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INCENTIVES IN MULTI-PERIOD REGULATION
AND PROCUREMENT: A GRAPHICAL ANALYSIS

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RÉSUMÉ

Cet article analyse les politiques de réglementation et d'achat public sur plusieurs périodes en présence d'asymétrie d'information entre le régulateur et les entreprises réglementées. Le cadre général de Laffont et Tirole est utilisé. Nous proposons une analyse graphique du modèle de second-rang en termes de la capacité d'engagement du régulateur. Comme dans Laffont et Tirole, nous distinguons les cas de plein engagement, d'engagement avec contrainte de renégociation et de non-engagement. Notre analyse graphique de l'environnement à deux périodes-deux types nous permet de mettre l'accent sur les fondements des principaux résultats concernant la nature des contrats incitatifs optimaux et de proposer des extensions à la contribution de Laffont et Tirole. Le modèle peut être appliqué à des secteurs où la production de biens publics (comme la sécurité dans le transport des matières dangereuses) est déléguée à des entreprises privées. (JEL D82, H57)

Mots-clés: incitations, contrats à plusieurs périodes, réglementation, achats publics, contrainte de renégociation, information asymétrique

ABSTRACT

This paper analyses multi-period regulation or procurement policies under asymmetric information between the regulator and regulated firms within the general framework developed by Laffont and Tirole. We provide a graphical analysis of the second-best policy in terms of the regulator's commitment capacity. As in Laffont and Tirole, we distinguish between full commitment (long-term contracts that can be committed to), commitment and renegotiation (renegotiation-proof long-term contracts) and noncommitment (a series of short-term contracts). Our graphical analysis of the two-period, two-type environment emphasizes the rationale of the main results concerning the form of the optimal incentive scheme and extends Laffont and Tirole's contribution. The analysis can be applied to situations where the production of a public good or service (such as the level of safety in the transport of hazardous materials) is delegated to private firms. (JEL D82, H57)

Keywords: Incentives, multi-period contracts, regulation, procurement, renegotiation proofness, asymmetric information
1. Introduction

The study of incentives in procurement and regulation under asymmetric information is now a significant subject of research. One of the main problems addressed in the recent literature is that of multi-period contracting. In this respect, Laffont and Tirole (1993) have introduced a general framework that allows the consideration of different assumptions about the parties' commitment capacity. They distinguish between three possibilities: full commitment, commitment and renegotiation, and noncommitment. Under full commitment, the regulator can fully commit to a long-term contract. Under noncommitment, the relationship between the regulator and the regulated firm is governed by a series of short-term contracts. In contrast to the two extreme forms of full commitment and noncommitment, commitment and renegotiation describes a situation where the parties can sign long-term contracts, but can alter the initial contract whenever this is mutually advantageous ex post. In this case, the relationship is essentially restricted to renegotiation-proof contracts and its optimal allocation results in a regulator's expected welfare intermediate between those of the full commitment and the noncommitment assumptions.

The different issues raised in designing the optimal incentive schemes under commitment and renegotiation and under noncommitment (the ratchet effect, the take-the-money-and-run-strategy, the role of the discount rate, etc.) are somewhat intricate and some results are far from intuitive. In this article, we propose a graphical analysis of the two-period, two-type environment in order to show the rationale of Laffont and Tirole's main results. Our analysis also allows us to extend Laffont and Tirole's contribution on some points. We hope such a presentation may in particular be useful for the "dazed and confused" referred to by Rogerson (1994).

We begin by a detailed comparative statics analysis of the one-period model. This first step is useful in understanding the different trade-offs of the dynamic problem. In the situation considered, the production of a public good or service is delegated to a private firm. The regulator monitors the firm's realized cost, which depends on the firm's cost-reducing effort and on some intrinsic cost parameter, both of which are unobservable by the regulator. The analysis deals with a two-type situation in that, depending on its intrinsic cost characteristics, the firm may be labeled as either the efficient or the inefficient type. In such a situation, it is well-known that the solution to the regulator's problem involves a trade-off between incentives and rent extraction: more cost reducing effort on the part of
the firm can only be induced by paying out more rent. The optimal incentive scheme in the one-period problem is characterized by full separation between types: the inefficient type exerts a suboptimal level of effort and earns no rent, while the efficient type exerts the first-best effort and earns a rent.

In the multi-period situation, the optimal scheme under full commitment is equivalent to a repetition of the optimal static scheme in each period. Such a repetition of the optimal static scheme is not feasible in long-term contracts without full commitment, because of a form of "ratcheting". This refers to the fact that any information obtained about the firm's type in the first period will induce renegotiation in the second period so as to induce the firm to exert more effort, whenever this can be mutually beneficial ex post. If the discount factor is large, this implies that full separation may become too costly in terms of the extra rent that now has to be paid out to the efficient type. We show graphically that under commitment and renegotiation some degree of pooling may then be preferable to full separation, because it reduces the impact of ratcheting by reducing the speed of information revelation. Specifically, partial pooling introduces some efficiency cost in the first period (it reduces incentives) but this is compensated by the lower overall rent paid to the efficient firm. This trade-off is analyzed graphically in a diagram showing how changes in the degree of pooling generate an intertemporal welfare frontier between the first and second period welfare levels. The shape of this frontier is determined in part by the regulator's prior with respect to the firm's type and by the efficiency parameters. The optimal two-period scheme amounts to choosing the point on the intertemporal frontier which maximizes the overall discounted welfare. This explains graphically why the solution always involves full separation when the discount factor is low enough and why the degree of pooling is non-decreasing with respect to the discount factor. Because the intertemporal frontier is generally not concave, our analysis also shows that, in general, there will be jumps in the optimal degree of pooling when the discount factor increases. Finally, it is easily shown graphically that full pooling in the first period is never optimal and that the full commitment solution strictly dominates the commitment and renegotiation one for any positive discount factor.

Under noncommitment the regulator is restricted in the timing of the transfers that can be made to the firm: because of his inability to commit, the regulator cannot promise to pay out rent in the second period (to be more precise, only self-enforceable promises are credible). As a consequence, compared to commitment and renegotiation, more rent must now be paid out in the first period in order to obtain some degree of separation. This leads to the possibility of the
"take-the-money-and-run" strategy, in that the inefficient firm could profit by misrepresenting its type in the first period (by choosing the larger transfer designed for the efficient firm), but then quit the relationship in the second period. When this occurs, the two types' self-selection constraints are binding. We first show how the take-the-money-and-run strategy affects the regulator's intertemporal welfare frontier. When the two self-selection constraints are binding, the new welfare frontier is always below that of commitment and renegotiation and its form depends on the discount factor. Because the take-the-money-and-run strategy is a consequence of the ratchet effect (given the constraint on the timing of transfers) and because the impact of the ratchet effect can be reduced by more pooling in the first period, the optimal solution under noncommitment is generally characterized by more pooling than under commitment and renegotiation. In particular, the optimal solution may involve double randomization. Using simulation results, we show graphically how double randomization can improve the intertemporal welfare trade-off. We also discuss the meaning of full pooling under double randomization and obtain that full pooling may be optimal under noncommitment. Finally, we use simulations to compare the optimal schemes under different commitment assumptions and for different values of the discount factor.

The paper develops as follows. Section 2 introduces the notation and the single-period model. Section 3 extends the analysis to the two-period environment under full commitment. Section 4 and 5 discuss the commitment and renegotiation and the noncommitment models respectively, and section 6 presents simulation results for the different commitment possibilities. The last section concludes.

2. One-Period Relationship

2.1. The model

A given firm is to be employed in the realization of an indivisible public project. The regulator's task is to determine the terms of the firm's contract, taking into account the fact that the latter has superior information with respect to the intrinsic cost characteristics of the project. The firm's cost function is $C = \beta - e$, where $C$ is the project's monetary cost, $\beta$ is an exogenous efficiency or cost parameter and $e$ is the producer's effort. The cost $C$ refers to the actual monetary

\footnote{On procurement see also McAfee and McMillan (1987), Tirole (1986) and Riordan and Sappington (1988).}
expenditures on the project and is monitored by the regulator. The effort stands for any discretionary actions taken by the firm which are not observed by the regulator and which affect the project’s actual monetary cost. The parameter is a characteristic of the project’s cost or of the firm’s efficiency in implementing certain productive tasks and is known only to the firm; for expository purposes will be referred to as the firm’s efficiency parameter.

When the producer exerts effort, the monetary cost of the project is reduced but the firm incurs a disutility (in monetary equivalent) of , a strictly increasing and strictly convex function of the effort level, with \( \psi(0) = \psi'(0) = 0 \); to ensure that the regulator’s problem is concave, it is also assumed that \( \psi''(e) \geq 0 \). Since monetary expenditures are observed by the regulator, we use the convention that the firm is paid a net transfer \( t \) in addition to being reimbursed the cost \( C \). The firm’s utility level or surplus is accordingly \( U = t - \psi(e) \). The firm’s reservation utility on the basis of its outside opportunities is normalized to zero: to induce participation in the project, the regulator must consequently offer a contract satisfying the individual rationality (IR) constraint \( U \geq 0 \).

The project has value \( S \) for consumers. The net surplus of consumers (or taxpayers) is

\[
S - (1 + \lambda)(C + t),
\]

where \( C + t \) is the total monetary transfer to the firm (i.e., the price of the project) and \( \lambda \) is the marginal shadow cost of public funds; \( \lambda \) reflects the fact that taxation is distorsionary, in the sense that a levy of $1 actually imposes a cost of $(1+\lambda)$ on taxpayers. Ex post welfare is the sum of the net consumers’ surplus and of the producer’s surplus:

\[
W = S - (1 + \lambda)(C + t) + U. \tag{2.1}
\]

Equivalently, substituting for \( t \) from the definition of \( U \),

\[
W = S - (1 + \lambda)(C + \psi(e)) - \lambda U. \tag{2.2}
\]

In words, ex post welfare is equal to the gross value of the project, minus its total cost (inclusive of the disutility of effort) as perceived by taxpayers, and minus the social opportunity cost of the firm’s rent (its surplus above its reservation level).

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2For models where the regulator does not observe costs, see Baron and Myerson (1982) and Baron and Besanko (1988).

3For more details on the shadow cost of public funds, see Atkinson and Stiglitz (1980).
Welfare is at a maximum, given the IR constraint, when the effort level is such as to minimize the total cost of the project and when the firm receives no rent. The conditions for a maximum are:

\[
1 - \psi'(e) = 0 \quad \text{or} \quad e = e^*, \\
U = 0 \quad \text{or} \quad t = \psi(e^*).
\]

The optimal effort \( e^* \) equalizes the marginal disutility of effort and the marginal savings in monetary expenditures; the net transfer to the firm is just sufficient to compensate the disutility of effort. If the efficiency parameter \( \beta \) were known, this first-best solution would be implementable even though the manager's effort is unobservable. One possibility would be for the regulator to offer a take-it-or-leave-it contract specifying the cost target \( C^* = \beta - e^* \) and a net transfer \( t = \psi(e^*) \) to be paid only if the firm meets the cost target.

In figure 1a, contracts are represented by the cost-transfer pairs \((C, t)\). The straight lines with slope equal to minus one are iso-transfer lines: a line through the contract point \((C, t)\) has vertical intercept \(C + t\), which corresponds to the total transfer promised to the firm under the contract if it meets the cost target. The firm's indifference curves in the cost-transfer space are generated by the equation

\[t - \psi(\beta - C) = U\]

and are vertically parallel. From the definition of welfare in (2.1), for any level of the firm's surplus, welfare increases when the total transfer \(C + t\) is reduced. In figure 1a, contract \(a\) minimizes the total transfer compatible with the utility level \(U_1\) and is therefore preferable to contract \(b\) on the same indifference curve. Minimizing the total transfer for a given utility level is easily seen to imply the minimization of the total cost inclusive of effort \(\beta - e + \psi(e)\): contract \(a\) and (since indifference curves are parallel) all contracts on the vertical line through \(a\) are characterized by the optimal effort level \(e^*\). Because welfare is also increased when the firm's rent is reduced, contracts below \(a\) on the vertical line through this point are preferable to \(a\) and the best feasible contract, given the IR constraint, is therefore \(a'\).

Figure 1b illustrates the contract offered under complete information when the firm's efficiency parameter is either \(\beta\) or \(\bar{\beta}\), where \(\beta < \bar{\beta}\). The more efficient firm is offered contract \(A\) specifying the cost target \(C^* = \bar{\beta} - e^*\); the less efficient one is offered contract \(B\) with cost target \(C^* = \beta - e^*\). Note that at any contract point the slope of the inefficient firm's indifference curve is always greater in absolute
value than that of the more efficient one (i.e., indifference curves have the single-crossing property). It follows that the more efficient firm prefers contract $B$ to contract $A$: if it could misrepresent its type, it would move to the higher (dotted) indifference curve through $B$. Under complete information, the contract offered by the regulator is contingent on the firm’s $\beta$ and contract $B$ would not be offered to the more efficient firm.

In what follows, the notation

$$W(\beta, C, t) \equiv S - (1 + \lambda)(C + t) + [t - \psi(\beta - C)]$$

(2.5)

will be used for the regulator’s welfare when a type $\beta$ firm is offered the contract $(C, t)$. $W^F$ and $\overline{W}^F$ will be used to denote the full-information welfare when the firm is of the type $\underline{\beta}$ or $\overline{\beta}$ respectively.

2.2. The Two-Type Case Under Asymmetric Information

When the efficiency parameter is unknown to the regulator, the first-best contracts $A$ and $B$ are not implementable because of the incentive for the more efficient firm to mimic the less efficient one.\(^4\) The regulator can nevertheless offer a separating menu of contracts $(C, t)$ and $(\overline{C}, \underline{t})$ designed for type $\underline{\beta}$ and type $\overline{\beta}$ respectively. A pair of contracts inducing the firm to self-select the one designed for its type must satisfy the incentive compatibility (IC) constraints

$$U \equiv t - \psi(\overline{\beta} - C) \geq \underline{t} - \psi(\overline{\beta} - \overline{C}), \quad \text{(IC constraint)}$$

(2.6)

$$\overline{U} \equiv \overline{t} - \psi(\underline{\beta} - \overline{C}) \geq \overline{t} - \psi(\overline{\beta} - \overline{C}), \quad \text{(IC constraint)}$$

(2.7)

together with the individual rationality constraints

$$U \geq 0, \quad \overline{U} \geq 0. \quad \text{(IR constraint)}$$

(2.8)\hspace{1cm}(2.9)

The pooling offer, where $(C, t)$ and $(\overline{C}, \underline{t})$ are identical, constitutes a special case: the incentive compatibility constraints are then automatically satisfied and only the individual rationality constraints need be considered.

We now examine the characteristics of the optimal menu. Consider in figure 2 a contract such as $E$ designed for the inefficient firm: it is on the indifference

\(^4\)The asymmetric information considered here is of the adverse selection kind with no stochastic output but with an unobserved action. See Guesnerie and Lauffont (1984) and Picard (1987) for different adverse selection models.
curve $\bar{U} = 0$ and therefore satisfies constraint $\bar{U}$. To satisfy the $\bar{U}$ constraint, the contract for the efficient type must be on the indifference curve $\bar{U} = 0$ or on the left of this curve; if $\bar{C}$ is to be satisfied as well, this contract must furthermore be above or on the $\beta$ indifference curve through $E$. Thus, the contract designed for the more efficient type must be in the shaded area of figure 2, which implies $\bar{C} \leq \bar{C}$ and $\bar{U} > 0$ (i.e., the $\bar{U}$ constraint is not binding). From the regulator's point of view the best contract in the shaded area is the one on the lowest iso-transfer line: given $E$, the contract designed for the efficient firm must consequently be contract $D$ characterized by a binding $\bar{U}$ constraint and by $g = e^*$.

It remains to discuss the contract designed for the inefficient type. First, because paying out rent is costly, this contract must be on this type's zero-rent indifference curve as shown in figure 2. Secondly, the inefficient type's contract must be at the right of his first-best contract $B$: a contract at the left of $B$ would imply greater transfers to both the inefficient and the efficient firm; moreover, contract $B$ cannot itself be part of an optimum, because moving slightly to the right of $B$ on the curve $\bar{U} = 0$ implies only a second-order loss with respect to the inefficient type's cost distortion, but allows a first-order gain with respect to the rent paid to the efficient type. The optimal menu of contracts must therefore have the following characteristics: (i) $\bar{U} = 0$, and $\bar{C} \geq \bar{C}$ or equivalently $\bar{e} < e^*$; (ii) $\bar{U} > 0$, and $\bar{C} = \bar{C}$ or equivalently $\bar{e} = e^*$. Observe that these results imply that $\bar{U}$ and $\bar{C}$ are binding, while $\bar{R}$ and $\bar{C}$ are not binding.

The contracts $D$ and $E$ involve a welfare loss with respect to the complete information situation because of the rent earned by the efficient type and because of the inefficient type's suboptimal effort. The rent that must be paid out is given by

$$
\bar{U} = \bar{\ell} - \psi(\bar{\beta} - \bar{C}) \\
= \psi(\bar{\beta} - \bar{C}) - \psi(\bar{\beta} - \bar{C}) \\
= \Phi(\bar{e})
$$

(2.10)

where, letting $\Delta \beta = \bar{\beta} - \bar{\beta}$,

$$
\Phi(\bar{e}) \equiv \psi(\bar{e}) - \psi(\bar{e} - \Delta \beta)
$$

(2.11)

\footnote{It follows that the equilibrium rent $AD$ (in figure 2) is smaller than the rent $AA'$ (in figure 1b) that would be required if there were no cost distortion.}
is the "rent function" in terms of the inefficient type's effort level.\footnote{When \( \bar{e} < \Delta \bar{\beta} \), \( \Phi(\bar{e}) = \psi(\bar{e}) \); that is, the efficient firm can misrepresent its type at zero cost in terms of effort.} Clearly \( \Phi'(\bar{e}) > 0 \): to induce more effort from the inefficient type requires paying out more rent to the efficient type. In designing the menu of contracts, the regulator will therefore be trading-off the rent paid to the efficient type — $1 of rent having social cost of $\lambda$ — against the cost distortion of the inefficient type — $1 of cost distortion having social cost of $ (1 + \lambda)$. The regulator will also want to take into account the relative likelihood of facing a $\beta$ or a $\bar{\beta}$ firm. Let $\nu$ denote the probability of facing the efficient type.

Under full information, expected welfare (prior to observing $\beta$ but knowing that it will be observed before a contract is offered) is given by

\[ W^{FI} = \nu W^{FI} + (1 - \nu)\bar{W}^{FI}, \]  

(2.12)

where \( W^{FI} \) and \( \bar{W}^{FI} \) are the first-best ex post welfare levels for a $\beta$ and $\bar{\beta}$ firm respectively. Under asymmetric information, the expected welfare

\[ W = \nu W(\beta, \bar{C}, \bar{i}) + (1 - \nu)W(\bar{\beta}, \bar{C}, \bar{i}) \]  

(2.13)

depends on the menu of contracts chosen by the regulator. From the preceding discussion, different menus will differ only in the inefficient type’s cost target or effort level, so that $W$ can be written as a function of $\bar{e}$. Choosing the optimal incentive scheme is equivalent to maximizing $W(\bar{e})$ with respect to $\bar{e}$. In turn, this is equivalent to minimizing the welfare loss with respect to the full information situation,

\[ W^{FI} - W(\bar{e}) = \nu \lambda \Phi(\bar{e}) + (1 - \nu)(1 + \lambda)[(\bar{\beta} - \bar{e}) + \psi(\bar{e})] - (\bar{\beta} - \bar{e} - \psi(\bar{e})] \]  

(2.14)

This leads to the first-order condition:

\[ 1 - \psi'(\bar{e}) = \frac{\nu \lambda}{1 - \nu 1 + \lambda} \Phi'(\bar{e}) \]  

(2.15)

The left-hand side of equation (2.15) is the marginal reduction in the total cost of the inefficient firm following an increase in its effort level; the right-hand side is the ensuing marginal increase in the rent earned by the efficient firm, corrected
for the relative cost of rent versus cost distortions and for the odds of facing an efficient versus an inefficient firm. Let the solution to (2.15) be denoted by $\bar{\varepsilon}^S$.

In figure 3, the area from an arbitrary $\bar{\varepsilon}$ to $\varepsilon$ under the downward sloping curve is the value of the inefficient type’s cost distortion for an arbitrary $\bar{\varepsilon}$. The area from the origin to $\bar{\varepsilon}$ under the upward sloping curve is proportional to the rent paid to the efficient type. The total welfare loss with respect to the full information situation is proportional to $a + b$\textsuperscript{7} If the principal wanted to induce the inefficient type to exert the first-best effort, the welfare loss would equal the area $a + b + c$. The comparative statics of the second-best solution are easily derived from figure 3. If the probability $\nu$ of facing an efficient firm increases, the upward sloping curve rotates counterclockwise and as a result the effort required from the inefficient type will decrease: an increase in $\nu$ increases the expected relative cost of paying a rent, and less effort should consequently be required from the inefficient type in order to reduce the prospective rent. Writing $\bar{\varepsilon}^S$ explicitly in terms of $\nu$, we therefore have $d\bar{\varepsilon}^S(\nu)/d\nu < 0$, with $\bar{\varepsilon}^S(0) = \varepsilon^*$. As a final remark, we may ask whether the regulator should necessarily realize the project irrespective of the firm’s type, as taken for granted until now. If the regulator decides to keep only the efficient type, he should offer contract $A$ in figure 1b. Because $A$ does not satisfy IR, the project will not be realized if the firm is the inefficient type and expected welfare will equal $\nu W^{F1}$. Letting $W^{A1}$ denote the expected welfare under the previous solution (AI stands for “asymmetric information”), it is profitable to keep both types if $W^{A1} \geq \nu W^{F1}$, a condition that is obviously satisfied if the probability of facing the efficient type is small. To see whether it holds for all values of $\nu$, consider the menu composed of contract $A$ and of the contract $(C, t) \equiv (\bar{\beta}, 0)$, the zero-effort contract for the inefficient type.\textsuperscript{8} This menu gives the expected welfare

$\nu W^{F1} + (1 - \nu) \{ S - (1 + \lambda) \bar{\beta} \}.$

Now, if $S - (1 + \lambda) \bar{\beta} > 0$, offering this menu is preferable to shutting down the inefficient firm. For simplicity, it is assumed that $S$ is large enough for the preceding condition to hold. The regulator then always keeps both types and $\bar{\varepsilon}^S(\nu)$, as defined in (2.15), characterizes the solution for any $\nu$ between 0 and 1.\textsuperscript{9}

\textsuperscript{7}The welfare loss $W^{F1} - W(\varepsilon^*)$ is equal to $(1 - \nu)(1 + \lambda) \times \text{area} a + b$.

\textsuperscript{8}This menu is implementable because $(\bar{\beta}, 0)$ does not dominate $A$ for the low-cost firm: in figure 1b, the efficient type’s indifference curve through $A$ coincides with the horizontal axis for $t = 0$ and $\beta \geq \beta$.

\textsuperscript{9}$\bar{\varepsilon}^S(\nu)$ tends to 0 as $\nu$ tends to 1. When the assumption on $S$ does not hold, there exists a critical $\bar{\nu}$ such that the inefficient firm is shutdown when $\nu > \bar{\nu}$. 9
3. Two-Period Relationship under Full Commitment

Consider now a continuing relationship between the regulator and the firm over a two-period horizon for the case where the same project is to be realized in each period. Full commitment means that at the beginning of the first period the regulator can offer an immutable menu of long-term contracts. A long-term contract is a sequence of cost targets and net transfers, denoted \((C_1, t_1, C_2, t_2)\). The interpretation of such a contract is as follows: if the realized cost in the first period is \(C_1\), the transfer \(t_1\) is paid in that period and the firm is entitled to the transfer \(t_2\) in period two, provided in that period it meets the cost target \(C_2\).

Both parties have the same discount factor \(\delta\). Letting \(U_\tau \equiv t_\tau - \psi(\beta - C_\tau)\) denote the firm’s surplus in period \(\tau\), for \(\tau = 1, 2\), its overall discounted surplus is \(U_1 + \delta U_2\). The menu of long term contracts \((C_1, t_1, C_2, t_2)\) and \((\overline{C}_1, \overline{t}_1, \overline{C}_2, \overline{t}_2)\) must satisfy the incentive compatibility constraints

\[
[t_1 - \psi(\beta - C_1)] + \delta [t_2 - \psi(\beta - C_2)] \geq [t_1 - \psi(\beta - C_1)] + \delta [t_2 - \psi(\beta - C_2)],
\]

\((IC\ \text{constraint})\) \hspace{1cm} (3.1)

\[
[t_1 - \psi(\overline{\beta} - \overline{C}_1)] + \delta [t_2 - \psi(\overline{\beta} - \overline{C}_2)] \geq [t_1 - \psi(\overline{\beta} - \overline{C}_1)] + \delta [t_2 - \psi(\overline{\beta} - \overline{C}_2)],
\]

\((IC\ \text{constraint})\) \hspace{1cm} (3.2)

and the individual rationality constraints

\[
[t_1 - \psi(\beta - C_1)] + \delta [t_2 - \psi(\beta - C_2)] \geq 0, \hspace{1cm} (IR\ \text{constraint}) \hspace{1cm} (3.3)
\]

\[
[t_1 - \psi(\overline{\beta} - \overline{C}_1)] + \delta [t_2 - \psi(\overline{\beta} - \overline{C}_2)] \geq 0. \hspace{1cm} (IR\ \text{constraint}) \hspace{1cm} (3.4)
\]

This formulation of the constraints takes for granted that the firm is bound by the contract it has chosen in period one; that is, it cannot quit the relationship in period two. In fact, we need not assume that the firm has the capacity to commit, since the timing of transfers can always be chosen so that the second period surplus is non negative, implying that the firm will want to stick to the contract. To make the comparison with noncommitment easier, it will henceforth be assumed that only the regulator can commit. To prevent the firm from quitting the relationship, we therefore add the second-period individual rationality constraints:

\[
U_2 \equiv t_2 - \psi(\beta - C_2) \geq 0, \hspace{1cm} (3.5)
\]

\[
\overline{U}_2 \equiv \overline{t}_2 - \psi(\overline{\beta} - \overline{C}_2) \geq 0. \hspace{1cm} (3.6)
\]

The regulator’s objective is to maximize the overall discounted welfare \(W \equiv W_1 + \delta W_2\), where \(W_1\) and \(W_2\) are ex ante welfare levels, given the probability
priors with respect to the firm's type, as defined in the preceding section. The basic result is that the optimal long-term menu of contracts is equivalent to a repetition of the optimal one-period menu. That is, the inefficient firm earns no rent and it exerts the effort level $\bar{e}^S$ in each period; the efficient firm exerts the first-best effort $e^*$ in each period and it earns a total rent equal to $\Phi(\bar{e}^S) + \delta \Phi(\bar{e}^S)$.

To see why, note first that both the IR and the LC constraints must be binding in the solution (otherwise the rent transferred to either type could be reduced). Furthermore, as in the static case, for any rent earned by the efficient type, the total gross payment to this type is minimized if it exerts the first-best effort. Given that the inefficient type earns no rent and that the efficient type's effort is $e^*$ in each period, the only remaining degrees of freedom are the inefficient type's effort levels $\bar{e}_1$ and $\bar{e}_2$ in period one and two. By straightforward substitution from the binding IR and the LC constraints, discounted welfare can be written as

$$W = W(\bar{e}_1) + \delta W(\bar{e}_2), \quad (3.7)$$

where $W(\cdot)$ is the static ex ante welfare as a function of the inefficient type's effort. Since $\bar{e}^S$ maximizes the ex ante static welfare, maximizing $W$ with respect to $\bar{e}_1$ and $\bar{e}_2$ leads to

$$\bar{e}_1 = \bar{e}_2 = \bar{e}^S.$$  

4. Commitment and Renegotiation

4.1. Renegotiation-Proofness

Under full commitment, the regulator offers a menu of long-term contracts whereby, in each period, the low-cost firm is induced to exert the first-best effort level $e^*$ while the high-cost firm exerts the static second-best effort $\bar{e}^S$. At the beginning of the second period the firm's type is known to the regulator. If the firm turns out to be the high-cost type, the effort level $\bar{e}^S$ could then obviously be improved upon ex post; that is, the second period welfare could be increased if the regulator offered to renegotiate the initial contract by paying the net transfer $\psi(e^*)$ for the realization of the first-best cost $C^* = \bar{\beta} - e^*$, rather than paying $\psi(\bar{e}^S)$ for the second-best cost $C^S = \bar{\beta} - \bar{e}^S$ as specified in the original contract. The full commitment framework therefore assumes that somehow the parties will not be allowed to exploit ex post Pareto-improving opportunities. In general, such long-term contracts are not renegotiation-proof (Dewatripont (1989)).
Under "commitment and renegotiation", such a strong form of commitment is not feasible. It follows that, in any equilibrium where types are revealed at date 1, it will be common knowledge that the high-cost firm will be induced to exert the first-best effort at date 2. Taking this fact into account in the incentive compatibility constraints, separation can now be obtained only by promising more rent to the low-cost firm, compared to what is required in the full-commitment framework. To see this, consider the separating outcome where the low-cost firm exerts $e'$ at each date, while the high-cost exerts $\bar{e}^S$ at date 1 and $e^*$ at date 2. To ensure separation, the low-cost firm must be promised the rent level $\Phi(\bar{e}^S) + \delta \Phi(e^*)$, which corresponds to the present value of the rent it would earn if it mimicked the high-cost firm. If $\Phi(\bar{e}^S)$ is paid out at date 1 and $\Phi(e^*)$ at date 2, the first-period welfare is $W^{AI}$ as under full-commitment while the second-period welfare is $W^{FI} - \nu_1 \lambda \Phi(e^*)$, where $W^{FI} - \nu_1 \lambda \Phi(e^*) < W^{AI}$.

The date 1 and date 2 welfare levels for the separating outcome under commitment and renegotiation are represented by point $A$ in figure 4. The figure is drawn under the convention that, in the contract designed for the low-cost firm, the rent paid at date $\tau$ is equal to $\Phi(\bar{e}_\tau)$, where $\bar{e}_\tau$ is the high-cost firm's effort at date $\tau$. In other words, the timing of transfers is assumed to be such that the efficient type's incentive compatibility constraint is satisfied on a date by date basis. Point $C$ represents the welfare levels under full-commitment. For any welfare pair $(W_1, W_2)$, the overall discounted welfare is equal to $W_1 + \delta W_2$. An isowelfare line with (negative) slope equal to $1/\delta$ have been drawn through $A$. The discounted welfare loss due to the inability to commit not to renegotiate is obviously greater the larger the value of $\delta$. Point $A$ is the best the regulator can do under commitment and renegotiation with a separating menu of contracts in the first-period and will be referred to as the best separating contract.\footnote{Other separating contracts are of course feasible (e.g., more rent could be promised to the efficient type) but would lead to a lower total discounted welfare.}

By contrast, point $B$ depicts the welfare levels that can be reached by offering a contract which pools the two types with respect to the cost target for date 1. Because with such a contract the firm does not reveal its type, the regulator's information at date 2 will be the same as in the static one-period framework. A commitment to offer the best static menu at date 2 (thus leading to the welfare level $W^{AI}$ at that date) would then satisfy the renegotiation-proofness requirement. The first-period welfare level, $W^P$, is the optimal one-period welfare that
can be attained by a single (pooling) contract, i.e.,

\[ W^P = \max_{\beta, t} \nu W(\beta, C, t) + (1 - \nu)W(\overline{\beta}, C, t) \]  \hspace{1cm} (4.1) \]

where the maximization is subject to the static incentive-compatibility and individual compatibility constraints (see the section 2.2). Letting \( C^P \) and \( t^P \) denote the solution to (4.1), with \( \overline{\beta}^P = \overline{\beta} - C^P \) as the inefficient firm's effort, it is easily seen that \( t^P = \psi(\overline{\beta}^P) \) so that the inefficient firm earns no rent; furthermore, \( Q^* \leq C^P \leq \overline{C}^* \) or equivalently \( e^* \leq \overline{e}^P \leq e^* + \Delta \beta \). The effort level of the efficient firm is \( \overline{e}^P - \Delta \beta \), which is less than the first best, and the firm earns a rent equal to \( \Phi(\overline{e}^P) \). Since \( W^{A1} \) is the best feasible static level of welfare, we have \( W^P < W^{A1} \). Point B for the two-period relationship will be referred to as the best pooling contract.

Considered as long-term contracts, the best pooling and best separating contracts are renegotiation-proof in the sense that the terms of the contract cannot be improved upon ex post (i.e., at date 2). In the separating outcome, a firm that realizes \( Q^* \) at date 1 is paid the net transfer \( \psi(e^*) + \Phi(\overline{e}^S) \) at that date and is promised \( \psi(e^*) + \Phi(e^*) \) if it realizes \( Q^* \) at date 2; although the rent committed to for date 2 is greater than under full-commitment, there is no scope for mutually beneficial renegotiation. A firm that realizes \( \overline{C}^S \) in period one is paid \( \psi(\overline{e}^S) \) at that date and is promised \( \psi(e^*) \) if it realizes \( \overline{C}^* \) at date 2. In the pooling outcome, any firm that participates at date 1 is promised the opportunity to choose at date 2 its best option in the optimal static menu. The latter is trivially renegotiation-proof.

It is also possible to interpret the best-pooling solution as a sequence of short-term (i.e., one-period) contracts, in the sense that the second period allocation would be implemented even in the absence of any form of commitment; this follows from the fact that, given the regulator's information at the beginning of the second period, the optimal static menu is sequentially optimal. The best-separating solution, on the other hand, necessarily implies a form of long-term commitment with respect to a firm which reveals that it is the low-cost type, since this firm is promised to be paid a rent at date 2; in other words, the second-period welfare is a constrained sequential optimum, subject to the transfers committed to at the beginning of the first period. From this point of view, the best-separating solution can be interpreted as a menu with a long-term contract (designed for the low-cost type) and a series of short-term contracts (designed for the high-cost type).

In figure 4, the slope of the isowelfare lines is such that the best separating solution dominates the best pooling solution. Whether or not this is the case
depends on the discount factor and there clearly exists a critical value $\delta$ such that the best pooling allocation dominates the best separating one whenever $\delta$ is greater than this critical value.

4.2. Semi-Separating Contracts

Compared to the full-commitment scheme, the best separating contract under commitment and renegotiation involves too much information revelation in the first period. Because the parties cannot commit not to renegotiate, it will not be possible to disregard that information at the beginning of the second period and, as a consequence, the second-period allocation will be distorted away from the second-best static scheme. By contrast, the best pooling contract involves too little information revelation in the first period. Although the optimal static scheme will remain feasible in the second period, the first-period allocation is distorted because the regulator extracts too little information from the firm.

A semiseparating menu of contracts constitutes an intermediate solution, with more information revelation than under pooling but less than under full separation. The purpose of a semiseparating menu is to reduce the ratchet effect with respect to the inefficient firm’s effort in order to reduce the rent that must be paid to the efficient firm, while still obtaining some information at the beginning of the relationship. This can be done by offering the firm a choice between two contracts in the first period. One contract (call it $b$) is picked by the low-cost firm only. The other contract (call it $a$) involves partial pooling in the sense that it is picked by the high-cost firm and also, with some probability, by the low-cost firm.

Let $x$ denote the probability that the efficient firm chooses contract $b$ and let $\nu_1$ now denote the prior probability of facing the low-cost type. Contract $b$ is chosen with probability $x\nu_1$. Contract $a$ is chosen with probability $(1-x)\nu_1 + (1-\nu_1)$. If the firm has been observed to choose $a$, the posterior probability (at date 2) that the firm is the low-cost type is therefore

$$\nu_2(x) = \frac{(1-x)\nu_1}{(1-x)\nu_1 + (1-\nu_1)}$$ (4.2)

Note that $x = 1$ corresponds to full separation (i.e., the limiting case where contract $a$ is picked by the high-cost firm only) and $x = 0$ to full pooling (both types pick $a$ and contract $b$ is not offered).

Contract $b$ is a long term contract specifying the first-best cost target $C^*$ at each date and paying the net transfers $t^*_1$ and $t^*_2$ at date 1 and 2. For the efficient
firm, the total discounted utility of \( b \) is

\[
U^b = \left[ t_1^b - \psi(\beta - C_1^b) \right] + \delta \left[ t_2^b - \psi(\beta - C_2^b) \right] \\
= \left[ t_1^b - \psi(e^*) \right] + \delta \left[ t_2^b - \psi(e^*) \right]
\]  

(4.3)

Contract \( a \) is a short-term one-period contract specifying the cost-target \( C_1^a \) and net transfer \( t_1^a \) for date 1 (the case where \( a \) is a long-term two-period contract is dealt with below). When the firm has chosen \( a \) in the first period, at date 2 the regulator puts posterior beliefs \( \nu_2(x) \) on the firm’s having the efficient type and will offer the menu \( \{(C_2, t_2); (\overline{C}_2, \overline{t}_2)\} \) which maximizes welfare ex post on the basis of these beliefs. The second-period contract is therefore the optimal static scheme for the beliefs \( \nu = \nu_2(x) \). Therefore,

\[
C_2 = C^* \text{ or equivalently } e_2 = e^*, \text{ and } t_2 = \psi(e^*) + \Phi(\overline{e}_2),
\]  

(4.4)

\[
\overline{C}_2 = \overline{C}^S[\nu_2(x)] \text{ or equivalently } \overline{e}_2 = \overline{e}^S[\nu_2(x)], \text{ and } \overline{t}_2 = \psi(\overline{e}^S[\nu_2(x)]).
\]  

(4.5)

We now consider the incentive-compatibility and individual rationality constraints. First, since there is no point in paying out rent to the high-cost type, contract \( a \) is characterized by

\[
t_1^a = \psi(\overline{\beta} - C_1^a)
\]  

(4.6)

where \( \overline{\beta} - C_1^a \equiv \overline{e}_1^a \) is the inefficient firm’s effort under \( a \). For the efficient firm, the discounted utility of the one-period contract \( a \), given the prospect of the conditionally optimal static menu at date 2, is given by

\[
U^a = \left[ t_1^a - \psi(\beta - C_1^a) \right] + \delta \Phi(\overline{e}^S[\nu_2(x)]).
\]  

(4.7)

For the efficient type to randomize between \( a \) and \( b \), we must have \( U^a = U^b \). This may be done, on a date by date basis so to speak, by setting

\[
t_2^b = t_2^a, \quad t_1^b - \psi(e^*) = t_1^a - \psi(\beta - C_1^a).
\]  

(4.8)

(4.9)

Whether it chooses \( a \) or \( b \), the low-cost firm’s rent at date 2 will then be \( \Phi(\overline{e}^S[\nu_2(x)] \) and its rent at date 1,

\[
[\psi(\beta - C_1^b) - \psi(\beta - C_1^a)] = \Phi(\overline{\beta} - C_1^a)
\]
We now examine how expected welfare at date 1 and 2 is determined given the randomization probability $x$:

(i) Expected welfare at date 2 is equal to

$$W_2 = x\nu_1 W(\bar{\beta}, C^*_1, t^*_1) + (1-x)\nu_1 W(\bar{\beta}, \bar{C}^*_2, t^*_2) + (1-\nu_1)W(\bar{\beta}, \bar{C}^*_2, \bar{t}_2)$$

(4.10)

Substituting from (4.4) and (4.8), this can be rewritten as

$$W_2 = \nu_1 W[\bar{\beta}, \bar{C}^*, \psi(e^*) + \Phi(\bar{\beta} - \bar{C}^*_2)] + (1-\nu_1)W[\bar{\beta}, \bar{C}^*_2, \psi(\bar{\beta} - \bar{C}^*_2)]$$

(4.11)

Since $\bar{C}^*_2 = \bar{C}^S[\nu_2(x)]$ by (4.5), expected welfare at date 2 is completely determined once $x$ is known and will be denoted $\tilde{W}_2(x)$.

(ii) Expected welfare at date 1 is given by

$$W_1 = x\nu_1 W(\bar{\beta}, C^*_1, t^*_1) + (1-x)\nu_1 W(\bar{\beta}, C^*_1, t^*_1) + (1-\nu_1)W(\bar{\beta}, C^*_1, t^*_1)$$

(4.12)

Substituting from (4.9) and writing out explicitly we have

$$W_1 = S - (1+\lambda)[x\nu_1 [\rho + \psi(\beta - C^*_1)] + (1-x)\nu_1 [C^*_1 + \psi(\beta - C^*_1)]]$$

$$+ (1-\nu_1)[C^*_1 + \psi(\beta - C^*_1)] - \lambda \nu_1 \Phi(\beta - C^*_1)$$

(4.13)

For any given $x$, the short-term first-period contract should maximize $W_1$. This problem is similar to that of finding the optimal pooling contract in the preceding section, except for the fact that with probability $x$ the efficient type will realize his first-best cost target. Let $C^*_1(x)$ or equivalently $\bar{C}^*_1(x) = \bar{\beta} - C^*_1(x)$ maximize $W_1$; because this is a concave program, $C^*_1(x)$ solves

$$\partial W_1 / \partial C^*_1 = 0$$

(4.14)

It is easily seen that $C^p \leq C^*_1(x) \leq \bar{C}^S$ for $x$ in $[0,1]$ and furthermore that $dC^*_1(x)/dx < 0$. When $x = 0$, we have the full-pooling solution $C^*_1 = C^p$; when $x = 1$, only the inefficient type chooses a and the cost target is $C^*_1 = \bar{C}^S$. Let $\tilde{W}_1(x)$ denote the date 1 welfare as a function of $x$. 

16
4.3. The Intertemporal Welfare Frontier

The randomization probability $x$ determines how much information is revealed in
the first period. Figure 4 depicted the trade-off between the date I and date 2
welfare levels for the two extreme cases of full separation ($x = 1$) or full pooling
($x = 0$) in the first period. Allowing $x$ to vary between zero and one, $\bar{W}_1(x)$
and $\bar{W}_2(x)$ will trace out an opportunity locus in the $(W_1, W_2)$ plane. We now
examine the form of this locus which will be referred to as the intertemporal
welfare frontier.

Consider first the date 2 welfare. From (4.11),

$$\frac{d\bar{W}_2(x)}{dx} = \frac{\partial W_2}{\partial C_2} \frac{dC^S[
u_2(x)]}{dx} \quad (4.15)$$

Clearly, $d\nu_2(x)/dx < 0$ and $0 \leq \nu_2(x) \leq \nu_1$ with strict inequalities
for $x \neq 0, 1$. Since $C^S$ is decreasing in the probability of facing the low-cost type, we have

$$\frac{dC^S[
u_2(x)]}{dx} > 0 \quad (4.16)$$

so that

$$C^* = C(0) < C^S[\nu_2(x)] < C^S[\nu_1] \equiv \overline{C}^S \quad \text{for} \quad x \neq 0, 1. \quad (4.17)$$

We know that $W_2$ is maximized (and equals $W^{AI}$) for $\overline{C}_2 = \overline{C}^S$, which occurs
when $x = 0$. Therefore, given (4.17), $\partial W_2/\partial C_2 > 0$ for $x \neq 0$ and $\partial W_2/\partial C_2 = 0$
at $x = 0$, leading to

$$\frac{d\bar{W}_2(x)}{dx} < 0 \quad \text{for} \quad x \neq 0 \quad (4.18)$$

and

$$\frac{d\bar{W}_2(x)}{dx} = 0 \quad \text{for} \quad x = 0 \quad (4.19)$$

When $x = 1$, $\nu_2 = 0$ and $W_2 = W^{FI} - \nu_1 \lambda \Phi(e^*)$.

Figure 5 illustrates the second-period welfare loss due to the inability to fully
commit. Welfare would be maximized by setting $\overline{e}_2 = \overline{e}^S$ as in the static scheme.
However, in the absence of full commitment, the effort required from the inefficient
firm is the sequentially optimal $\overline{e}_2 = \overline{e}^S[\nu_2(x)]$. This solves

$$1 - \psi'(\overline{e}_2) = \frac{\nu_2(x)}{1 - \nu_2(x)} \frac{\lambda}{1 + \lambda} \Phi'(\overline{e}_2)$$

$$= (1 - x) \frac{\nu_1}{1 - \nu_1} \frac{\lambda}{1 + \lambda} \Phi'(\overline{e}_2) \quad (4.20)$$
Equation (4.20) is the constraint arising from the renegotiation-proofness requirement. The shaded area in the figure is the welfare loss $W^A_1 - \bar{W}_1(x)$ relatively to the optimal static allocation. Except when $x = 0$, the inefficient type is induced to exert more effort (i.e., it is induced to reach a lower cost target) than in the optimal static scheme. When $x$ decreases, less information is revealed in the first period and the renegotiation-proofness constraint rotates counterclockwise; this reduces the second period welfare loss (it vanishes at $x = 0$). When $x = 1$, the constraint coincides with the horizontal axis and $\bar{e}_2 = e^*$.

Consider now the date 1 welfare. From (4.13),

$$\frac{d\bar{W}_1(x)}{dx} = \frac{\partial W_1}{\partial C_1^e} \frac{dC_1^e(x)}{dx} + \frac{\partial W_1}{\partial x}$$  \hspace{1cm} (4.21)

Using the first-order condition (4.14) and writing out $\partial W_1/\partial x$, we have

$$\frac{d\bar{W}_1(x)}{dx} = \frac{\partial W_1}{\partial x} = (1 - \lambda)\nu_1\{(C_1^e + \psi(\beta - C_1^e)) - [C^* + \psi(\beta - C^*)]\} > 0,  \hspace{1cm} (4.22)$$

where the inequality follows from the fact that $C_1^e \neq C^*$.

Figure 6 is similar to figure 4, except that we have drawn the welfare opportunity locus between point $B$ (full pooling at date 1 with $x = 0$) and point $A$ (full separation at date 1 with $x = 1$). The slope of the locus is given by

$$\frac{dW_2}{dW_1} = \frac{d\bar{W}_2(x)/dx}{d\bar{W}_1(x)/dx}$$  \hspace{1cm} (4.23)

The slope is negative for $x \neq 0$ and it equals zero at $x = 0$. The locus is concave in a neighborhood of $x = 0$ but need not be concave for all values of $x$.

Along the $AB$ curve in figure 6, the value of $x$ increases when we move from $B$ to $A$. The optimal intertemporal scheme under commitment and renegotiation is obtained by choosing the randomization probability $x$ so as to maximize the total discounted welfare

$$\bar{W}_1(x) + \delta\bar{W}_2(x)$$

This is equivalent to choosing the point on the $AB$ curve that lies on the highest isowelfare line. Two cases are represented in figure 6 for different discount factors. When $\delta$ is less than some critical value $\delta_{CR}$, the optimal scheme is the full separation solution $x = 1$. When $\delta = \delta_{CR}$, the regulator is indifferent between full separation at date 1 and the semiseparating contract denoted by $D$. For $\delta > \delta_{CR}$,
the solution is a semiseparating contract and the equilibrium $x$ is non-increasing in $\delta$; that is, the higher the discount rate the less information will the regulator want to extract from the firm at date 1. Note that, because the slope of $AB$ is zero at $x = 0$, a full pooling solution is never optimal.\footnote{Full pooling would require an infinite discount factor, which is equivalent to giving no weight to the first period welfare loss.}

4.4. Short-Term vs Long-Term Contracts

In the preceding discussion, contract $b$ is a long-term contract whereby the regulator commits to pay out a rent at date 2 to the efficient firm; since the date 2 cost-target is the first-best cost, there is no scope at that date for a mutually beneficial renegotiation. Contract $a$ has been described as a short-term (one-period) contract, following which the firm can anticipate the sequentially optimal static menu at date 2. We now inquire whether welfare could not be increased if, rather than $a$, the regulator offered in period one a long-term contract $a' = \{(C_1', t_1'), (C_2', t_2'), (C_3', t_3')\}$. With contract $a'$, the regulator is committed to pay the transfers $t_2'$ and $t_3'$ at date 2 if the firm realizes the cost target $C_2'$ or $C_3'$. For any given $x$, it is clear that the total discounted welfare will be different with $a'$ only if the second period menu written in the contract differs from the sequentially optimal menu $\{(C_2, t_2), (C_3, t_3)\}$ which follows a one-period contract. Now, if $\{(C_2', t_2'), (C_3', t_3')\}$ is to be adhered to at date 2, it must be renegotiation-proof, which means that it must be a constrained sequential optimum, the constraints being the levels of rent promised to the high and low cost type at date 2. These constraints are binding only if at least one of the two types can expect to earn more rent under $a'$ than with the unconstrained sequentially optimal menu. It follows that the second-period welfare under $a'$ cannot be greater than under $a$, that is, $W_{2'}^a(x) \leq W_2(x)$. Therefore, if $a'$ is to dominate $a$, it must be because it allows an increase in the first-period welfare. But then, given any renegotiation-proof second-period menu, it is easily seen that the best the regulator can do with respect to the first-period allocation is to set $(C_1', t_1')$ equal to $(C_1, t_1)$, as defined in the previous section, so that $W_1^a(x) = W_1(x)$. Therefore, $a'$ cannot strictly dominate $a$ and the best long-term contract is in fact the one which promises the sequentially optimal menu for date 2.
5. Noncommitment

5.1. The Timing of Transfers

In the previous section, the lack of full commitment introduced some inefficiency because of a form of ratcheting: information revealed in period one could not be disregarded in period two and led to the ratcheting of the inefficient type’s effort; this in turn increased the cost of separation at the beginning of the relationship. The absence of any form of commitment introduces an additional difficulty, since now the regulator cannot defer to period two the payment of the rent needed to induce separation in the initial period (i.e., only short-term contracts are feasible). By revealing its type today, the efficient firm jeopardizes its future rent. As a consequence, if separation is to be obtained, the efficient firm must be paid its informational rent at the beginning of the relationship. In other words, noncommitment introduces a constraint on the timing of transfers. With respect to the inefficient type, this leads to the possibility of the take-the-money-and-run strategy; that is, the inefficient type could misrepresent its type in period one, pocket the larger incentive payment designed for the efficient type, and then quit the relationship in period two. Since the incentive payment that must now be paid in period one increases with the discount factor, the take-the-money-and-run strategy will matter only when the discount factor is above some critical value. When this is the case, the incentive compatibility constraints of both the efficient and the inefficient type become binding in period one. This will distort the allocation from what was feasible under commitment and renegotiation.

There are therefore two cases to consider. In the first one, only the incentive compatibility constraint of the efficient type is binding. Although the timing of transfers will differ, this leads to the same allocation as under commitment and renegotiation. In the second case, the two incentive compatibility constraints are binding and the allocation will be distorted from that under commitment and renegotiation. The intuition is the following. In order to avoid the take-the-money-and-run strategy, the regulator may adopt one of the two following strategies. Either he tolerates more pooling and reduces the incentives to the efficient type; because the first-period transfer to the efficient type is smaller, the inefficient firm has less incentive to mimic. Or he increases even more the incentives to the efficient type by fixing its cost at a level lower than the first-

12 This is the standard “ratchet effect” noted by various authors. See for instance Freixas et al. (1985).
best; this can also prevent the take-the-money-and-run strategy by increasing the mimicking cost of the inefficient type. In either case there will be more distortion from the first-best than under commitment and renegotiation.

When the two incentive compatibility constraints are binding, both types may randomize in equilibrium. Let \((C^0, t^0)\) and \((C^1, t^1)\) constitute the two-contract menu offered in period one.\(^{13}\) Let \(x\) denote the probability that the efficient type chooses \((C^0, t^0)\); similarly, let \(y\) denote the probability that the inefficient type chooses \((C^0, t^0)\). Without loss of generality, we may take \(x \geq y\); that is, contract \((C^0, t^0)\) is by convention the one that is more likely to be chosen by the efficient type. At date two, if contract \((C^0, t^0)\) has been chosen, the posterior probability that the firm is the efficient type is given by

\[
\nu^0(x, y) = \frac{x \nu_1}{x \nu_1 + y(1 - \nu_1)}.
\]  

(5.1)

If contract \((C^1, t^1)\) has been chosen, the posterior probability that the firm is the efficient type is

\[
\nu^1(x, y) = \frac{(1 - x) \nu_1}{(1 - x) \nu_1 + (1 - y)(1 - \nu_1)}.
\]  

(5.2)

At date two, it is sequentially optimal for the regulator to offer as short-term second-period contracts the optimal static scheme with respect to \(\nu^0\) or \(\nu^1\), depending on what contract was chosen by the firm in the initial period. Following \((C^0, t^0)\), the second-period expected welfare is therefore \(W^{AI}[\nu^0(x, y)]\). Following \((C^1, t^1)\), it is equal to \(W^{AI}[\nu^1(x, y)]\). Observe that \(x = 1\) and \(y = 0\) correspond to full separation; in period two, we then have \(\nu^0 = 1\) and \(\nu^1 = 0\). By contrast, when \(x = y\) we have \(\nu^0 = \nu^1 = \nu\): as with full pooling, the firm’s choice of contract in the first period provides no information about its type. We now turn to the first-period contracts.

5.2. Best Separating and Best Pooling First-Period Contracts

If the efficient firm chooses contract \((C^0, t^0)\), it will earn in period two a rent equal to \(U(\nu^0) \equiv \Phi[\pi^S(\nu^0)]\). If it chooses \((C^1, t^1)\), it will earn \(U(\nu^1) \equiv \Phi[\pi^S(\nu^1)]\) tomorrow. By contrast, the inefficient firm expects no rent in the next period. With two first-period contracts, and given the convention that the efficient type

\(^{13}\) Although, Laffont and Tirole discuss the possibility that the optimal first-period menu may consist of more than two contracts, the implication of the two-contract restriction is far from obvious.
at least some times chooses \((C^0, t^0)\), while the inefficient one at least some times chooses \((C^1, t^1)\), the incentive compatibility and individual rationality constraints for period one can be written as follows:

\[
\begin{align*}
t^0 - \delta U(\nu) + \delta U(\nu^0) & \geq t^1 - \delta U(\nu^1) \quad IC \\
t^1 - \delta U(\nu) & \geq t^0 - \delta U(\nu^0) \quad IC \\
t^0 - \delta U(\nu^0) & \geq 0 \quad IR \\
t^1 - \delta U(\nu) & \geq 0 \quad IR
\end{align*}
\] (5.3, 5.4, 5.5, 5.6)

As in the preceding sections, IR and IC imply IR; furthermore, in the solution IR is binding.

When IC is not binding, the inefficient type strictly prefers contract \((C^1, t^1)\) and therefore \(y = 0\), which implies that \(U(\nu^0) = U(1) = 0\). For the given \(x\), maximizing the total discounted welfare, subject to IR and IC, is easily seen to lead to the same allocation as under commitment and renegotiation. The only difference is the timing of the transfers paid to the efficient type. To see this, consider the full separation scheme defined by \(x = 1\), so that \(U(\nu) = U(0) = \Phi(e^*)\). Because the inefficient type earns no rent, (5.6) holds as an equality. After substituting for \(t^1\), the IC constraint can be written as

\[
t^0 = \delta U(\nu) + \delta U(\nu^0) + \delta U(\nu) = \psi(e^*) + \Phi(e^*) + \delta \Phi(e^*).
\] (5.7)

Under commitment and renegotiation, when the efficient type revealed its type in period one (which corresponds to choosing \((C^0, t^0)\) in the present context), it could be paid \(\psi(e^*) + \Phi(e^*)\) in period one and be promised to be paid \(\Phi(e^*)\) as rent in period two. Under noncommitment such a promise cannot be enforced and the total first-period transfer must therefore be as in (5.7).

For IC to be satisfied, we must have \(t^0 \leq \psi(\beta - Q^*)\). From the definition of \(t^0\) in (5.7), it is easily seen that this condition will be satisfied only if \(\delta\) is below some critical value. The situation is represented graphically in figure 7. The best separating contract under commitment and renegotiation corresponds to the menu \(D\) and \(E\). Under noncommitment, the first-period menu will be given by \(D'\) and \(E\). As drawn, the menu \(D'\) and \(E\) is feasible. However, larger values of \(\delta\) will push \(D'\) upwards and there will come a point where the inefficient type prefers \(D'\) to \(E\) (the "take-the-money-and-run" strategy). We now analyze the best separating
first-period menu when the inefficient type's incentive compatibility constraint is binding.

When $\mathcal{IC}$ and $\overline{\mathcal{IC}}$ are both binding, the first-period menu must be such that both types are indifferent between the two short-term contracts offered in period one. The best separating menu corresponds to $D''$ and $E''$, as shown in figure 8, and is characterized by $C < C^*$ and $\overline{C} > \overline{C}^\delta$. Formally, the contracts $(C^0, t^0)$ and $(C^1, t^1)$ are chosen so as to maximize

$$
\nu_1 W(\overline{\beta}, C^0, t^0) + (1 - \nu_1) W(\overline{\beta}, C^1, t^1)
$$

subject to the constraints (5.3) to (5.6). Letting $e^0$ denote the efficient type's effort if it picks $(C^0, t^0)$ and $\overline{e}^1$ the inefficient type's effort if it chooses $(C^1, t^1)$, and substituting from the binding $\overline{\mathcal{IR}}$ and $\mathcal{IC}$ constraints to eliminate $t^0$ and $t^1$, this is easily seen to be equivalent to minimizing

$$
(1 + \lambda)\{\nu_1[\overline{\beta} - e^0 + \psi(e^0)] + (1 - \nu_1)[\overline{\beta} - \overline{e}^1 + \psi(\overline{e}^1)]\} + \lambda \nu_1 \Phi(\overline{e}^1)
$$

subject to

$$
\Phi(e^0 + \Delta \beta) \geq \Phi(\overline{e}^1) + \delta \Phi(\psi^*)
$$

(5.8) (5.9)

The maximand is the same as under commitment and renegotiation. The difference is the added condition (5.9) which follows from the inefficient type's incentive compatibility constraint. When this condition is binding (i.e., for $\delta$ large enough), the efficient type's effort will be increased above the first-best level. The required increase is attenuated by decreasing the inefficient type's effort below $\overline{e}^\delta$. In other words, separation is maintained by increasing the effort differential between the two types.

In figure 9a, the curve $AB$ is the welfare frontier under commitment and renegotiation. The best pooling scheme (point $B$) of commitment and renegotiation remains feasible under noncommitment (the inefficient type's incentive compatibility constraint is then trivially satisfied). However, for a sufficiently large $\delta$, the best separating allocation represented by point $A$ is not feasible and the regulator cannot do better than $S_1$; if $\delta$ were still larger, the regulator could do no better than $S'$. In order to compare commitment and renegotiation with noncommitment, the figure has been drawn with the convention that the timing of transfers under noncommitment is the same as under commitment and renegotiation. 14

This explains why $A$, $S$ and $S'$ lead to the same second-period welfare.

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14Thus, for the menu $D''$ and $E''$ of figure 8, the payment of $U(0)$ to the efficient firm is by convention measured as if it were made at date 2, even though under noncommitment the amount $\delta U(0)$ has to be paid at date 1.
5.3. Double Randomization

Until now, the discussion has focused on the best pooling and best separating contracts. In Figure 9a, these correspond to $B$ and $A$ or, when the inefficient type’s self-selection constraint is binding, to $B$ and $S$ or $B$ and $S’$ depending on the value of the discount factor. As under commitment and renegotiation, allowing randomization generates a locus between the best separating and best pooling contracts. For instance, the curve $BS$ could have been generated by setting $y = 0$ and letting $x$ vary between 0 and 1. However, when both self-selection constraints are binding, one or both types could randomize between the first-period contracts $(C_0, t_0)$ and $(C_1, t_1)$; that is, both $x$ and $y$ could be greater than zero (with $x \geq y$).

For given $x$ and $y$, these first-period contracts maximize

$$x \nu_1 W(\beta, C_0, t_0) + y(1 - \nu_1) W(\beta, C_0, t_0)$$
$$+(1 - x) \nu_1 W(\beta, C_1, t_1) + (1 - y)(1 - \nu_1) W(\beta, C_1, t_1)$$

subject to (5.3) to (5.6). Recall that if the only binding self-selection constraint is $\text{LCE}$, we have $y \equiv 0$ and the solution is the same as under commitment and renegotiation. From now on both constraints are assumed to be binding. As in the previous section, let $g^0$ denote the efficient type’s effort if it picks $(C^0, t^0)$; its effort if it chooses $(C^1, t^1)$ is $g^1 - \Delta \beta$. And let $g^1$ denote the inefficient type’s effort if it chooses $(C^1, t^1)$; its effort, if it chooses $(C^0, t^0)$, is $g^0 + \Delta \beta$. Substituting from the binding constraints to eliminate $t^0$ and $t^1$, this program is equivalent to minimizing

$$(1 + \lambda) \{x \nu_1[\beta - g^0 + \psi(g^0)] + y(1 - \nu_1)[\beta - g^0 + \psi(g^0 + \Delta \beta)]$$
$$+ (1 - x) \nu_1[\beta - g^1 + \psi(g^1 + \Delta \beta)] + (1 - y)(1 - \nu_1)[\beta - g^1 + \psi(g^1)]\}$$
$$+ \lambda x \nu_1 \Phi(g^0 + \Delta \beta) + \lambda (1 - x) \nu_1 \Phi(g^1)$$

subject to the constraint

$$\Phi(g^0 + \Delta \beta) + \delta U(\nu^0) = \Phi(g^1) + \delta U(\nu^1).$$

(5.10)

A basic result is that, whenever $x = y$, the two first-period contracts $(C^0, t^0)$ and $(C^1, t^1)$ solving the preceding problem are identical and are in fact equal to the best pooling scheme. Since the posterior probabilities at date 2 satisfy $\nu^0 = \nu^1 = \nu_1$, the case where $x = y$ yields the best pooling outcome depicted by
point $B$. As under commitment and renegotiation, the solution to the principal’s problem is obtained by choosing the optimal degree of randomization. In the present case, this implies that the regulator optimize with respect to both $x$ and $y$. The complete solution can only be obtained numerically and some results are presented in the next section. Two general statements are nevertheless possible:

(i) First, if $\delta$ is sufficiently small, the optimal solution is the best separating contract. With $\delta$ small enough for $\tilde{I}C$ not to be binding, this yields point $A$ in figure 9a. When the constraint is binding, separation corresponds to a point such as $S$ or $S'$.

(ii) For $\delta$ sufficiently large, the solution necessarily involves double randomization, including as a possible case the best pooling solution (with arbitrary $x$ and $y$ satisfying $x = y$)\footnote{The possibility of a full pooling solution contradicts Proposition 9.10 in Laffont and Tirole. Note that their proof is in fact limited to a type 1 equilibrium (which implies that $\tilde{I}C$ is not binding and rules out the possibility of double-randomization).}. To see the intuition of this result, consider the case where, as in figure 9b, $\delta$ is so large that the best separating point $S''$ is at the left of $B$. Then it is clear that $B$ dominates $S''$ (in fact $S''$ cannot be part of an intertemporal welfare frontier). Now, a locus like $BS''$ can be generated by $y = 0$ and $x \in [0,1]$, as was done previously (and as was assumed in figure 9a). But it can also be generated by $x = 1$ and $y \in [0,1]$: this follows from the fact that point $S''$ is defined by $x = 1$ and $y = 0$, while point $B$ can be defined by $x = 1$ and $y = 1$. Both cases involve simple randomization. Because in each case (for a $\delta$ sufficiently large) simple randomization may be associated with a curve at the left of $B$ (such as the curve $BS''$), it is clear that the solution will require double randomization (including the possibility of full pooling). The effect of double randomization is to generate a locus (containing point $B$) which will be at the right of the best locus obtained under simple randomization.

6. Simulations

In this section we first present some simulation results for the case of commitment and renegotiation in order to show how different assumptions on critical parameters affect the optimal incentive scheme. These results will then be used as a benchmark in analyzing the more difficult problem of noncommitment. The
simulations are based on the quadratic utility of effort functions used by Laffont and Tirole in their Appendix 9.9.

6.1. Commitment and Renegotiation

Figure 10 depicts the intertemporal welfare frontier for different values of $\nu_1$. The values of the other parameters are $\beta = 1.5$, $\bar{\beta} = 2$, $s = 100$ and $\lambda = 0.1$. Point $A$ is the full separation scheme ($x = 1$) and point $B$ the full pooling one ($x = 0$). The shape of the welfare frontier depends on $\nu_1$; larger values of $\nu_1$ lead to a severely non-convex frontier. Figures 11 and 12 compare the optimal solutions for different values of $\nu_1$ and $\delta$. The overall discounted expected welfare, normalized as

$$W(x) = \frac{\tilde{W}_1(x) + \delta \tilde{W}_2(x)}{(1 + \delta)},$$

is represented as a function of $x$, the degree of separation in period one. For a given $\nu_1$, the type of equilibrium depends on $\delta$. Figure 11 describes the solution for $\nu_1 = 0.9$: when $\delta = 0.1$ the optimal solution is full separation, when $\delta = 10$ we have a semi-separating solution, while $x$ is practically equivalent to full pooling (without ever reaching it strictly speaking) for large values of $\delta$ such as $\delta = 100$. The results of Figure 12 also show that the fully separating scheme is more likely for smaller values of $\nu_1$, such as $\nu_1 = 0.5$. In fact, when $\nu_1 = 0.1$, full separation is optimal for all $\delta \leq 100$ (results not reported here but available on request). We now examine how the introduction of a second binding self-selection constraint affects the results.

6.2. Noncommitment

Under noncommitment, two types of equilibrium are of interest, depending on whether or not the incentive compatibility constraint of the inefficient type is binding. Recall that, for given parameters, the take-the-money-and-run strategy will matter only when the discount factor is sufficiently large. Table 1 reproduces the results from table 9.1 in Laffont and Tirole. Figures 13 and 14 depict the intertemporal welfare locus that correspond to these results.

In figure 13a, the curve $AB$ is the intertemporal welfare frontier under commitment and renegotiation as drawn in Figure 10. The optimal solutions under noncommitment for $\delta = 0.01$ and $\delta = 0.1$ are still on this frontier since only one self-selection constraint is binding. Full separation (point $A$) is optimal for these two low values of the discount factor. The curve $CB$ is the intertemporal welfare
locus for \( \delta = 1 \) when \( x \) varies between zero and unity, given \( y = 0 \); for this larger value of \( \delta \) the two self-selection constraints are binding. The curve \( CB \), as well as the curves represented in figure 13b for different positive values of \( y \), is always dominated by the frontier \( AB \) of commitment and renegotiation, except at the full pooling contract.\(^{16}\) In figure 13a, it is obvious that some points of \( CB \) cannot be part of the solution (those at the left of \( B \) for instance). The purpose of figure 13b is to show that, as we move towards the full pooling scheme, the introduction of double randomization (i.e., positive values of \( y \)) will at some point improve the intertemporal welfare locus. The actual intertemporal welfare frontier (which is not drawn) would be a curve from \( C \) to \( B \) for which both \( x \) and \( y \) are allowed to vary in an optimal fashion (so as to maximize \( W_1 \) for a given value of \( W_2 \)). Note that when \( y > 0 \), we are moving towards the full pooling scheme when \( x \) decreases from 1 to \( y \) (for any value of \( y \), we have full pooling when \( x = y \)). The apparent “discontinuity” between the curve with \( y = 0 \) and the curves corresponding to positive values of \( y \) illustrate the fact that it is better to move from full pooling by following a double-randomization route, rather than letting only the efficient type randomize. However, with \( \delta = 1 \), the optimal solution is in fact full separation \((x = 1 \text{ and } y = 0)\), which corresponds to point \( C \) in figure 13a. Full separation was also optimal under commitment and renegotiation, but noncommitment imposes a welfare loss equal to the difference between the discounted welfare at \( A \) and at \( C \).

In figure 14, the curve \( BA'' \) corresponds to commitment and renegotiation and all the other curves stand for different values of \( y \) under noncommitment for \( \delta = 10 \). The optimal solution is full pooling \((x = y)\) under noncommitment (point \( B \)), while it was full separation under commitment and renegotiation.\(^{17}\) As can be seen, even a slight departure from full pooling is very costly. This is particularly true when only simple randomization \((y = 0)\) is allowed. When \( \delta = 10 \), noncommitment prevents the regulator from providing any incentives in the initial period.

\(^{16}\)In 13b the curves are drawn only in a neighborhood of the full pooling solution: \( A'B \) and \( C'B \) are the relevant portions of \( AB \) and \( CB \) of figure 13a.

\(^{17}\)As in figure 13b, figure 14 is drawn only in a neighborhood of the full pooling scheme: \( A''B \) and \( C''B \) correspond to portions of \( AB \) and \( CB \) respectively.
7. Conclusion

In this paper we have proposed a graphical analysis of multi-period procurement under asymmetric information. We have shown how the different commitment assumptions generate different allocation results over time. In particular, we have obtained that, when the discount factor is sufficiently high, full pooling may become optimal in the non-commitment model while it is never optimal under full commitment or under commitment and renegotiation.

Our analysis was based on the intertemporal welfare frontier, between the first and second period welfare levels, generated by varying the degree of randomization that characterizes semi-separating incentive schemes. The shape of this frontier is determined by the prior with respect to the firm's type, by the efficiency parameters and by the commitment assumptions. The frontier emphasizes the trade-off between efficiency and rent under commitment and renegotiation and shows how some degree of pooling (semi-pooling) permits more efficiency with less rent by reducing the speed of information revelation. Under noncommitment, when all self-selection constraints are binding, the frontier itself becomes a function of the discount factor. This demonstrates the difficulty of finding simple solutions even in the two-period-two-type case.

Many extensions of this analysis are possible. Here we want to emphasize three that differ from or complement those suggested by Laffont and Tirole.18 The first concerns competition. Suppose that the firms employed to realize the project can switch from this activity to other activities each period. An example is the transportation of dangerous goods for a public agency where the trucking firms can move easily from this activity to any other one. This means that the regulator must introduce some non-switching constraints in the design of the long-term contracts if he wants to benefit from the revelation of information. How these constraints affect the ranking of the solutions under the different commitment assumptions is not clear, because such constraints do not have the same role under noncommitment and under commitment and renegotiation.19 Under commitment and renegotiation, their role should not be very important because the regulator can commit to pay out rent in the next period. Under noncommitment this is not possible, but the constraint would presumably have the same role as in Kanemoto and Macleod (1992), as long as there is some separation in the first period. In the

18See also Rey and Sulanić (1995) for an extension to more than two periods.
19See Dionne and Doherty (1994) for a model where the principal is under competition and the agent can switch from one principal to another.
case of full pooling, the constraints should not have any role.

Another extension concerns private hierarchies in the provisions of contracts. Let us go back to the example of the transportation of dangerous goods and let us suppose that a regulated shipper of dangerous goods has to write contracts with some transportation firms. Now the questions are: 1) Who is liable for the external damages in the event of an accident? 2) How do banks and insurance companies share this liability? 3) Which of these markets should be regulated, if any: production, transportation, insurance or financial?\textsuperscript{20}

Finally, the above examples introduce risk and risk behavior considerations which imply that the transfers should become functions of the net wealth positions and not only of the firm's effort. Extending the results of this paper to a general valuation function becomes rapidly a difficult exercise when the function is not additively separable.

Although the above questions highlight many issues not covered in the actual framework proposed by Laffont and Tirole to study the regulation and procurement decisions under asymmetrical information, the latter remains a very useful starting point for their analysis.

\textsuperscript{20}Boyer and Laffont (1995) propose a first step in that direction by analyzing a model where the banks share some liability.
References


Figure 1a

Figure 1b
Figure 4
Figure 5
Figure 6
Figure 7
Figure 10: Intertemporal welfare frontiers under commitment and renegotiation
Figure 11: Welfare and discount factors for $\nu_1 = .9$
under commitment and renegotiation
Figure 12: Welfare and discount factors for $v_1 = .5$
under commitment and renegotiation
Figure 13: No commitment and separation
\[ \delta = 10, \Delta \beta = .5, \nu_1 = .5 \]

**Figure 2**: No commitment and full pooling

**Table 1** Varying the discount factor \((\beta = 1.5, \bar{\beta} = 2, S = 100, \nu_1 = 0.5, \lambda = 0.1)\)

<table>
<thead>
<tr>
<th>Type of equilibrium yielding the upper bound</th>
<th>(\delta = 0.01)</th>
<th>(\delta = 0.1)</th>
<th>(\delta = 1)</th>
<th>(\delta = 10)</th>
</tr>
</thead>
<tbody>
<tr>
<td>(x^0 = 1) (y^0 = 0) (z^0 = 1)</td>
<td>1</td>
<td>1</td>
<td>(x^0 = 1)</td>
<td>(x^0 = y^0)</td>
</tr>
<tr>
<td>(z^0 = 0) (y^0 = 0) (z^0 = 1)</td>
<td>(z^0 = 0) (y^0 = 0) (z^0 = 1)</td>
<td>(z^0 = 0) (y^0 = 0) (z^0 = 1)</td>
<td>(z^0 = 0) (y^0 = 0) (z^0 = 1)</td>
<td>(z^0 = 0) (y^0 = 0) (z^0 = 1)</td>
</tr>
<tr>
<td>(t_1)</td>
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<td>0.95</td>
<td>0.85</td>
<td>1.23</td>
</tr>
<tr>
<td>(s_1)</td>
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<td>1.28</td>
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</tr>
<tr>
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<td>0.36</td>
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<td>Expected welfare ((1 + \delta))</td>
<td>98.6</td>
<td>98.6</td>
<td>98.6</td>
<td>98.6</td>
</tr>
<tr>
<td>Expected rent ((1 + \delta))</td>
<td>0.35</td>
<td>0.38</td>
<td>0.34</td>
<td>0.36</td>
</tr>
</tbody>
</table>

Note: Table 9.1 in Laflont and Tirole. There are two differences from the original table. In the column \(\delta = 1\), 1.10 and 0.85 are interchanged and \(x^0 = y^0\) replaces \(x^0 = y^0 = .9\) since at full pooling \(x^0 = y^0\) whatever the values.
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