w)^{-1} \left(q_1(w) + \pi'(w)\right)$, and

$$\pi'(\beta) = \left(P'\left(Q(\beta)\right) Q'(\beta) - 1\right) q_1(\beta) + \left(p(\beta) - \beta\right) q_{11}'(\beta).$$

First-order necessary conditions for profit maximization give $\left(p(w)-w\right) = -q_1(w)\; P'\left(Q(w)\right)$.

Substituting this latter equation in the expression for $\pi'(w)$ yields:

$$\pi'(w) = -q_1(w) + P'\left(Q(w)\right) q_1(w)\left(Q_1'(w) - q_{11}'(w)\right)$$

and

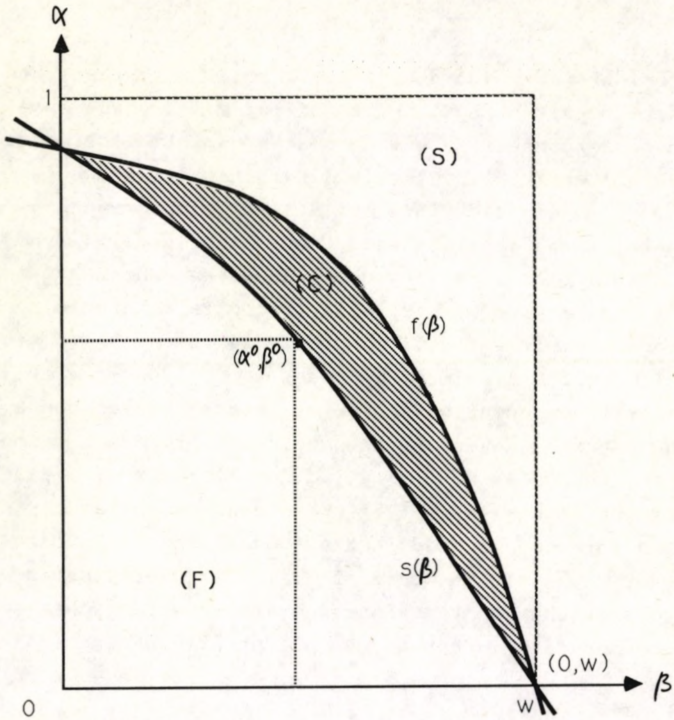
$$\Phi'(w) = \pi(w)^{-1} P'\left(Q(w)\right) q_1(w) \left(Q_1'(w) - q_{11}'(w)\right).$$

Using then the results of Lemma 4 and $P' < 0$ shows that $\Phi'(w) < 0$. Since $\Phi(w) = 0$, there exists $\delta > 0$, such that $\beta^0 < w$ and $w-\beta^0 < \delta$ implies $\Phi(\beta^0) > 0$. Q.E.D.

- insert here Fig. 1 -

<u>Corollary</u>: There exists an optimal (profit-maximizing) contract for the firm, which strictly improves the firm's profits, and under the conditions of which the firm's employees exactly receive the market wage in oligopoly equilibrium. Formally, there exists $(\alpha^0, \beta^0) \varepsilon C$ such that $\Pi_1\left(q(\beta, w, \ldots, w), \alpha, \beta\right)$ is maximized at (α^0, β^0) subject to $(\alpha, \beta) \varepsilon C$. Moreover, $t\left(q(\beta^0, w, \ldots, w), \alpha^0, \beta^0\right) = w$ and $\Pi_1\left(q(\beta^0, w, \ldots, w), \alpha^0, \beta^0\right) > \Pi^0(w)$.

<u>Proof</u>: Since C is compact and Π_1 is continuous with respect to (α, β), the optimal contract exists. Theorem 1 shows that firm 1 can do strictly better than $\Pi^0(w)$. Finally, a standard argument would show that $t = w$ in equilibrium. Q.E.D.



Firm 1's best choice of a contract (α°,β°)

fig.1

Some comments are in order. First of all, note that the wage system is not a perfect equilibrium of our multi-stage game, since firm 1's best response to the wage system is to introduce some profit-sharing contract. Clearly, in this multi-stage framework, the adoption of a contract is a commitment which creates a strategic advantage in the last-stage Cournot oligopoly. By means of such a contract, firm 1 can increase its market share and its profits at the expense of its rivals. If contracts are to be viewed as a strategic commitment device, one would then wish to study the problem of their optimality. In other words, does there exist an optimal general compensation scheme t, such that at the equilibrium of the subgame induced by the choice of t, one has both $t \geq \bar{w}$ and $\Pi_1(t) > \Pi_1[q(\beta, w, \ldots, w), \alpha, \beta]$ for all $(\alpha, \beta) \epsilon C$? It would then be a nice result if the linear two-parameter schemes studied here were undominated in the above sense. Unfortunately, this is not true. In the case of a linear inverse demand, it is possible to show that there exist quadratic reward schemes which are better for firm 1 than any simple profit-sharing system (α, β).

In more general cases, it might happen that the optimal scheme of firm 1 is a corner solution (i.e.: $\beta^0 = 0$). This means that relaxing the constraints imposed on the class of admissible compensation functions t would allow for an increment of firm 1's subgame equilibrium profits.

4. Subgame-Perfect Nash Equilibria in Contracts

We consider now the complete game in which each firm i chooses a contract (α_i, β_i). Firms then compete through the choice of profit-sharing schemes, knowing that it affects their strategic power in the second-stage Cournot oligopoly. We study here the properties of such a 'subgame-perfect equilibrium in contracts'. It is particularly striking that the strategic choice of profit-sharing versus the wage system has the structure of a Prisoner's Dilemma.

Definition 4-1. A perfect equilibrium is a 2n-tuple $(\alpha^*, \beta^*) = [(\alpha_i^*, \beta_i^*)_{i=1...n}]$ such that for all i

$$t[q(\beta^*), \alpha_i^*, \beta_i^*) \geqq w, \quad (\alpha_i^*, \beta_i^*) \in [0, 1) \times [0, w]$$

and

$$(1-\alpha_i^*)[P[Q(\beta^*))-\beta_i^*]q_i(\beta^*) \geqq (1-\alpha_i)[P[Q(\beta_i,\beta_{-i}^*))-\beta_i]q_i(\beta_i, \beta_{-i}^*)$$

for all $(\alpha_i, \beta_i) \in [0, 1) \times [0, w]$ such that

$$t[q(\beta_i, \beta_{-i}^*), \alpha_i, \beta_i] \geqq w.$$

Under A1-A3, one proves the following Theorem.

Theorem 2: If (α, β) is a perfect equilibrium, then

(i) $0 < \alpha_i < 1$ and $\beta_i < w$ for all i;

(ii) the equilibrium is symmetric [i.e.: $\alpha_i = \alpha_j$ and $\beta_i = \beta_j$ for all (i, j)];

(iii) $t[q(\beta), \alpha_i, \beta_i] = w$.

(For Proof, see the Appendix.)

According to the statement of Theorem 2, if an equilibrium in contracts exists, it involves non-trivial profit-sharing on the part of all firms. Note that it is not possible to prove (without adding assumptions to A1-A3) that any perfect equilibrium satisfies $\beta_i > 0$ for all i. It might be the case that firms would like to implement negative values of β. This leads to a true difficulty, both technical and conceptual. On the one hand, this fact jeopardizes the existence of an equilibrium in contracts. On the other hand, if β_i is to be regarded as a base wage, negative values of this parameter are meaningless.

The existence problem is discussed further below. It is anyway possible to state:

Theorem 3: If $(\alpha^*, \beta^*)^n$ is a perfect equilibrium, then for all i

$$\Pi_i(q(\beta^*), \alpha^*, \beta^*) < \Pi^0(w) \quad \text{and} \quad Q(\beta^*) > Q(w).$$

The equilibrium contract is Pareto-dominated (among firms) by the wage system $(0, w)^n$.

Proof of Theorem 3: We establish first that the quantities produced at any potential equilibrium decrease when β increases. By Theorem 2, an equilibrium is symmetric. For a given β, clearly

$$P'(nq^s(\beta))q^s(\beta) + P(nq^s(\beta)) - \beta = 0 \tag{1}$$

and by A3, applying the implicit function theorem:

$$\frac{dq^s}{d\beta} = \left((n+1)\, P'(nq^s) + nq^sP''(nq^s)\right)^{-1} < 0. \tag{2}$$

Define $\Pi^s(\alpha, \beta) = (1-\alpha)\left[P(nq^s(\beta)) - \beta\right] q^s(\beta)$. The proof of Theorem 2 shows that $t(nq^s(\beta), \alpha, \beta) = w$, so that

$$\alpha = (w-\beta)\left(P(nq^s(\beta))-\beta\right)^{-1}.$$

Define then

$$\Pi^s(\beta) = \Pi^s\left((w-\beta)(P-\beta)^{-1}, \beta\right) \equiv \left(P(nq^s(\beta))-w\right)q^s(\beta).$$

Differentiation with respect to β yields:

$$\frac{d\Pi^s}{d\beta} = \frac{dq^s}{d\beta}\left(nq^s\, P'(nq^s) + P(nq^s) - w\right). \qquad (3)$$

Substituting (1) in (3) yields:

$$\frac{d\Pi^s}{d\beta} = \frac{dq^s}{d\beta}\left((n-1)q^s\, P'(nq^s) + \beta - w\right).$$

Since $\beta < w$ and $(dq^s/d\beta) < 0$ and $P' < 0$, one finds

$$\frac{d\Pi^s}{d\beta} > 0.$$

Q.E.D.

We have thus shown that if a perfect equilibrium exists, it yields smaller profits than the wage system $(0, w)^n$. But the wage system is not a perfect equilibrium, as shown by Theorem 1. For some $(\alpha^0, \beta^0) \varepsilon (0, 1) \times [0, w)$, one has

$$\Pi_1\left(q(\beta^*), \alpha^*, \beta^*\right) < \Pi^0(w) < \Pi_1\left(q(\beta^0, w, \ldots, w), \alpha^0, \beta^0\right),$$

where $(\alpha^*, \beta^*)^n$ is a perfect equilibrium. In this sense, the strategic problem of profit-sharing has the same structure as that of the Prisoner's Dilemma.

This in turn has some strong implications. If the game under study is repeated, then the Folk Theorem says that there exist non-cooperative (inter-temporal) strategies which support the wage system as a Nash equilibrium.

Thus, if one believes in the story told here, one should observe, initially, pioneering firms adopting profit-sharing schemes in a given industry. This first stage would be followed by a period of adjustment, during which all firms would progressively switch to profit-sharing, eventually leading to the above-described perfect equilibrium.

Finally, firms would discover the advantages of cooperation with their rivals and revert to the wage system, under some equilibrium with tacit collusion. Since employment unambiguously increases (and any reasonable welfare function also does) when profit-sharing rules are adopted, there is here scope for state intervention. It is also worth noting that if a single firm is forced to implement profit-sharing, it is in the interest of others to do the same.

We close this section with a result to do with the existence of perfect equilibrium in the standard linear case, followed by some comments.

Theorem 4: If $P(Q) = \max\{0, b-aQ\}$ with $b > w$, there exists a perfect equilibrium in contracts $(\alpha^*, \beta^*)^n$ and

(i) if $w/b \leq (n-1)/n(n+1)$, one has a corner solution with $\beta^* = 0$ and $\alpha^* = w(n+1)/b$;

(ii) if $w/b > (n-1)/n(n+1)$ (which is always true if n is large enough), the solution is interior and given by

$$\alpha^* = \frac{n-1}{n} \to 1 \quad \text{as } n \to +\infty$$

$$\beta^* = \frac{(n^2+n)w-b(n-1)}{(n^2+1)} \to w \quad \text{as } n \to +\infty$$

Proof: (Direct Computation)

In order to illustrate the results of Theorem 4 in a simple case, assume that $n = 2$ and $b = 3w$. Then, $\alpha^* = 1/2$ and $\beta^* = (3/5)w$. This numerical example shows that the magnitudes of profit-sharing and base-wage reduction are high in a concentrated industry's perfect equilibrium.

But, as soon as $n = 10$, one has $\alpha^* = 9/10$ and $\beta^* \simeq (4/5)w$ and when $n = 100$, one almost reaches the perfectly competitive limit with $\alpha^* = 99/100$ and $\beta^* \simeq (96/100)w$. In this latter case, α^* is very high because profits are very low and β^* is approximately equal to the market wage w.

It is also interesting to compute firm 1's best response to the other firms' choosing the wage system in the linear case. Let $(\alpha^0(w), \beta^0(w))$ denote this best response, then

$$\beta^0(w) = \frac{(3n-1)w - (n-1)b}{2n}$$

$$\alpha^0(w) = \frac{w - \beta^0(w)}{p(\beta^0(w), w, \ldots, w) - \beta^0(w)} = \frac{n-1}{n}$$

so that if $n = 2$, $\beta^0(w) = w/2$ with $b = 3w$ and $\alpha^0 = 1/2$, and if $n = 10$, $\beta^0(w) = w/10$ and $\alpha^0 = 9/10$!

But the most dramatic changes happen when all firms imitate firm 1 and play their perfect equilibrium contract (α^*, β^*). The percentage of profit reduction when one shifts from a situation in which only firm 1 uses profit-sharing to the perfect equilibrum can be easily computed as

$$\frac{\Pi_1(\alpha^0, \beta^0) - \Pi(\alpha^*, \beta^*)}{\Pi_1(\alpha^0, \beta^0)} = \frac{(n^2-1)^2}{(n^2+1)^2} \equiv \rho_n,$$

so that $\rho_2 = 36\%$ and $\rho_{10} \simeq 96\%$! The percentage of profit reduction obtained while shifting from the wage system to the perfect equilibrium is given by

$$\frac{\Pi^0(w) - \Pi(\alpha^*, \beta^*)}{\Pi^0(w)} = 1 - \frac{n(n+1)^2}{(n^2+1)^2} \equiv \delta_n,$$

so that $\delta_2 \simeq 28\%$ and $\delta_{10} \simeq 88\%$. Finally, it is also worth comparing profit levels under the wage system with the levels reached by firm 1 after an optimal deviation from $(0, w)$ to $(\alpha^0(w), \beta^0(w))$. Simple computations show that

$$\frac{\Pi_1(\alpha^0, \beta^0) - \Pi^0(w)}{\Pi^0(w)} = 1 - \frac{4n}{(n+1)^2} \equiv \gamma_n.$$

It is then striking to see that the 'incentives' to deviate from the wage system strongly increase with n. For instance, γ_2 = 11%, $\gamma_4 \simeq 36\%$, $\gamma_6 \simeq 50\%$, $\gamma_8 \simeq 60\%$, and $\gamma_{10} \simeq 66\%$! This is due to the fact that as n increases, the market becomes very competitive and, therefore, $\Pi^0(w)$ converges quickly towards zero while a slight marginal cost advantage is able to create considerable imbalance of market shares in favour of the deviator.

5. Conclusion

Our main idea has been to stress the interpretation of compensation systems different from the classical wage system as strategic tools in the process of (imperfect) competition. It seems generally true that the wage system (which is a particular case of a constant compensation scheme) is not the best contract a firm can propose to its employees if this contract plays the role of a commitment creating a strategic advantage. In the context of a Cournot oligopoly, profit-sharing à la Weitzman has been proved to create such an advantage and to be involved in any (one-shot) non-cooperative equilibrium in contracts. Since an application of the 'Folk Theorem' to the infinitely repeated version of the two-stage oligopoly studied above has the wage system as a subgame-perfect equilibrium, the usual conclusions concerning state intervention to encourage profit-sharing must be somewhat modified.

In the case of a Cournot oligopoly, it is not necessary to create tax incentives in order to trigger the adoption of profit-related pay. Public intervention should simply try to forbid the collusion of firms, to avoid complete reversion to the wage system once profit-sharing has been introduced. Some empirical facts seem to indicate that the role of many producers' federations is much more to organize negotiations with the workers' unions and to permit firms to reach an agreement on some common wage policy more easily than to implement quotas of production, or to collude in the usual sense of the term on the output market.

Finally, our results clearly apply to multinational oligopolies. In this case, collusion is much more difficult. It is thus not absurd to think that some Japanese firms gained a strategic advantage over their European or North-American rivals, among other reasons because they had developed profit-related pay, and their Western competitors had not.

Appendix

Proof of Lemma 1: By A2, $Q \geqq Q_0$ implies $P(Q) = 0$, and $Q < Q_0$ implies $P(Q) > 0$. Therefore, firms will never choose a production level greater than or equal to Q_0. Define the best response correspondence of any firm i using (α_i, β_i):

$$BR_{\beta_i}(Q_{-i}) = \{q_i \varepsilon [0, Q_o] \mid (P(Q_{-i}+q_i)-\beta_i)q_i \geqq$$

$$(P(Q_{-i}+q_i') - \beta_i)q_i' \text{ for all } q_i' \varepsilon [0, Q_o]\}.$$

Since $[0, Q_o]$ is compact, since $(P(Q_{-i}+q_i')-\beta_i)q_i'$ is continuous on $[0, Q_o]$ (A1) and strictly quasi-concave with respect to q_i' (A3), standard arguments ensure that $BR_{\beta_i}(Q_{-i})$ is a well-defined continuous function of Q. For all $\beta \varepsilon [0, w]^n$ and all $q \varepsilon R_+^n$, let us define

$$\overline{\overline{BR}}_\beta(q) = \prod_{i=1}^{n} BR_{\beta_i}(Q_{-i}),$$

where $Q_{-i} = \sum_{j \neq i} q_j$ for all i. $\overline{\overline{BR}}_\beta$ maps $[0, Q_0]^n$ into itself. Thus, by Brouwer's Theorem, there exists a fixed point $q^* = \overline{\overline{BR}}_\beta(q^*)$. This fixed point is a Cournot equilibrium of $\Gamma(\alpha, \beta)$ for all $(\alpha, \beta) \varepsilon [0, 1)^n \times [0, w]^n$. Q.E.D.

Proof of Lemma 2: Let $\beta = (b, b, \ldots, b)$ and let $q(\beta)$ be an equilibrium of $\Gamma(\alpha, \beta)$. Suppose that $q_1(\beta) = 0$. Then, necessarily, $P(Q(\beta)) \leqq b$ and $\Pi_i(q(\beta), \alpha_i, b) = 0$ for all i. Define $P(0) = \lim_{Q \to 0} P(Q)$. If $P(Q(\beta)) < b$, then $q_i(\beta) = 0$ for all i, but $P(Q(\beta)) = P(0) < b \leqq w$ contradicts A1. If $P(Q(\beta)) = b$, then $q_i(\beta) > 0$ for some i and choosing ε such that $0 < \varepsilon < q_i(\beta)$, one finds $(P(Q(\beta)-\varepsilon)-b)(q_i(\beta)-\varepsilon) > 0$, a contradiction. Thus, if $\beta = (b, b, \ldots, b)$ is a diagonal parameter value, any equilibrium of $\Gamma(\alpha, \beta)$ must satisfy $q_i(\beta) > 0$ for all i. It follows from this that first-order conditions for a symmetric equilibrium can be written $P(Q) + q_i P'(Q) = \beta_i$ for all i, $Q = Q(\beta)$. Subtracting these equations for i and $j \neq i$, one finds $(q_i - q_j)P'(Q) = 0$, which implies $q_i = q_j$ for all (i, j). Q.E.D.

Proof of Lemma 3: Let q be an interior equilibrium of $\Gamma(\alpha, \beta)$. Then, $P(Q) + q_i P'(Q) = \beta_i$ for all i.

Summing these relations over i gives

$$P(Q) + (Q/n)P'(Q) = (1/n)\sum_i \beta_i \geqq 0.$$

Thus, by A3

$$P'(Q) + (Q/n)P''(Q) < 0.$$

Define

$$g(Q) = nP(Q) + QP'(Q) - \sum_i \beta_i.$$

If q^1 and $q^2 \neq q^1$ are two interior equilibria at β and Q^1 and Q^2 are the corresponding total productions, then one has

$$Q^1 \neq Q^2, \quad g(Q^1) = g(Q^2) = 0 \quad \text{and} \quad g'(Q^k) < 0, \quad k = 1, 2.$$

Since g is C^1, it would be easy to show that this implies the existence of a third equilibrium Q^3 such that

$$g(Q^3) = 0 \quad \text{and} \quad g'(Q^3) \geqq 0,$$

which is impossible. Therefore, all interior Nash equilibria at β have the same total production $Q(\beta)$. It follows from this that $q_i(\beta)$ is also uniquely determined by

$$q_i(\beta) = -[P(Q(\beta)) - \beta_i] \;/\; P'(Q(\beta)).$$

Q.E.D.

<u>Proof of Lemma 4</u>: It is sufficient to apply the Implicit Function Theorem. Let $\Psi\colon R^n_{++} \times [0, w]^n \to R^n$ be defined as $\Psi = (\Psi_1, \ldots, \Psi_n)$ and $\Psi_i(q, \beta) = P(Q) + q_i P'(Q) - \beta_i$. Then, q^* is an interior equilibrium at β if and only if $\Psi(q^*, \beta) = 0$, since by A3, first-order conditions are also sufficient. If $D_q\Psi$ is regular at the equilibrium point, then

$$\left(\frac{\partial q}{\partial \beta}\right) = [D_q\Psi]^{-1}.$$

Let $J\Psi$ denote the Jacobian determinant of $D_q\Psi$. Differentiating the first-order conditions with respect to q gives:

$$J\Psi = \begin{vmatrix} 2P'+q_1P'' & P+q_1P'' & \ldots & P'+q_1P'' \\ P+q_2P'' & 2P+q_2P'' & \ldots & P'+q_2P'' \\ \cdot & \cdot & & \cdot \\ \cdot & \cdot & & \cdot \\ \cdot & \cdot & & \cdot \\ P'+q_nP'' & P'+q_nP'' & \ldots & 2P'+q_nP'' \end{vmatrix},$$

subtracting the last column from the others yields:

$$J\Psi = \begin{vmatrix} P' & 0 & \ldots & 0 & P'+q_1P'' \\ 0 & P' & \ldots & 0 & P'+q_2P'' \\ \cdot & \cdot & & \cdot & \cdot \\ \cdot & \cdot & & \cdot & \cdot \\ \cdot & \cdot & & \cdot & \cdot \\ 0 & 0 & & P' & P'+q_{n-1}P'' \\ -P' & -P' & \ldots & -P' & 2P'+q_nP'' \end{vmatrix},$$

and adding the $(n-1)$ first rows to the last one yields:

$$J\Psi = \begin{vmatrix} P' & 0 & \ldots & 0 & P' + q_1P' \\ 0 & P' & \ldots & 0 & P' + q_2P'' \\ \cdot & \cdot & & \cdot & \cdot \\ \cdot & \cdot & & \cdot & \cdot \\ \cdot & \cdot & & \cdot & \cdot \\ 0 & 0 & \ldots & P' & P'+q_{n-1}P'' \\ 0 & 0 & \ldots & 0 & (n+1)P'+QP'' \end{vmatrix} = [(n+1)P'+QP''](P')^{n-1}.$$

Clearly, by A3, $J\Psi \neq 0$ and the Implicit Function Theorem can be applied. Let $\frac{\partial q}{\partial \beta}$ be the matrix $(\frac{\partial q_i}{\partial \beta_j})_{i,j}$ where i is the row index and j is the column index. Then $(\partial q_i/\partial \beta_i)$ is easily computed as the cofactor of $D_q\Psi$'s i-th diagonal term (i.e.: the minor obtained by deleting the i-th row and the i-th column of $J\Psi$), divided by $J\Psi$. This minor has exactly the same structure as $J\Psi$ and one easily finds

$$\frac{\partial q_i}{\partial \beta_i} = \frac{(nP'+Q_{-i}P")(P')^{n-2}}{((n+1)P'+QP")(P')^{n-1}}, \quad Q_{-i} = \sum_{j\neq i} q_j,$$

which gives the result and is negative by A3 and since $P' < 0$. Cumbersome algebraic computations of the same type yield the result for $(\partial q_i/\partial \beta_j)$, $j \neq i$. Since $nP(Q) + QP'(Q) = \sum_i \beta_i$, using A3 again, one easily obtains

$$\frac{\partial Q}{\partial \beta_i} = ((n+1)P'(Q) + QP"(Q))^{-1} = \sum_{k=1}^{n} \frac{\partial q_k}{\partial \beta_i} < 0.$$

Q.E.D.

<u>Proof of Lemma 5</u>: Point (i) is obvious. To prove (ii) assume that for some equilibrium q, $q_i = 0$, $i \neq 1$. Then, since (S) is satisfied by (α, β), $P(Q) \leq w \leq t(q, \alpha, \beta)$. But these inequalities implie $P(Q)-t(q, \alpha, \beta) \leq 0$, that is, $\Pi_1(q, \alpha, \beta) \leq 0$. Thus, since $\Pi^0(w) > 0$, condition (F) is violated, a contradiction. If $q_1 = 0$, then $P \leq \beta \leq w$, and for any firm $i \neq 1$, it follows that $q_i = 0$ and $Q = 0$. Since by A1, $\lim_{Q\to 0} P(Q) = P(0) \geq w$ one again finds a contradiction. Thus, $(\alpha, \beta) \varepsilon C$ and q is an equilibrium of $\Gamma(\alpha, 0, \ldots 0, \beta, w, \ldots, w)$ imply that q is interior. By Lemma 3, q is unique and $q = q(\beta, w, \ldots, w)$. To prove point (iii), it is sufficient to prove that C is closed, since C is clearly bounded. Let $(\alpha^k, \beta^k) \varepsilon C$ be a converging sequence. Let (α, β) be its limit. First note that $(1, \beta)$ does not belong to C for all $\beta \varepsilon [0, w]$ since $\Pi^0(w) > 0$. Assume that $\alpha = 1$. Since by Lemma 4, $q(\beta, w, \ldots, w)$ is continuous, $\Pi_1(q(\beta^k, w, \ldots, w), \alpha^k, \beta^k) \leq (1-\alpha^k)M$ (where M is some given constant), and therefore, (F) will be violated for

sufficiently large k. Moreover, by continuity of q, t and Π_1, conditions (S) and (F) are satisfied at (α, β). Q.E.D.

Proof of Theorem 2: Note first that if (α, β) is a perfect equilibrium, then $P > w \geq \beta_i$ (where $P = P(Q(\beta))$). Suppose that $P < w$, then by A1, $Q > 0$. Thus, there exists i such that $q_i > 0$ and $\Pi_i < 0$, a contradiction. If $P = w$, then again $Q > 0$ and there exists i such that $q_i > 0$ and $\Pi_i = 0$. But one again reaches a contradiction, since by choosing to produce $(q_i - \varepsilon)$, $\varepsilon > 0$, firm i could increase its profits.

-

Proof of (i)

To prove (i) assume first that $\alpha_i = 0$ for some i. The wage constraint then trivially implies $\beta_i = w$. Since we then have a corner solution, the Kuhn-Tucker necessary conditions for firm i's profit maximization are as follows:

$$(P-\beta_i)(\lambda_i - q_i) \leq 0 \tag{1}$$

$$(1-\alpha_i)\left[(P'Q'-1)q_i + (P-\beta_i)q'_{ii}\right] + \lambda_i\left[\alpha_i(P'Q'_i-1)+1\right] = \mu_i$$

$$\mu_i \geq 0 \text{ and } \mu_i(w-\beta_i) = 0; \tag{2}$$

$$\lambda_i\left[\alpha_i(P-\beta_i) + \beta_i - w\right] = 0, \quad \lambda_i \geq 0; \tag{3}$$

where λ_i and μ_i are Lagrange multipliers. The use of derivatives is justified here, since $P > w \geq \beta_i$ for all i and $P > \beta_i$ implies $q_i > 0$ (see Lemma 4). These conditions reduce to

$$\lambda_i \leq q_i \text{ since } P > w = \beta_i \tag{1'}$$

$$(P'Q'_i-1)q_i + (P-w)q'_{ii} + \lambda_i \geq 0 \tag{2'}$$

since $\alpha_i = 0$. Adding $q_i - \lambda_i \geq 0$ to (2') yields

$$P'Q'_i q_i + (P-w)q'_{ii} \geq 0. \tag{2''}$$

But first-order conditions for a subgame interior equilibrium implie $-P'q_i = P-w$, and substituting this in (2") yields

$$(P'q_i)(Q_i'-q_{ii}') \geq 0.$$

This is a contradiction, since the results of Lemma 4 implie $Q_i' > q_{ii}'$. Finally, assume $\beta_i = w$. Firm i's best choice is then clearly to set $\alpha_i = 0$, subject to the wage constraint. This contradicts the above result.

Proof of (ii) and (iii)

To prove (ii) and (iii), assume $0 > \alpha_i > 1$ and $\beta_i < w$ for all i. The Kuhn-Tucker necessary conditions (1) and (2) are transformed into

$$(P-\beta_i)(\lambda_i-q_i) = 0, \tag{4}$$

$$(1-\alpha_i)\left((P'Q_i'-1)q_i + (P-\beta_i)q_{ii}'\right) + \lambda_i\left(\alpha_i(P'Q_i'-1) +1\right) = -\mu_i,$$

$$\mu_i \geq 0, \quad \mu_i\beta_i = 0. \tag{5}$$

Since $P > w > \beta_i$ for all i, (4) implies $\lambda_i = q_i > 0$ and (3) thus implies $\alpha_i(P-\beta_i) + \beta_i = w$. This proves (iii). Expression (5) can then be rewritten as

$$P'Q_i'q_i + (P-w)q_{ii}' \leq 0, \tag{5'}$$

since

$$(1-\alpha_i)(P-\beta_i) = (P-w) \quad \text{and} \quad \lambda_i = q_i.$$

Substituting the expressions for Q_i' and q_i' given by Lemma 4 in (5') gives

$$(P')^2q_i + (P-w)(nP'+Q_{-i}P") \leq 0, \tag{5"}$$

where $Q_{-i} = Q-q_i$. If $\beta_j > 0$ for some j, (5") must be satisfied as an equality ($\mu_j = 0$).

Assume that there exists (i, j) with $\beta_j > \beta_i \geqq 0$. Then

$$(P')^2 q_j + (P-w)(nP' + Q_{-j}P") = 0, \tag{6}$$

and subtracting (6) from (5") yields

$$[(P')^2 - P"(P-w)](q_i-q_j) \leqq 0, \tag{7}$$

because $(Q_{-i}-Q_{-j}) = (q_j-q_i)$. The first-order conditions for an interior subgame equilibrium are $P + q_k P' = \beta_k$, k = i, j. By subtraction again, one finds

$$(q_i-q_j)P' = (\beta_i-\beta_j) < 0,$$

so that $(q_i-q_j) > 0$. Expression (7) then implies

$$(P')^2 - P"(P-w) \leqq 0 \quad \text{and} \quad 0 < (P')^2 \leqq P"(P-w).$$

Thus, (6) implies

$$(P-w)P"(q_j+Q_{-j}) + (P-w)nP' \geqq 0,$$

and since $P > w$, this last inequality reduces to $QP" + nP' \geqq 0$, which contradicts A3.

Finally, it has been proved that

$$\beta = \beta_i = \beta_j, \quad \alpha = \alpha_i = \alpha_j = (w-\beta)/(P-\beta), \quad \text{and}$$

$$q_i = q_j = q^s(\beta)$$

for all (i, j). A perfect equilibrium is symmetric. Q.E.D.

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