Commitment, asymmetric information and exhaustible resources

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Abstract

Information asymmetry between a regulated firm and a government has major effects on the tax revenue collected, especially if the government is unable to commit. If so, the ratchet effect appears and it becomes more costly to separate firms. This paper studies the optimal contracts (payment and extraction path) implemented by a regulator unable to commit to long term contracts who delegates the extraction of a resource available in limited quantity to a firm. This study extends the contract theory literature about non commitment by adding a stock constraint. It also contributes to the exhaustible resource literature by introducing information asymmetry and by studying the impact of commitment. We find that if the stock is low, the inability to commit have no impacts on the extraction path and on the tax revenue when the discount factor is low. However, if the discount factor is large and the stock is low, the efficient firm can produce higher or lower quantity than the first best while under full commitment it always produces the first best. Finally, we show that an increase in the discount factor may intensify the extraction which contradicts the Hotelling rule.

1 Introduction

Governments often delegate the exploration and extraction of natural resources to international companies. Indeed, they may not have the technical skills or the financial means to efficiently exploit their natural resources or to create a national oil company. As a result, oil producing countries usually have to rely on international oil companies and the terms of their relationship have evolved over time. Following the reinforcement of state permanent sovereignty over natural resources in the 1960s, the share of oil and gas revenue the government receives highly increased. Yet, oil rich countries, especially developing countries, are far from capturing the entire oil revenue. Indeed, oil companies make huge profit and

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the top five integrated oil and gas companies announced in 2012 an annual profit of $118 billions.

The inability of the government to capture the entire revenue can be partly explained by information asymmetries between the government and the firms (Boadway and Keen (2010) and Osmundsen (2008)). Indeed, the oil company has more expertise to estimate the quality or the quantity of resources and has more information on the technology it uses to foster and extract the resource. As a consequence, it may have the incentive to conceal information in order to capture a higher share of revenue.

Oil delegation contracts are dynamic, hence, the strength of commitment binding the oil company to the government is crucial. In reality, we observe a lack of commitment since governments often renegotiate petroleum agreements. For instance, in the 1970s and early 1980s, the increase in price of oil led to contracts renegotiation and in some cases, nationalizations. More recently, in 2006-07, contracts signed in Russia, Kazakhstan or Venezuela in the 1990s have been revisited to increase the government's take.

In contract theory, we can distinguish between three types of commitment power: full commitment, long term renegotiable contracts and non commitment. In the first case, the contracts implemented are the repetition of the static contracts. In the second case, the regulator can offer a new contract which may *ex-post* benefit both parties. In the last case, the regulator can change contracts unilaterally. Without commitment, if there the firm has private information, the regulator updates his belief at the end of each contract. The firm knows that if it reveals its type it will not get any informational rents in the subsequent periods. As a result, the firm has to be highly compensated to reveal information (ratchet effect) and countervailing incentives may appear.

Generally speaking, this paper is related to two strands of literature. The first is the literature on natural resources taxation with information asymmetry and the second one is concerned with the impact of commitment on the optimal contracts. First, we extend the contract theory literature on non commitment by introducing a stock constraint. Indeed, our results show that the contracts implemented highly depends on the stock constraint. As a result, specific contracts shoul be implemented to delegate the production of a resource available in limited quantity. Then, we contribute to the literature on petroleum taxation with information asymmetry by relaxing the full commitment assumption. Indeed, so far, the literature has only considered the case where governments commit to long term contracts.

The non commitment literature such as Freixas et al. (1985), Laffont and Tirole (1988), Laffont and Tirole (1990) and Dionne and Fluet (2000) points out two important effects. On the one hand, some pooling can be optimal and on the other hand, both types may have the incentive to lie (countervailing incentives). So far, the principal-agent model has rarely been used to study the relationship between a government and an oil company. Nevertheless, one can cite two main attempts to introduce asymmetric information in delegation contracts for non renewable resource. Gaudet et al. (1995) and Osmundsen (1998) study in a two-period model the impact on the optimal contract of asymmetric information on the productive efficiency. Gaudet et al. (1995) mainly focus on the dynamics implied by the resource constraint and show that when it is optimal for all types of firms to exhaust the stock, the inefficient firms should produce lower quantity than the first best (symmetric information case) whereas the efficient firm should produce the first best (no distortion at the top). However, if it is not optimal for some types of firms to exhaust the stock in the second period, it may be optimal for the most efficient firm to produce more than the first best. Osmundsen (1998) mainly focuses on the impact of the stock effect on the optimal contracts by assuming that the efficiency decreases as the stock is depleted. He finds that at each period no distortion at the top is optimal and that the productive distortion of the inefficient firm should be higher in the first period since the extraction increases the second period costs.

The aim of this paper is to determine the optimal contracts implemented if the government and the firm are unable to commit to long term contracts and if the firm has private information on its extraction costs. We study how the non commitment affects the firm's incentives, the tax revenue and the extraction path. We compare the outcome under symmetric information and asymmetric information with and without commitment and we place an emphasis on the impact of the discount factor. We complement the previous works by introducing an informational dynamics along with the dynamics due to the limited stock. As in Hung et al. (2006), we consider firms with a constant efficiency parameter. Thus, we study an extreme case of ratchet effect since if the information is revealed in the first period, there is symmetric information in the second one.

The paper is organized as follows. Section 2 presents the general settings and the assumptions. Section 3 characterizes the benchmarks: the optimal contracts under symmetric information and under asymmetric information and full commitment. In section 4, we define the allocation under non commitment. We study the case where only the efficient firm lies about its type and the case where all types of firms may misrepresent their type. We find that if there are no countervailing incentives, the unablity to commit has no effects as long as the stock is exhausted. If not, the tax revenue is lower than under full commitment. In both cases, the efficient firm produces the same as under symmetric information and the inefficient firm produces lower quantity than the first best but at least as much as under full commitment. If there are countervailing incentives, a pooling contract can be optimal and the efficient firm may produce more or less than the first best. Moreover, its extraction can be more intensive as the discount factor increases which contradicts the Hotelling rule. We conclude this paper in section 5 by comparing our results to the previous studies. All proofs are given in the appendices.

2 General settings

We consider a two-period model $t = \{1, 2\}$ in which a regulator delegates to a firm the production of a resource available in quantity S. The firm's production cost increases with the quantity extracted q_t and with the efficiency parameter θ. We use the same production cost function as Gaudet et al. (1995) but we assume that the efficiency parameter is constant over time.

$$C(\theta, q_t) = \theta\, q_t + \frac{b}{2}\, {q_t}^2 \tag{1}$$

The discount factor is $\delta > 0$. We do not restrict to $\delta \leq 1$, since our results highly depends on δ. We denote U_R and U_F and the regulator and the firm's payoff.

$$U_F = p_1\, q_1 - C(\theta, q_1) - T_1 + \delta\, [p_2\, q_2 - C(\theta, q_2) - T_2] \tag{2}$$

$$U_R = T_1 + \delta\, T_2 \tag{3}$$

The firm gets the revenue net of the production costs and pays a fixed payment T_t at each period. The regulator gets the discounted sum of payments. The first period affects the second period since the stock of resource available in the second period decreases with the first period extraction. We focus on cases where the firm is active at each period, if not, the model is similar to a static model.

We use the following subscripts: (FB) for symmetric information, (FC) for asymmetric information and full commitment, (NC) for asymmetric information and non commitment. The subscripts NE and E stands respectively for not exhausted and exhausted (in the second period).

3 Benchmarks

3.1 Symmetric information

The regulator maximizes its payoff subject to the firm's participation and a stock constraint which states that the quantity extracted cannot exceed the initial stock of resource. We normalize the firm's outside opportunity to zero. Under symmetric information (the first best), the regulator gets all the revenue and set the transfer to:

$$T_t^{FB} = p_t\, q_t - C(\theta, q_t) \tag{4}$$

Maximizing the transfer with respect to quantities defines the optimal extraction level. The extraction depends on S, p_1, p_2, b and θ. There are multiple equilibria but we only focus on the two cases where the firm is active at each period.
If $\theta_a \leq \theta \leq p_t$, the stock is not exhausted and the extraction at each period is: q_{tNE}^{FB}.
If $\theta_b \leq \theta \leq Min\{\theta_c, \theta_a\}$, the stock is exhausted and the extraction is: q_{1E}^{FB}.

Lemma 1 *The stock is exhausted if at each period, the price is relatively high compared to the firm's efficiency and if the stock is relatively low. Moreover, the firm spreads the extraction over time if the price path is smooth. The first period extraction depends on whether the remaining stock is exhausted in the second period.*

If the stock is exhausted, the extraction follows a standard Hotelling rule, the higher the discount factor, the less intensive the extraction.

From now on, we assume that the regulator does not know the firm's efficiency. The firm can be efficient ($\underline{\theta}$) with probability ν_0 or inefficient ($\overline{\theta}$) with the complementary probability. If the regulator does not know the firm's efficiency, the first best contracts cannot be used. Indeed, the efficient firm undervalues its efficiency to receive the cost differential.

3.2 Asymmetric information and full commitment

The regulator is able to commit to long term contracts. At each period he proposes a contract that specifies the production q_t and the payment T_t it receives. We denote $(\underline{T}_t, \underline{q}_t)$ the contract designed for the efficient firm and $(\overline{T}_t, \overline{q}_t)$ the one designed for the inefficient firm. The regulator maximizes its payoff subject to the stock constraint and to the firm's incentive and participation constraints.

At equilibrium the efficient firm's incentive constraints and the inefficient firm's participation constraint bind so that $\overline{T}_t^{FB} = \overline{T}_t^{FB}$ and $\underline{T}_t^{FB} = \underline{T}_t^{FB} - \Delta\,\theta\,\overline{q}_t$. The efficient firm's informational rent is $\Delta\,\theta\,(\overline{q}_1 + \delta\,\overline{q}_2)$.

The optimal contracts are such that the efficient firm extracts the first best quantity in both periods.

If the stock is not exhausted, the inefficient firm produces at each period lower quantity than the first best. If the stock is exhausted, if $\delta < 1$ ($\delta > 1$), the firm produces in the first period lower (higher) quantity than the first best and in the second period higher (lower) quantity than the first best. Since the regulator can commit *ex ante* to long-term contracts, the contracts are similar to the optimal static ones.

The rent efficiency trade off is such that the regulator decreases the quantity produced by the inefficient firm to decrease the informational rent. When the stock is exhausted, the regulator cannot decrease the production in one period without increasing the production in the other. As a result, the regulator chooses to decrease the informational rent left to the efficient firm and so the extraction requested by an inefficient firm at the period he values the most. When the stock is exhausted, the inefficient firm may produce more or less than the first best.

Under asymmetric information the inefficient firm may not exhaust the stock or be active whereas under symmetric information it would have been optimal. Because of the rent efficiency trade off, the size of information asymmetry ($\Delta\theta$) and the probability to face an efficient firm (ν_0) decrease the inefficient firm's extraction.

Lemma 2 *Under full commitment and asymmetric information, the efficient firm always produces the first best. If the stock is not exhausted, the inefficient firm produces lower quantity than the first best. However, if the stock is exhausted, depending on the discount factor it produces more or less than the first best. If $\delta < 1$ ($\delta > 1$), it produces in the first period less (more) than the first best and in the second period it produces more (less). Because of the informational rent left to the efficient firm, the regulator's expected tax revenue is lower than the first best.*

This section is used as benchmark and only repeats the results from Gaudet et al. (1995). As compared to the previous model, we assume that θ is constant over time and we relax the assumption that $\delta < 1$. Relaxing this assumption allows to consider the case where the information asymmetry intensifies the extraction.

4 Asymmetric information and non commitment

Under non commitment, the regulator proposes at each period a contract designed for each type. The second period contracts are designed after the regulator observed the contract chosen in the first period. The steps of the game are the following:

- Depending on his prior belief, the regulator proposes one contract for each type $(\underline{q}_1, \underline{T}_1)$ and $(\overline{q}_1, \overline{T}_1)$.
- The firm chooses one contract and the regulator updates his belief (he may have full information) depending on the contract chosen.
- Depending on his updated belief, the regulator proposes one contract for each type $(\underline{q}_2, \underline{T}_2)$ and $(\overline{q}_2, \overline{T}_2)$ or the first best contract if he knows the firm's type.

The regulator updates his prior belief (ν_0) according to a Bayesian rule and the posterior belief $\nu_1 = \{\underline{\nu}_1, \overline{\nu}_1\}$ are:

$$\underline{\nu}_1 = \frac{x\,\nu_0}{x\,\nu_0 + y\,(1-\nu_0)} \quad \text{and} \quad \overline{\nu}_1 = \frac{(1-x)\,\nu_0}{(1-x)\,\nu_0 + (1-y)\,(1-\nu_0)} \quad \text{with } x \in [0,1] \text{ and } y \in [x,1]$$

$\underline{\nu}_1$ is the probability that the firm is efficient knowing that $(\underline{q}_1, \underline{T}_1)$ is chosen.
$\overline{\nu}_1$ is the probability that the firm is efficient knowing that $(\overline{q}_1, \overline{T}_1)$ is chosen.
x is the probability that the efficient firm chooses $(\underline{q}_1, \underline{T}_1)$ in the first period.
y is the probability that the inefficient firm chooses $(\underline{q}_1, \underline{T}_1)$ in the first period.
Without loss of generality, we can assume that $x > y$

The type of equilibrium depends on x and y. In the first period, there is:

- Full separation if $(x, y) = (1, 0)$. Updating is perfect, the regulator fully identify the type of firms he faces. The first period contracts are the same as under full commitment. In the second period, there is symmetric information, if $\nu_1 = 1$ ($\nu_1 = 0$), the contract proposed is the efficient (inefficient) firm's first best contract and the regulator captures all the revenue. In the second period the inefficient firm produces the first best, which increases the efficient firm's incentive to lie (and so its informational rent).

- Semi separation if one type of firms plays a pure strategy while the other plays a mixed strategy: $(x, y) = (1, y)$ or $(x, 0)$. In the second period, the regulator imperfectly updates his belief, there is still information asymmetry.

- Pooling when both types choose the same strategy ($x = y$). In the second period, no updating is possible, $\nu_0 = \nu_1$ and the contracts are similar to the full commitment ones.

We solve the problem using backward induction. First, we define the second-period contracts that maximize the regulator's second period payoff (for a given stock and updated beliefs). Then, we derive the first-period optimal contracts knowing that in the second period, the optimal contracts are implemented.

The second period problem is exactly the same as the full commitment one except that ν_0 is replaced by ν_1. Indeed, under full commitment the allocation is the same as the repetition of the optimal static contracts at each period. As a result, the efficient firm extracts the first best as under the full commitment and the inefficient firm's extraction is exactly the same as under full commitment except that ν_0 is replaced by ν_1.

The trade off between rent extraction and efficiency favours efficiency when ν_1 is low and the rent extraction when ν_1 is high. If $\nu_0 > \nu_1$, for a given price path and a given stock, as compared to the full commitment scheme, the inefficient firm produces more. Because the regulator is less confident about facing an efficient firm he is less willing to distort the quantity extracted by the inefficient firm to reduce the efficient firm's rent. Using the same argument, if $\nu_0 < \nu_1$, the inefficient firm produces less than under full commitment.

We now define the optimal first-period contracts. The firm knows its first period strategy affects the second period contracts through the updated beliefs and the stock. The incentive and participation constraints take into account that in the second period, the inefficient firm never gets a rent and does not have the incentive to lie. Moreover, in the second period, the efficient firm is indifferent between lying and telling the truth and gets an informational rent: $\Delta\theta\,\overline{q}_2(\nu_1)$ that depends on the contract chosen in the first period. The first period incentive and participation constraints are:

$$p_1\,\underline{q}_1 - C(\underline{\theta},\underline{q}_1) - \underline{T}_1 + \delta\,\Delta\theta\,\overline{q}_2(\underline{\nu}_1) \geq 0 \tag{$\underline{\text{PC}}$}$$

$$p_1\,\overline{q}_1 - C(\overline{\theta},\overline{q}_1) - \overline{T}_1 \geq 0 \tag{$\overline{PC}$}$$

$$p_1\,\underline{q}_1 - C(\underline{\theta},\underline{q}_1) - \underline{T}_1 + \delta\,\Delta\theta\,\overline{q}_2(\underline{\nu}_1) \geq p_1\,\overline{q}_1 - C(\underline{\theta},\overline{q}_1) - \overline{T}_1 + \delta\,\Delta\theta\,\overline{q}_2(\overline{\nu}_1) \tag{$\underline{\text{IC}}$}$$

$$p_1\,\overline{q}_1 - C(\overline{\theta},\overline{q}_1) - \overline{T}_1 \geq p_1\,\underline{q}_1 - C(\overline{\theta},\underline{q}_1) - \underline{T}_1 \tag{$\overline{IC}$}$$

The stock constraints are:

$$\underline{q}_1 + \underline{q}_2(\underline{\nu}_1) \leq S \tag{EC_1}$$

$$\overline{q}_1 + \overline{q}_2(\overline{\nu}_1) \leq S \tag{EC_2}$$

$$\overline{q}_1 + \underline{q}_2(\overline{\nu}_1) \leq S \tag{EC_3}$$

$$\underline{q}_1 + \overline{q}_2(\underline{\nu}_1) \leq S \tag{EC_4}$$

Depending on the binding constraints different equilibria occur. ($\overline{PC}$) always binds; if not, the regulator can increase his revenue and keep the other constraints satisfied. From ($\underline{\text{IC}}$) and ($\overline{PC}$), ($\underline{\text{PC}}$) is always satisfied. We first study the case where, only ($\underline{\text{IC}}$) binds. However, if ($\overline{IC}$) is not satisfied when ($\underline{\text{IC}}$) binds, then both incentive constraints must bind. The case where ($\underline{\text{IC}}$) is slacked is never optimal since the regulator could always increase its revenue by binding this constraint.

4.1 Only the efficient firm's incentive constraint binds

The efficient firm is indifferent between the two contracts. It chooses the contract designed for its type with the probability x and the other contract with the complementary probability. We assume that the inefficient chooses the contract designed for its type ($y = 0$) and we check *ex post* the conditions under which it is true.

As $\overline{\nu}_1 = \frac{(1-x)\,\nu_0}{(1-x)\,\nu_0+(1-\nu_0)} \leq \nu_0$, the inefficient firm's production in the second period is higher than under full commitment.

If the contract $(\underline{T}_1, \underline{q}_1)$ is chosen, $\underline{\nu}_1 = 1$, in the second period, only the efficient firm's first best contract is proposed: $\overline{q}_2(\underline{\nu}_1) = 0$. If the contract $(\overline{T}_1, \overline{q}_1)$ is chosen, there is still information asymmetry. The efficient firm's participation and incentive constraints can be rewritten as:

$$p_1\,\underline{q}_1 - C(\underline{q}_1,\underline{\theta}) - \underline{T}_1 \geq 0 \tag{\underline{PC}a}$$

$$p_1\,\underline{q}_1 - C(\underline{q}_1,\underline{\theta}) - \underline{T}_1 \geq p_1\,\overline{q}_1 - C(\overline{q}_1,\underline{\theta}) - \overline{T}_1 + \delta\,\Delta\theta\,\overline{q}_2(\overline{\nu}_1) \tag{\underline{IC}a}$$

From the binding constraints, we obtain: $\underline{T}_1 = \underline{T}_1^{FB} - \Delta\,\theta(\overline{q}_1 + \delta\,\overline{q}_2(\overline{\nu}_1))$ and $\overline{T}_1 = \overline{T}_1^{FB}$. The efficient firm gets an informational rent $\Delta\theta(\overline{q}_1 + \delta\,\overline{q}_2(\overline{\nu}_1))$.

The regulator chooses the first period extraction to maximize its payoff under the stock constraints and the inefficient firm's incentive constraint.

$$\max_{\underline{q}_1,\overline{q}_1} {U_R}^{NC} = \nu_0\,(x\,\underline{T}_1 + (1-x)\,\overline{T}_1) + (1-\nu_0)\,\overline{T}_1 \tag{5}$$
$$+\delta\left\{\nu_0\,x\,\underline{T}_2^{FB} + (\nu_0\,(1-x) + (1-\nu_0))\,[\overline{\nu}_1\,\underline{T}_2 + (1-\overline{\nu}_1)\,\overline{T}_2]\right\}$$
$$\text{s.t } (\overline{IC}), (EC_1), (EC_2), (EC_3)$$

The regulator's payoff is the weighted sum of the transfers he might get. The first part of the payoff is the transfer the regulator gets when the firm is efficient (it may lie or tell the truth). The second part is the transfer when the firm is inefficient (the regulator gets all the rent). The last part is the second period transfer, full information if the firm is efficient and tells the truth and asymmetric information if the firm is inefficient or if it is efficient and lies. Solving this problem, we show in the appendices that:

The efficient firm extracts the first best level and gets an informational rent (as under full commitment). If it reveals, this payment is given in the first period (upfront payment). If it lies it gets in the first period $\Delta\theta\,\overline{q}_1^{NC}$ and in the second period $\Delta\theta\,\overline{q}_2^{NC}(\overline{\nu}_1)$.

The inefficient firm's extraction depends on the exogenous parameters (S, p_1, p_2, $\overline{\theta}$ and $\underline{\theta}$) and on x. Depending on which stock constraints bind, different equilibria occurs. We focus only two cases: (i) one where the stock is never exhausted (none of the stock constraint bind) and (ii) another one where the stock is always exhausted (all the stock constraint bind). We only consider those two cases since one of the objective of this paper is to study the effect of the resource constraint on the ratchet effect.[1]

Because of the rent efficiency trade off, the inefficient firm's production is distorted. However, as compared to full commitment, the production is closer to the first best. Indeed, since the efficient firm may choose the inefficient firm's contract the distortion is smaller and the informational rent is larger.

[1] In appendixes I consider a third case (iii) where only (EC_1) and (EC_3) bind.

Lemma 3 *Under non commitment, the efficient firm produces the first best and the inefficient firm's production is closer to the first best than under non commitment. Since, the distortion is lower than under full commitment, the informational rent is higher and the tax revenue is lower.*

The optimal contracts are obtained by the probability x which maximizes the regulator's payoff. The separation level x allows the regulator to trade off between the informational rent given at each period. By separating firms in the first period (increase in x), the regulator increases the first period distortion and so decreases the informational rent related to this period ($\Delta\theta\,\overline{q}_1^{NC}$). However, as information is revealed, the production in the second period increases and so does the informational rent. As a consequence, the optimal level of separation decreases as the discount factor increases. Moreover, the level optimal level of separation decreases with the probability to face an efficient firm (ν_0). Indeed, ν_0 is large, the regulator has to give up a large amount of rents and is less willing to separate.

For $x = 1$, there is full separation, in the first period the contracts are the optimal static ones (same as full commitment) and in the second period, the first best contracts are proposed. The informational rent related to the second period is maximized whereas the one related to the first period is minimized: $\Delta\theta\,(\overline{q}_1^{FC} + \delta\,\overline{q}_2^{FB})$. For $x = 0$, there is full pooling in the first period, in the second period, the contracts are the optimal static ones (same as full commitment). For $x \in]0, 1[$, semi separating contracts are implemented in the first period. In the second period, there is still information asymmetry. We show in the appendices that if the exogenous parameters are such that ($\overline{IC}$) is satisfied:

Proposition 1 *If the stock is low and or both firms are relatively efficient, the stock is exhausted by both types. If so, the regulator is always better off when the firm reveals. It proposes in the first period separating contracts and in the second period the first best contracts are implemented. The tax revenue and the extraction path are exactly the same as under full commitment. Implementing a full pooling contract is never optimal.*

The intuition behind this proposition is the following: if both firms exhaust the stock, whatever the first period's production is, the second period's production is the remaining stock. Under non commitment separation is costly since in the second period the inefficient firm's production increases with the level of separation. As a result, separation increases the informational rent related to the second period. At the extreme case (full separation), the inefficient firm produces the first best and the informational rent related to the second period is maximized. Nevertheless, if the stock is exhausted separation comes without costs since the production is limited by the stock and does not increase with separation. As a result, the regulator fully separates, the extraction and the tax revenue is the same as under full commitment. The type of commitment has no effect on the extraction path and on the tax revenue, only the information asymmetry has.

Proposition 2 *If the stock is large and or both firms are relatively inefficient, the stock is never exhausted. If so, the regulator chooses between fully separating contracts and semi separating contracts. Fully separating contracts are implemented if the discount factor is below a threshold. If the discount factor is above this threshold, the efficient firm has to be highly compensated to reveal its information and semi separating contracts are offered. The regulator's payoff is lower than under full commitment. Implementing a full pooling contract is never optimal.*

The optimal level of separation decreases with the discount factor since separation increases the second period informational rent.

As compared to full commitment, when the stock and the discount factor are low, the first period contracts are the same and the second period ones are the first best. However, when the stock is low and the discount factor is large, the inefficient firm produces at each period higher quantity than under full commitment. Since the inefficient firm's extraction is larger than under full commitment, the tax revenue under non commitment is lower.

We now check under which conditions ($\overline{IC}$) is satisfied at the equilibrium. The inefficient reveals its type only if the cost of lying exceeds the gains:

$$\underline{q}_1^{NC} \geq \overline{q}_1^{NC} + \delta\, \overline{q}_2^{NC}(\overline{\nu}_1) \tag{6}$$

When the inefficient firm misrepresent its type, in the first period, its overproduces and bears the costs $\Delta\theta\, \underline{q}_1^{NC}$ but it captures the informational rent: $\Delta\theta\, (\overline{q}_1^{NC} + \delta\, \overline{q}_2^{NC}(\overline{\nu}_1))$. In the second period, only the efficient firm's first best contract is proposed and the inefficient firm leaves the relationship, this is the take-the-money-and-run strategy.

The incentive constraint is more stringent than under full commitment, this latter being $\underline{q}_1^{FC} + \underline{q}_2^{FC} > \overline{q}_1^{FC} + \overline{q}_2^{FC}$.

Lemma 4 *When the second period price and the discount factor are high or when the information asymmetry is low, countervailing incentives appear. If so, both incentive constraints bind.*

As compared to Dionne and Fluet (2000), introducing a stock constraint changes drastically the effect of commitment. Indeed, when the production is constrained (low stock), the ratchet effect disappears. The principal gets the same payoff under full and non commitment. As compared to Gaudet et al. (1995), the inability to commit is costly since the extraction rate is closer to the first best and the informational rent is larger.

If ($\overline{IC}$) is not satisfied then, both firms' incentives constraints bind. Both firms may randomize. The efficient firm chooses its contract with the probability x and the inefficient firm chooses its contract with the probability $1 - y$. The regulator has still to decide whether he proposes in the first period, semi separating contracts, separating contracts or full pooling contracts.

4.2 Both incentive constraints bind

From (IC) and ($\overline{PC}$) binding, we obtain:
$\underline{T}_1 = \underline{T}_1^{FB} - \Delta\theta\,(\overline{q}_1 + \delta\,\overline{q}_2(\overline{\nu}_1) - \delta\,\overline{q}_2(\underline{\nu}_1))$ and $\overline{T}_1 = \overline{T}_1^{FB}$.
The efficient firm gets an informational rent equals to $\Delta\theta\,(\overline{q}_1 + \delta\,\overline{q}_2(\overline{\nu}_1))$.
If the inefficient firm's incentive constraint ($\overline{IC}$) binds:

$$\Delta\theta\,\underline{q}_1 = \Delta\theta\,(\overline{q}_1 + \delta\,\overline{q}_2(\overline{\nu}_1) - \delta\,\overline{q}_2(\underline{\nu}_1))) \tag{7}$$

$$\underline{q}_1 = \overline{q}_1 + \delta\,(\overline{q}_2(\overline{\nu}_1) - \delta\,\overline{q}_2(\underline{\nu}_1)) \tag{8}$$

The right hand side represents the costs of lying (overproduction) while the left hand side represents the gains from lying (informational rent). Since the inefficient firm's gets nothing when it reveals and since its incentive constraint binds, then it must receive nothing when it lies and so (8) must hold. The efficient firm's extraction is always greater than the inefficient's one. Indeed:

$$\overline{q}_2(\overline{\nu}_1) - \overline{q}_2(\underline{\nu}_1) = \frac{\Delta\theta\nu_0\,(x-y)}{b\,(1-y)\,(1-\nu_0)\,y} > 0 \tag{9}$$

Each type of firm is more likely to choose the contract designed for its type ($x > y$). As a result, if the contract designed for the inefficient firm is chosen in the first period, the regulator is less willing to distort the extraction requested from an inefficient firm in the second period. The rent efficiency trade off favours productive efficiency.

The regulator's payoff is the weighted sum of the transfers he might get:

$$\begin{aligned}
&\max_{\overline{q}_1} U_R{}^{NC} = \nu_0\,(x\,\underline{T}_1 + (1-x)\,\overline{T}_1) + (1-\nu_0)\,(y\,\underline{T}_1 + (1-y)\,\overline{T}_1) \qquad (10)\\
&+ \delta\left\{(\nu_0\,x) + (1-\nu_0)\,y)\,[\underline{\nu}_1\,\underline{T}_2 + (1-\underline{\nu}_1)\,\overline{T}_2] + (\nu_0\,(1-x) + (1-\nu_0)(1-y))\,[\overline{\nu}_1\,\underline{T}_2 + (1-\overline{\nu}_1)\,\overline{T}_2]\right\}\\
&\text{s.t } (EC_1), (EC_2), (EC_3), (EC_4), (8)
\end{aligned}$$

$\underline{q}_1$ is defined by (8) so the regulator only chooses $\overline{q}_1$ to maximize its payoff. Given the extraction level, it decides the separation level by choosing x and y. We only focus on two cases (i) none of the firms exhaust the stock and (ii) all types of firms exhaust the stock. Indeed, one of the aim of this paper is to study how the resource constraint affects the optimal contracts.

(i) If none of the firm exhaust the stock, the inefficient firm extracts:

$$\overline{q}_{1NE}^{NC_b} = \overline{q}_{1NE}^{FB} - \ \delta \ (y + \nu_0 \, (x - y))[\overline{q}_2(\overline{\nu}_1) - \overline{q}_2(\underline{\nu}_1)] \tag{11}$$

$\overline{q}_1$ affects the welfare only through the first period payment $\overline{T}_1$ and $\underline{T}_1$. The intuition behind (11) is as follows:
$\overline{T}_1$ is maximized by $\overline{q}_1$ such as: $p_1 - C'(\overline{\theta}, \overline{q}_1) = 0 \Leftrightarrow \overline{q}_1 = \overline{q}_1^{FB}$.
$\underline{T}_1$ is maximized by $\underline{q}_1$ such as: $p_1 - C'(\underline{\theta}, \underline{q}_1) - \Delta\,\theta = p_1 - C'(\overline{\theta}, \underline{q}_1) = 0$.
The regulator wants to decrease the inefficient firm's extraction due to the informational rent. From (8), the extraction of each firm is perfectly correlated. Hence, the regulator wants to decrease the efficient firm's production. Within our specifications, it implies setting $\underline{q}_1 = \overline{q}_1^{FB}$.
Yet, from (8), $\underline{q}_1 = \overline{q}_1 + \delta\,[\overline{q}_2(\overline{\nu}_1) - \overline{q}_2(\underline{\nu}_1)]$. Hence, $\underline{T}_1$ is maximized by:
$\underline{q}_1 = \overline{q}_1^{FB} = \overline{q}_1 + \delta\,[\overline{q}_2(\overline{\nu}_1) - \overline{q}_2(\underline{\nu}_1)] \Leftrightarrow \overline{q}_1 = \overline{q}_1^{FB} - \delta\,[\overline{q}_2(\overline{\nu}_1) - \overline{q}_2(\underline{\nu}_1)]$.
The higher $\delta\,[\overline{q}_2(\overline{\nu}_1) - \overline{q}_2(\underline{\nu}_1)]$ is, the lower $\overline{q}_1$ should be.

Replacing $\overline{q}_1^{NC}$ in the regulator's payoff (10) and deriving with respect to x and y, we define three solutions: a pooling equilibrium, a semi separating equilibrium and a fully separating equilibrium. By comparing these three equilibria, we show (proof in appendices) that:

Proposition 3 *If the discount factor is low, the regulator fully separates firms. If the discount factor is large, full pooling contracts are implemented. Semi separating contracts are proposed for medium value of discount factor but only if the information asymmetry and or the probability the firm is efficient are large.*

In what follows, we describe the three types of equilibria.

- Pooling ($x = y$)

If $x = y$, $\underline{\nu}_1 = \overline{\nu}_1 = \nu_0$ and (8) gives $\overline{q}_1 = \underline{q}_1$. In the first period, both firms produce the inefficient firm' first best level $\overline{q}_1^{FB}$. In the second period, they produce the same quantity as under full commitment.

If the discount factor is large, the regulator does not want the information to be disclosed in the first period and thus offers a pooling contract. In this case, non commitment induces a distortion at the top in the first period, since the efficient firm underproduces as compared to the first best. Furthermore, since in the first period the inefficient firm produces the first best, the informational rent left to the efficient firm is large.

- Full separation ($x = 1$ and $y = 0$)

$x = 1$ and $y = 0$, $\overline{q}_2(\overline{\nu}_1) = \overline{q}_2^{FB}$ and $\overline{q}_2(\underline{\nu}_1) = 0$. The quantities extracted are:

$$\overline{q}_{1NE}^{NC_b} = \overline{q}_{1NE}^{FB} - \delta\,\nu_0\,\overline{q}_{2NE}^{FB} \quad \text{and} \quad \underline{q}_{1NE}^{NC_b} = \overline{q}_{1NE}^{NC_b} + \delta\,\nu_0\,\overline{q}_{2NE}^{FB} = \overline{q}_{1NE}^{FB} + \delta\,(1-\nu_0)\,\overline{q}_{2NE}^{FB}$$

Because of the informational rent, the inefficient firm produces a lower level than the first best. The efficient one produces lower or higher quantity than the first best. The discount factor decreases the inefficient firm's production and increases the efficient firm's production. It is straightforward that the efficient firm produces higher quantity than the first best when the discount factor and the second period price is high. For $\delta = 0$, the contract is similar to the full pooling contract.

Interestingly enough, the efficient firm's efficiency ($\underline{\theta}$) does not affect the quantity extracted. On the one hand, if the efficient firm is more efficient, its extraction should be higher. On the other hand, the informational rent is also higher and thus the quantity extracted by the inefficient firm should be lower. Since the quantity extracted by each firm are positively correlated, this leads to a decrease in the quantity produced by the efficient firm. These two opposite effects perfectly offset and $\underline{\theta}$ has no effect on the extraction.

In the second period, both firms produce the first best.

- Semi separation: $x = 1$ and $y^* = \frac{2\,\delta\,\nu_0}{2\,\delta\,\nu_0 - \delta + 1}$[2]

This contract is defined for $\delta \in [0, 1]$:
For $\delta = 0$, $y^* = 0$, the semi separating contract is similar to a full separating contract.
For $\delta = 0$, $y^* = 1 \Leftrightarrow x = y^* = 1$, the semi separating contract is similar to a full pooling contract.

This contract can only be implemented for $\delta \in [0, 1]$, it does not mean that it is always implemented under this interval. In fact, this contract is never implemented if the information asymmetry and or the probability the firm is efficient are large.

Under this contract, in the first period both firm produces lower quantity than the first best and the extraction decreases with the discount factor. In the second period, the efficient firm produces lower quantity than the first best while the efficient firm produces the first best.

As the discount factor increases, the regulator is better off if few information is disclosed in the first period, so y^* increases.

When the probability to face an efficient firm (ν_0) and or the discount factor (δ) are large, the regulator chooses to implement a pooling contract rather than these separating contracts. Indeed, as ν_0 and δ increase the informational rent increases as well.

[2] We show in the appendices that the second semi separating contract $x = 1$ and $y > 0$ is never implemented, since the regulator's payoff is convex in x.

This paper shows that if the regulator is unable to commit there might be a distortion at the top. The efficient firm may produce lower or higher quantity than the first best. If the discount factor is high, both firms produce in the first period the inefficient firm's first best level and in the second period the same as under full commitment. As compared to full commitment, a distortion at the top appears and a pooling contract can be optimal.

(ii) Both firms exhaust the stock

If the discount factor is above δ_1^E defines by (24), both firm's incentive constraints bind. We show in the appendices that semi separating contracts are never optimal. [3] The regulator proposes fully separating contracts if $\delta < \delta_2^E$ where $\delta_1^E < \delta_2^E < 1$.

Under a full pooling contract both firms produce $\overline{q}_{1E}^{FB}$. The inefficient firm produces the first best while the efficient firm's produces lower quantity. As a result, if the discount factor is high, the efficient firm underproduces as compared to the first best. Under full commitment, the efficient firm produces the first best and if the discount factor is such as $\delta > 1$ and if the stock is exhausted, the inefficient firm produces in the first period a higher amount than the first best. On the opposite, under non commitment, if $\delta > 1$ and if the stock is exhausted, the inefficient firm produces the first best while the efficient firm produces a lower amount.

Under full separating contracts, the inefficient firm produces:

$$\overline{q}_{1bE}^{NC} = \overline{q}_{1NE}^{FB} + \frac{(1-\delta)\ \delta\ \left(\delta\,\overline{\theta} - 2\,\overline{\theta} + \underline{\theta} - b\,S - \delta\,p_2 + p_1\right)\ \nu_0}{b\ (\delta+1)\ ((\delta-2)\ \delta\,\nu_0 + 1)} \tag{12}$$

The efficient firm produces $\underline{q}_{1E}^{NCb} = \overline{q}_1^{NC_b}(1-\delta) + \delta\,S$.

The efficient firm produces higher quantity than the first best while the inefficient firm always produces less. The discount factor decreases the inefficient firm production which is consistent with the Hotelling rule. However, the discount factor has an ambiguous effect on the efficient firm's extraction. On the one hand, an increase in the discount factor increases the informational rent associated with the second period and so decreases the second period extraction (information effect). On the other hand, it is optimal for the regulator to postpone the extraction since the second period is more valued (resource effect). As a result, the efficient firm first period's extraction can increase with the discount factor when the information asymmetry is high. This last result contradicts the Hotelling rule.

[3] If $x = 1$ and $y > 0$, (8) implies that $\overline{q}_1 = \underline{q}_1$ which is equivalent to pooling contract. If $x > 0$ and $y = 0$, the regulator's payoff is convex in x.

Proposition 4 *If both firms exhaust the stock, separating contracts are never implemented. The regulator proposes fully separating contract if the discount factor is below a threshold. If the discount factor is above this threshold, the regulator proposes a pooling contract. Under full separation, the efficient firm produces lower quantity than the first best whereas the efficient one produce less than the first best. An increase in the discount factor may intensify the efficient firm's extraction which contradict the Hotelling rule.*

5 Results and discussion

This work extends the analysis by Gaudet et al. (1995) and Osmundsen (1998) which study the impact of information asymmetry on the extraction path and the tax revenue.

First, we show that if firms are efficient and the price path is smooth, all types of firms exhaust the stock and spread the extraction over time. If so, and if the discount factor is low, there are no countervailing incentives and the inability to commit is not costly. The optimal contracts are similar under full and non commitment and are such that the efficient firm produces the first best and gets an informational rent whereas the inefficient one produces lower quantity. Nevertheless, if the discount factor is large, countervailing incentives appear. If the discount factor is relatively large, the efficient firm produces larger quantity than the first best while the inefficient firm produces lower quantity than the first best. Moreover, an increase in the discount factor may intensify the efficient firm's extraction. Finally, if the discount factor is really large,a pooling contract is proposed in the first period, the efficient firm under produces and the inefficient firm produces the first best.

Then, if the stock is large and none of the firm exhausts the stock, if the discount factor is low, the efficient firm produces the first best as under full commitment but the inefficient firm produces higher quantity. As a result, the tax revenue is lower than under full commitment. If the discount factor is large, semi separating or fully separating contracts are implemented. If the discount factor is really large full pooling contracts are implemented.

Finally, we illustrate this paper with the case of oil production. However our results are more general and can be applied to any delegation contracts. To standard consumption goods when the production is available in limited quantity.

References

Boadway, R. and Keen, M. (2010). *Theoretical perspectives on resource tax design.*

Dionne, G. and Fluet, C. (2000). Full pooling in multi-period contracting with adverse selection and noncommitment. *Review of Economic Design*, 5(1):1–21.

Eller, S., Hartley, P., and Medlock, K. (2011). Empirical evidence on the operational efficiency of national oil companies. *Empirical Economics*, 40(3):623–643.

Freixas, X., Guesnerie, R., and Tirole, J. (1985). Planning under incomplete information and the ratchet effect. *Review of Economic Studies*, 52(2):173–91.

Gaudet, G., Lassere, P., and Long, N. V. (1995). Optimal resource royalties with unknown and temporally independent extraction cost structures. *International Economic Review*, 36(3):715–49.

Hung, N. M., Poudou, J.-C., and Thomas, L. (2006). Optimal resource extraction contract with adverse selection. *Resources Policy*, 31(2):78–85.

Johnston, D. (1994). *International Petroleum Fiscal Systems and Production Sharing Contracts*. PennWell Publishing Company.

Laffont, J.-J. and Tirole, J. (1988). The dynamics of incentive contracts. *Econometrica*, 56(5):1153–75.

Laffont, J.-J. and Tirole, J. (1990). Adverse selection and renegotiation in procurement. *Review of Economic Studies*, 57(4):597–625.

Osmundsen, P. (1998). Dynamic taxation of non-renewable natural resources under asymmetric information about reserves. *Canadian Journal of Economics*, 31(4):933–951.

Osmundsen, P. (2008). Time consistency in petroleum taxation—the case of norway. pages 25–27.

Appendices

A Symmetric information

$$\max_{T_1,T_2,q_1,q_2} U_R = T_1 + \delta\, T_2 \text{ s.t} \tag{13}$$

$$U_F = p_1\, q_1 - C(\theta, q_1) - T_1 + \delta\,[p_2\, q_2 - C(\theta, q_2) - T_2] \geq\ 0 \tag{14}$$

$$q_1 + q_2 \leq\ S \tag{15}$$

(14) binds, if not the regulator could always increase his payoff by increasing $T_1 + \delta\, T_2$.

$$\max_{q_1,q_2} U_R = p_1\, q_1 - C(\theta, q_1) + \delta\,[p_2\, q_2 - C(\theta, q_2)] \text{ s.t} \tag{16}$$

$$q_1 + q_2 \leq\ S \tag{17}$$

The subscripts NE and E stands respectively for not exhausted and exhausted (in period 2). We focus on the cases where the firm is active at each period. For a given stock, the optimal extraction rule is:

$$q_t^{FB} = \begin{cases} S_t & \text{if } \theta < p_t - b\, S_t \\ q_{tNE}^{FB} & \text{if } p_t - b\, S_t \leq \theta \leq p_t \\ 0 & \text{if } \theta > p_t \end{cases}$$

If $Max\left\{\frac{p_2+p_1-bS}{2}, p_1 - b\, S\right\}\ \leq\ \theta\ \leq\ Min\,\{p_1, p_2\}$, the stock is not exhausted and the firm extracts:

$$q_{tNE}^{FB} = \frac{p_t - \theta}{b} \tag{18}$$

If $\frac{p_1-\delta\, p_2-bS}{1-\delta}\ \leq\ \theta\ \leq\ Min\left\{\frac{p_1-\delta\, p_2+\delta\, bS}{1-\delta}, \frac{p_2+p_1-bS}{2}\right\}$, the stock is exhausted and the firm extracts $q_{2E}^{FB} = S - q_{1E}^{FB}$ with:

$$q_{1E}^{FB} = \frac{p_1 + \delta\,(bS - p_2) - (1-\delta)\,\theta}{b(1+\delta)} \tag{19}$$

$\frac{\partial\, q_{1E}^{FB}}{\partial\, \delta} = \frac{2\,\theta + b\, S - p2 - p1}{b\,(1+\delta)^2} < 0$, $U_{R_{NE}}^{FB} = \frac{(p_1-\theta)^2}{2\, b} + \frac{\delta\,(p_2-\theta)^2}{2\, b}$

$U_{R_E}^{FB} = \frac{(p_1 - \theta\,(1-\delta) - \delta\, p_2)^2 - b\,\delta\, S\,(4\,\theta + b\, S - 2(p_2+p_1))}{2\, b\,(1+\delta)}$

B Full commitment

We denote $\underline{U}$ and $\overline{U}$ respectively, the efficient and the inefficient firm's payoff and U_R and U_L the payoff when the firm reveals its type and lies.

$$\max_{\{\underline{q}_1,\underline{q}_2,\underline{T}\},\{\overline{q}_1,\overline{q}_2,\overline{T}\}} U_R^{FC} = \nu_0\,\underline{T} + (1-\nu_0)\,\overline{T} \text{ s.t} \tag{20}$$

$$\underline{U}(\underline{\theta},\underline{q}_1,\underline{q}_2,\underline{T}) \geq 0 \tag{21}$$

$$\overline{U}(\overline{\theta},\overline{q}_1,\overline{q}_2,\overline{T}) \geq 0 \tag{22}$$

$$\underline{U}(\underline{\theta},\underline{q}_1,\underline{q}_2,\underline{T}) \geq \underline{U}(\underline{\theta},\overline{q}_1,\overline{q}_2,\overline{T}) \tag{23}$$

$$\overline{U}(\overline{\theta},\overline{q}_1,\overline{q}_2,\overline{T}) \geq \overline{U}(\overline{\theta},\underline{q}_1,\underline{q}_2,\underline{T}) \tag{24}$$

$$\underline{q}_1 + \underline{q}_2 \leq S \tag{25}$$

$$\overline{q}_1 + \overline{q}_2 \leq S \tag{26}$$

(23) and (22) imply (21). Furthermore, (22) has to be binding if not the regulator could always reduce $\underline{T}$ and $\overline{T}$ by the same small positive amount and keep the other constraints satisfied. This is a standard problem where we should consider (23) and (22) binding. To solve this problem, we get $\underline{T}$ and $\overline{T}$ from the binding constraints, and replace them in the regulator's payoff function. By deriving with respect to $\underline{q}_1$, $\underline{q}_2$, $\overline{q}_1$ and $\overline{q}_2$, we obtain the optimal extraction path and we always check *ex post* if the non binding constraints are satisfied at the equilibrium. We denote $\overline{S}_2 = S - \overline{q}_1$ and $\underline{S}_2 = S - \underline{q}_1$.

The efficient firm always produces the first best quantity in both periods.

The inefficient firm's second period extraction for a given stock is such as:

$$\overline{q}_2^{FC} = \begin{cases} \overline{S}_2 & \text{if } \overline{\theta} < (p_2 - b\overline{S}_2)(1-\nu_0) + \nu_0\underline{\theta} \\ \overline{q}_{NE_2}^{FC} & \text{if } (p_2 - b\overline{S}_2)(1-\nu_0) + \nu_0\underline{\theta} \leq \overline{\theta} \leq p_2\,(1-\nu_0) + \nu_0\,\underline{\theta} \\ 0 & \text{if } p_2\,(1-\nu_0) + \nu_0\,\underline{\theta} < \overline{\theta} \end{cases}$$

We focus on the two cases where both firms are active at each period. The first period extraction depends on whether the remaining stock is exhausted at the second period.

If $Max\left\{\underline{\theta}\,\nu + (1-\nu)\,\frac{p_2+p_1-bS}{2}, p_1 - b\,S\right\} \leq \overline{\theta} \leq Min\left\{\underline{\theta}\,\nu + (1-\nu)\,p_1, \underline{\theta}\,\nu + (1-\nu)\,p_2\right\}$, the stock may only be exhausted by an efficient firm, the efficient firm extracts

$$\overline{q}_{tNE}^{FC} = \overline{q}_{tNE}^{FB} - \frac{\Delta\theta\,\nu_0}{b\,(1-\nu_0)} \tag{27}$$

If $\underline{\theta}\,\nu + (1-\nu)\,\frac{p_1-\delta\,p_2-bS}{1-\delta}\;\le\;\overline{\theta}\;\le\;Min\left\{\underline{\theta}\,\nu + (1-\nu)\,\frac{p_1-\delta\,p_2+\delta\,bS}{1-\delta},\underline{\theta}\,\nu + (1-\nu)\,\frac{p_2+p_1-bS}{2}\right\}$, both firms exhaust the stock the inefficient extracts

$$\overline{q}_{1E}^{FC} = \overline{q}_{1E}^{FB} - \frac{\Delta\theta\,\nu_0\,(1-\delta)}{b\,(1-\nu_0)\,(1+\delta)} \tag{28}$$

$\frac{\partial\,q_{1E}^{FC}}{\partial\,\delta} = \frac{2\,\overline{\theta}-2\,\nu\,\underline{\theta}+(1-\nu)\,(b\,S-p_2-p_1)}{b\,(1+\delta)^2\,(1-\nu)} > 0$
$U_{R_{NE}}^{FC} = U_{R_{NE}}^{FB} - \nu\,\Delta\theta[\overline{q}_{1NE}^{FC} + \delta\,\overline{q}_{2NE}^{FC}] - \frac{(1+\delta)\,\nu^2\,\Delta\theta^2}{2\,b\,(1-\nu)}$
$U_{R_E}^{FC} = U_{R_E}^{FB} - \nu\,\Delta\theta[\overline{q}_{1E}^{FC} + \delta\,\overline{q}_{2E}^{FC}] - \frac{(1-\delta)^2\,\nu^2\,\Delta\theta^2}{2\,b\,(1+\delta)\,(1-\nu)}$

$\overline{U}_{Rev} = 0$ and $\overline{U}_{Lie} = -\Delta\theta\,[\underline{q}_1^{FC} - \overline{q}_1^{FC} + \delta\,(\underline{q}_2^{FC} - \overline{q}_2^{FC})] \Leftrightarrow$ the inefficient firm's incentive constraint is always satisfied since the efficient firm always produces at least as much as the inefficient one.

C Non commitment

Second-period contracts

$$\max_{\{\underline{q}_2,\underline{T}_2\},\{\overline{q}_2,\overline{T}_2\}} U_{R_2} = \nu_1\,\underline{T}_2 + (1-\nu_1)\,\overline{T}_2 \text{ s.t} \tag{29}$$
$$p_2\,\underline{q}_2 - C(\underline{\theta},\underline{q}_2) - \underline{T}_2 \ge 0 \tag{30}$$
$$p_2\,\overline{q}_2 - C(\overline{\theta},\overline{q}_2) - \overline{T}_2 \ge 0 \tag{31}$$
$$p_2\,\underline{q}_2 - C(\underline{\theta},\underline{q}_2) - \underline{T}_2 \ge p_2\,\overline{q}_2 - C(\underline{\theta},\overline{q}_2) - \overline{T}_2 \tag{32}$$
$$p_2\,\overline{q}_2 - C(\overline{\theta},\overline{q}_2) - \overline{T}_2 \ge p_2\,\underline{q}_2 - C(\overline{\theta},\underline{q}_2) - \underline{T}_2 \tag{33}$$
$$\overline{q}_1 + q_2(\overline{\nu}_1) \le S \tag{34}$$
$$\underline{q}_1 + q_2(\underline{\nu}_1) \le S \tag{35}$$

This is a standard problem where we should consider (31) and (32) binding. One can show that the non binding participation (30) and incentive (33) constraints are satisfied:
$\underline{U}_{2_{Lie}} = \underline{U}_{2_{Rev}} = \Delta\theta\,\overline{q}_2^{NC}(\nu_1) \Leftrightarrow$ (30) is always satisfied.
$\overline{U}_{2_{Rev}} = 0$ and $\overline{U}_{2_{Lie}} = -\Delta\,\theta\,(\underline{q}_2^{NC}(\nu_1) - \overline{q}_2^{NC}(\nu_1)) < 0 \Leftrightarrow$ (33) is always satisfied as the efficient firm always produces at least as much as the inefficient one.

C.1 Only the efficient firm's incentive constraint binds

The optimal extraction of an inefficient firm depends on S, p_1, p_2, b, $\overline{\theta}$, $\underline{\theta}$, ν_0 and x. There are several solutions depending on which stock constraints bind. We focus on the three

cases where firms are active at each period:
(i) If $(1-\nu_0\,x)(p_1-p_2-b\,S)+\underline{\theta}\,(2\nu_0\,x-1) \leq\; Min\left\{\frac{\underline{\theta}\,\nu_0\,(1-x)+p_2\,(1-\nu_0)}{1-\nu_0\,x}, \overline{\theta} \leq\; p_1(1-\nu_0\,x)+\nu_0\,x\underline{\theta}\right\}$, none of the firms exhaust the resource or only an efficient firm that reveals its type (none of the stock constraint or only (EC_1) bind), the inefficient firm extracts

$$\overline{q}_{1\overline{NE}}^{NC} = \overline{q}_{1NE}^{FB} - \frac{\Delta\theta\,\nu_0\,x}{b\,(1-\nu_0\,x)} \tag{36}$$

(ii) If $Max\left\{(p_1-b\,S)\,(1-\nu_0\,x)+\underline{\theta}\,\nu_0\,x-\delta\,(p_2-ti)\nu_0\,(1-x), \underline{\theta}-\frac{Z(\underline{\theta})\,(1-\nu_0)\,(1-\nu_0\,x)}{1-\nu_0+(1-\nu_0\,x)\,(1-\nu_0\,x+\delta\,\nu_0\,(1-x))}\right\} \leq$ $\overline{\theta}\;\leq\; Max\,\{\underline{\theta}-Z(\underline{\theta})\,(1-\nu_0\,x), \underline{\theta}\,\nu_0\,x+\delta\,\nu_0\,(1-x)\,(\underline{\theta}+bS-p_2)+p_1(1-\nu_0)\}$, only the efficient firm exhausts the stock (whatever its strategy in the first period is, (EC_1) and (EC_3) bind), the inefficient firm extracts

$$q_{1\underline{E}\overline{NE}}^{NC} = \overline{q}_{1NE}^{FB} - \frac{\nu_0[\Delta\theta(x-\delta(1-x))-\delta(1-x)Z(\underline{\theta})]}{b(1-\nu_0\,x+\delta\nu_0(1-x))} \tag{37}$$

(iii) Finally, if $p_1(1-\nu_0\,x)+\nu_0\,x\underline{\theta} \leq \overline{\theta} \leq\; Min\left\{\frac{p_1-\delta\,p_2-b\,S}{1-\delta}(1-\nu_0\,x)+\nu_0\,x\underline{\theta}, \frac{p_1+p_2-b\,S}{2}\frac{2(1-\nu_0)(1-\nu_0\,x)}{(1-\nu_0\,x)^2+1-\nu_0}+\underline{\theta}\frac{\nu_0(1-\nu_0}{(1-\nu_0\,x)}\right.$ all types of firms exhaust the stock (all the the stock constraints bind), the inefficient firm extracts

$$\overline{q}_{1\underline{E}\overline{E}}^{NC} = \overline{q}_{1E}^{FB} - \frac{\Delta\theta\,\nu_0\,x(1-\delta)}{b\,(1+\delta)(1-\nu_0\,x)} \tag{38}$$

where $Z(\underline{\theta}) = 2\underline{\theta}+bS-p_2-p_1$

Proof of Proposition 1

$$\frac{\partial\,U_{R_{\underline{E}\overline{E}}}^{NC}}{\partial\,x} = \frac{(1-\delta)^2\,\nu_0\,\Delta\theta^2}{2\,b\,(1+\delta)\,(1-\nu_0\,x)^2} > 0 \tag{39}$$

$U_{R_{\underline{E}\overline{E}}}^{NC}$ is maximized for $x=1$. The regulator offers full separating contracts in the first period and in the second period both firms extract the remaining stock.

$$U_{R_E}^{FC} - U_{R_{\underline{E}\overline{E}}}^{NC} = \frac{(1-\delta)^2\,\nu_0\,\Delta\theta^2\,(1-x)}{2\,b\,(\delta+1)\,(1-\nu_0)\,(1-\nu_0\,x)} > 0 \tag{40}$$

For $x=1$, the tax revenue under full and non commitment is the same.

($\overline{IC}$) is satisfied if $\underline{q}_1^{NC} \geq \overline{q}_1^{NC} + \delta\,(S-\overline{q}_1^{NC})$ which is equivalent to:

$$\delta\,(\delta\,\underline{\theta}-\underline{\theta}-b\,S-\delta\,p_2+p_1)\,(1-\nu_0\,x)+(1-\delta)^2\,\Delta\theta > 0 \tag{41}$$

Proof of Proposition 2

We consider two cases (i) None of the firm exhaust the stock and (ii) only the efficient firm exhausts the stock (whatever its strategy is).

(i) None of the firms exhaust the stock

$$\frac{\partial U^{NC}_{R_{\overline{NE}}}(x)}{\partial x} = \frac{\nu_0\,\Delta\theta^2\,(1-\nu_0-2\,\delta\,\nu_0\,x\,(1-\nu_0\,x)^2)}{2\,b\,(1-\nu_0)\,(1-\nu_0\,x)^2} \tag{42}$$

$$\frac{\partial^2 U^{NC}_{R_{\overline{NE}}}(x)}{\partial x^2} = \frac{\Delta\theta^2\,{\nu_0}^2\,\left(1-\nu_0-\delta\,(1-\nu_0\,x)^3\right)}{b\,\left(1-\nu_0\right)\,\left(1-\nu_0\,x\right)^3} \tag{43}$$

For high value of δ:
i) the problem is strictly concave in x and (42) defines a global maximum.
ii) $\frac{\partial U_{R_{\overline{NE}}}(x)^{NC}}{\partial x_{|x=1}} = \frac{(1-2\,\delta\,(1-\nu_0))\,\nu_0\,\Delta\theta^2}{2\,b\,(1-\nu_0)^2} < 0$. The regulator chooses a semi separating contract where the optimal level of separation x^* is given by $(42) = 0$. The level of separation decreases with δ.

For low value of δ, a full separating contract is proposed.

The switching point δ above which it is optimal to propose a semi separating contract is such as $U^{NC}_{R_{\overline{NE}}}(x^*) = U^{NC}_{R_{\overline{NE}}}(1)$.

$$U^{FC}_{R_{NE}} - U^{NC}_{R_{\overline{NE}}} = \frac{\nu_0\,\Delta\theta^2\,(\delta\,\nu_0\,x^{*2}\,(1-\nu_0\,x^*)+1-x^*)}{2\,b\,(1-\nu_0)\,(1-\nu_0\,x^*)} > 0 \tag{44}$$

($\overline{IC}$) is satisfied if $\underline{q}_1^{NC} \geq \overline{q}_1^{NC} + \delta\,\overline{q}_2^{NC}(\overline{\nu}_1)$ which is equivalent to:

$$\delta < \frac{\Delta\theta\,(1-\nu_0)}{(1-\nu_0\,x)\,(\Delta\theta\,\nu_0\,x+p_2-\underline{\theta}-\nu_0\,(p_2-\overline{\theta}))} \tag{45}$$

$$\frac{\partial U_{R_{\overline{NE}}}(x)^{NC}}{\partial x_{|x=0}} = \frac{\Delta\theta^2\,\nu_0}{2\,b} \tag{46}$$

A full pooling contract is never optimal.

(ii) Only the efficient firm exhausts the stock (whatever its strategy)

$$\frac{\partial U_{R_{\underline{E}}}^{NC}}{\partial x} = \frac{\nu_0 \left[(1+\delta)\,\Delta\theta\,[((1+\delta)\,(1-\nu_0) - 2\,\delta\,\nu_0\,x\,a^2)\,\Delta\theta + 2\,\delta\,(1-\nu_0)^2\,Z(\underline{\theta})] + \delta^2\,(1-\nu_0)^3\,Z(\underline{\theta})^2\right]}{2\,b\,(\delta+1)\,(1-\nu_0)\,a^2} \tag{47}$$

with $a = (1-{\nu_0}^2\,x + \delta\,\nu_0\,(1-x))$

x^* is given by (47) $= 0$ and the threshold $\widehat{\delta}$ above which a semi separating contract is proposed is such as $(47)_{|\delta=\widehat{\delta}} = 0$.

($\overline{IC}$) is satisfied if $\underline{q}_1^{NC} \geq \overline{q}_1^{NC} + \delta\,\overline{q}_2^{NC}(\overline{\nu}_1)$ which is equivalent to:

$$\delta\,(1-\nu_0)\,[(1-\nu_0)\,Z(\underline{\theta}) + c\,(1+\delta)\,(p_2-\underline{\theta})] + (1+\delta)\,\Delta\theta\,[1-\nu_0 - c\,\delta\,(1-\nu_0\,x)] > 0 \tag{48}$$

with $c = \delta\,\nu_0\,(x-1) + \nu_0\,x - 1$

C.2 Both incentive constraints bind

Proof of proposition 3

(i) None of the firms exhaust the stock

- Let's show that the problem is convex in x:

$$\frac{\partial U_{R_{NE}}^{NC_b}}{\partial x} = \nu \left(b\,\delta\,\left(2\,\nu\,x - 1\right)\,\overline{q}_2(\overline{\nu}_1(x)) + \frac{2\,\Delta\theta\,\left(1-\nu_0-\delta\,\nu\,x\,(1-\nu\,x)\right)}{1-\nu}\right) \tag{49}$$

$$\frac{\partial^2 U_{R_{NE}}^{NC_b}}{\partial x^2} = \delta\,\nu_0 \left(\frac{d\,\overline{q}_2(\overline{\nu}_1(x))}{d\,x}\left(b\,\delta\,x\,\left(\nu_0\,x-1\right)\frac{d\,\overline{q}_2(\overline{\nu}_1(x))}{d\,x} + 2\,b\,\delta\,\left(2\,\nu_0\,x-1\right)\,\overline{q}_2(\overline{\nu}_1(x)) + \Delta\theta\right)\right) + b\,[\delta\,\nu_0\,\overline{q}_2(\overline{\nu}_1(x))]^2 \tag{50}$$

Using (49), we can rewrite (50):

$$\frac{\partial^2 U_{R_{NE}}^{NC_b}}{\partial x^2} = \frac{\Delta\theta^2\,{\nu_0}^2\,\left(8\,\delta\,\nu_0\,x\,\left(1-\nu_0\,x\right) + 4\,\left(1-\nu_0\right) - 3\,\delta\right)\,\left(1-\nu_0-\delta\,\nu_0\,x\,\left(1-\nu_0\,x\right)\right)}{b\,(1-\nu_0)^2\,(1-2\,\nu_0\,x)^2} \tag{51}$$

$\forall\, x \in [0,1]$, $\forall\, \delta > 0$ and $\forall\, \nu \in [0,1]$ and $b > 0$ (51)>0.

$$\frac{\partial\, U_{R_{NE}}^{NC_b}}{\partial\, x_{|x=0}} = \nu_0\, (2\, \Delta\theta\, (1 - \delta\, \nu_0) - \overline{q}_2(\overline{\nu}_1(1))\, b\, \delta\, (1 - 2\, \nu_0)) > 0 \tag{52}$$

There are 3 types of equilibria: full pooling contract, full separating contract and semi separating contracts where $x = 1$ and $y > 0$

- The quantities extracted are given by:

$$\overline{q}_1^{NC_b} = \overline{q}_{1NE}^{FB} - \frac{\delta\, \Delta\theta\ \nu_0\, (y\, (1-\nu_0) + \nu_0)}{b\, (1-\nu_0)\, y} \tag{53}$$

Two types of cases:

a) A semi separating equilibrium is never optimal so the regulator chooses a fully separating contract for $\delta \in]0, \delta_1]$ and a full polling for $\delta > \delta_1$.

b) A semi separating equilibrium may be optimal so the regulator chooses a fully separating contract for $\delta \in]0, \delta_2]$, then a semi separating equilibrium for $\delta \in]\delta_2, 1]$ and a full polling for $\delta > 1]$.
With $\delta_1 = \frac{\Delta\theta\, (\overline{\theta}\, \nu_0 + \underline{\theta}\, \nu_0 + 2\, (p_2\, (1-\nu_0) - \overline{\theta}))}{(p_2 - \overline{\theta})^2\, (1-\nu_0)^2}$ and δ_2 is such that:

$$\begin{aligned} &\Delta\theta\ [(4\, \delta_2\, (\delta_2\, (\nu_0 - 2) - 1)\, \nu_0 + (\delta_2 + 1)\, (5\, \delta_2 + 1))\, \Delta\theta + 8\, \delta_2\, (p_2 - \underline{\theta})\, (\delta_2\, (\nu_0 - 1) - 1)\, (1 - \nu_0)] \\ &+ (2\, \delta_2\, (p_2 - \underline{\theta})\, (1 - \nu_0))^2 = 0 \end{aligned} \tag{54}$$

Under semi separation: $\underline{q}_{1bNE}^{NC} = \underline{q}_{1NE}^{FB} - \frac{(\delta+1)\, \Delta\theta}{2\, b}$ and $\overline{q}_{1bNE}^{NC} = \overline{q}_{1NE}^{FB} - \frac{(\delta+1)\, \Delta\theta\, \nu_0}{2\, b\, (1-\nu_0)}$
Under full separation: $\underline{q}_{1bNE}^{NC} = \underline{q}_{1NE}^{FB} + \frac{(\delta\, (p_2 - \overline{\theta})\, (1-\nu_0) - \Delta\theta)}{b}$ and $\overline{q}_{1bE}^{NC} = \overline{q}_{1NE}^{FB} - \delta\, \overline{q}_{2NE}^{FB}$

Proof of proposition 4

(ii) All firms exhaust the stock:

- A semi separating contract is similar to a pooling contract

(8) gives $\underline{q}_1 = \overline{q}_1 + \delta\, (\overline{q}_2(\overline{\nu}_1) - \delta\, \overline{q}_2(\underline{\nu}_1))$. If $y = 0$ and $x > 0$, $\underline{q}_2(\overline{\nu}_1) = \underline{q}_2^{FB}$ and if $x = 1$ and $y > 0$ $\overline{q}_2(\overline{\nu}_1) = \overline{q}_2^{FB}$. (8) becomes $\underline{q}_1 = \overline{q}_1 + \delta\, (S - \overline{q}_1(\overline{\nu}_1) - \delta\, (S - \overline{q}_1(\underline{\nu}_1)) \Leftrightarrow \underline{q}_1 = \overline{q}_1$.

This does not hold for a fully separating contract where $\overline{q}_2(\underline{\nu}_1) = 0$ and where (8) becomes $\underline{q}_1 = \overline{q}_1 + \delta\, \overline{q}_2(\overline{\nu}_1)$.

- Full separating and Full pooling

Under full separation: $\underline{q}_1 = \overline{q}_1 + \delta\,\overline{q}_2(\overline{\nu}_1)$, if the stock is exhausted: $\underline{q}_1 = \overline{q}_1\,(1-\delta) + \delta\,S$ since $\underline{q}_1 < S \Leftrightarrow \overline{q}_1\,(1-\delta) + \delta\,S < S \Leftrightarrow (\overline{q}_1 - S)\,(1-\delta) < 0$ since $\overline{q}_1 - S < 0$, then $1-\delta > 0$. The full separating contract is only defined for $\delta < 1$ and only relevant when $\delta > \delta_1^E$ (threshold above which both IC must bind).

If we denote U_R^{FP} and U_R^{FS}, the regulator payoff under a full pooling contract and under full separation. The regulator only chooses between these contracts for $\delta \in [\delta_1^E, 1[$. We define δ_2^E is such that $U_R^{FP} = U_R^{FS}$. For $\delta \in [\delta_1^E, \delta_2^E[$, fully separating contracts are proposed, for $\delta > \delta_2^E$, a full pooling contract is proposed.

$$U_R^{FP} - U_R^{FS} = \frac{\delta\,\nu_0\,\left(a^2\,\delta\,(1-\nu_0) + (1-\delta)^2\,\Delta\theta\,\left(\delta\,\overline{\theta} - 2\,\overline{\theta} + \underline{\theta} - b\,S - \delta\,p_2 + p_1 + a\right)\right)}{2\,b\,(\delta+1)\,((\delta-2)\,\delta\,\nu_0 + 1)} \tag{55}$$

with $a = \delta\,\underline{\theta} - \underline{\theta} - b\,S - \delta\,p_2 + p_1$.
For $\delta = 0$, $U_R^{FP} = U_R^{FS}$ and for $\delta = 1$ $U_R^{FP} > U_R^{FS}$.
The denominator is strictly positive $\forall\,\delta \in [0,1]$ and $\forall\,\nu_0 \in [0,1]$. The numerator can be rewritten as:

$$a\,[(1-\delta)^2\Delta\,\theta + \delta\,(1-\nu_0)\,a] + (1-\delta)^2\Delta\,\theta\,[\delta\,\overline{\theta} - 2\,\overline{\theta} + \underline{\theta} - b\,S - \delta\,p_2 + p_1] \tag{56}$$

Yet, when $\underline{IC}$ binds, $\overline{IC}$ is only satisfied if

$$(1-\delta)^2\Delta\,\theta + \delta\,(1-\nu_0)\,a > 0 \tag{57}$$

For $\delta = \delta_1^E$, (57)=0, since $(1-\delta)^2\Delta\,\theta > 0 \Leftrightarrow a < 0$. Hence, if $\delta = \delta_1^E$, (56) becomes $(1-\delta)^2\Delta\,\theta\,[\delta\,\overline{\theta} - 2\,\overline{\theta} + \underline{\theta} - b\,S - \delta\,p_2 + p_1] = (1-\delta)^2\Delta\,\theta\,[a - (2-\delta)\Delta\,\theta] < 0$. Then, for $\delta = \delta_1^E$, a full separating contract is proposed.
δ_2^E is such as $(55) = 0$, $\forall\,\delta \in [\delta_1^E, \delta_2^E[$, a full separating contract is proposed.

- The production level under full separation:

$$\underline{q}_{1bE}^{NC} = \underline{q}_{1E}^{FB} - \frac{(1-\delta)^2\Delta\,\theta + \delta\,(1-\nu_0)\,a}{b\,(\delta+1)\,((\delta-2)\,\delta\,\nu_0 + 1)} \tag{58}$$

Full separating contracts where both IC bind are only implemented if when $\underline{IC}$ binds, $\overline{IC}$ is not satisfied, i.e, if $(1-\delta)^2\Delta\,\theta + \delta\,(1-\nu_0)\,a < 0$. As a result, the efficient firm always overproduces in the first period as compared to the first best.

$$\frac{\partial\,\underline{q}_{1bE}^{NC}}{\partial\,\delta} = \frac{\delta\,(\underline{\theta} - p2)\,(1-\nu_0)}{b\,(\delta+1)\,((\delta-2)\,\delta\,\nu_0 + 1)} - \frac{(\delta-1)\,\Delta\,\theta\,((\delta-3)\,\delta^2\,\nu_0 + 2\,(2\,\delta+1)\,\nu_0 - \delta - 3)}{b\,(\delta+1)^2\,((\delta-2)\,\delta\,\nu_0 + 1)^2} + \frac{a\,(1-\nu_0)\,((1-2\,\delta)\,\delta^2\,\nu_0 + 1)}{b\,(\delta+1)^2\,(\delta^2\,\nu_0 - 2\,\delta\,\nu_0 + 1)^2} \tag{59}$$

An increase in the discount factor has two opposite effects on the efficient firm's first period extraction. On the one hand, it decreases the first best extraction and thus decreases $\underline{q}_{1bE}^{NC}$ (resource effect). On the other hand, it decreases the distortion and it thus increases the extraction (information effect). The sign of (59) is undetermined. If the information asymmetry is low, and increase in the discount factor decreases the extraction (standard effect). However, if the information asymmetry is high, the extraction may decrease for low value of the discount factor (close to δ_1^E) and increases for high value of the discount factor (close to δ_2^E).

$$\overline{q}_{1bE}^{NC} = \overline{q}_{1NE}^{FB} + \frac{(1-\delta)\ \delta\ \left(\delta\,\overline{\theta} - 2\,\overline{\theta} + \underline{\theta} - b\,S - \delta\,p_2 + p_1\right)\ \nu_0}{b\ (\delta+1)\ ((\delta-2)\ \delta\,\nu_0 + 1)} \tag{60}$$

$\delta\,\overline{\theta} - 2\,\overline{\theta} + \underline{\theta} - b\,S - \delta\,p_2 + p_1 = a - (2-\delta)\Delta\,\theta < 0$. The inefficient firm produces a lower amount than the first best.

$$\frac{\partial\,\overline{q}_{1bE}^{NC}}{\partial\,\delta} = \frac{\nu_0\ \left(\delta^2\ \left(\delta^2 - 2\,\delta + 3\right)\ \nu_0 - \delta^2 - 2\,\delta + 1\right)\ \left((\delta-2)\ \Delta\,\theta + a\right)}{b\,(\delta+1)^2\,(\delta^2\,\nu_0 - 2\,\delta\,\nu_0 + 1)^2} + \frac{(1-\delta)\ \delta\ (ts - p2)\ \nu_0}{b\ (\delta+1)\ ((\delta-2)\ \delta\,\nu_0 + 1)} \tag{61}$$

(61) is strictly negative.

The following tables summarizes the extraction path under non commitment when the stock of resource is low and large.

Full separation		Full pooling
$\underline{IC}$ binds and $\overline{IC}$ is slacked $\delta \in [0, \delta_1^E]$	Both IC bind $\delta \in [\delta_1^E, \delta_2^E]$	Both IC bind $\delta > \delta_2^E$
$\underline{q}_1 = \underline{q}_1^{FB}$ $\overline{q}_1 < \overline{q}_1^{FB}$	$\underline{q}_1 > \underline{q}_1^{FB}$ $\overline{q}_1 < \overline{q}_1^{FB}$	$\underline{q}_1 = \overline{q}_1^{FB} < \underline{q}_1^{FB}$ $\overline{q}_1 = \overline{q}_1^{FB}$
No distortion at the top AI slows down $\overline{\theta}$'s extraction NC has no effect only AI has	NC intensifies $\underline{\theta}$'s extraction NC slows down $\overline{\theta}$'s extraction Ambiguous effect of δ on $\underline{q}_1$	NC slows down $\underline{\theta}$'s extraction NC has no effect on $\overline{\theta}$'s extraction The extraction does not depend on $\underline{\theta}$

Table 1: Low stock