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Endogenous Information Structures in Conservation Contracting

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Endogenous information structures in conservation contracting

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Endogenous information structures in conservation contracting

Abstract

Landowners are commonly not only better informed about their private cost of conservation than conservation agencies, but also frequently in a position to spend resources on improving their knowledge about contract-relevant parameters before signing a contract on offer. We extend and generalize the literature on conservation contracting by endogenizing the information structure in a setting where the conservation agency is both asymmetrically informed about the efficiency of the landowner and unable to observe whether the landowner collects information after being offered the contract and before signing it. In this setting, we study the optimal contract the conservation agency should offer to the landowner conditional on the cost of information collection. This contract needs to balance moral hazard and adverse selection problems since by encouraging a landowner to collect information, the conservation agency simultaneously increases the landowner's incentive to misreport his 'type'. We term this the 'information rent effect'. Due to its presence, the terms of conservation contracts have to be significantly altered relative to a contract offered based on exogenous information structure or a contract based purely on information collection.

Keywords: Conservation; Contracts; Asymmetric Information; Information Collection;

JEL codes: Q220, Q280;

1. Introduction

1.1. Information management in conservation contracting

With the expansion of conservation activities on private lands, the relationship between conservation agencies and landowners has become a major focus of attention in the economics of conservation (cf. Shogren and Tschirhart 2001). One increasingly popular instrument available to conservation agencies for managing this relationship are conservation contracts (OECD 1999). A common theme in the literature on the design of such contracts is the observation that landowners are commonly better informed about their private cost of conservation than conservation agencies. This realization has given rise to the design of conservation contracts that ensure efficiency by taking this pre-contractual information asymmetry into consideration (Smith and Shogren 2002, Moxey et al. 1999, Wu and Babcock 1996, Smith 1995). Related to such information asymmetries is another, but quite distinct observation. This is that landowners are not only better informed about contract-relevant parameters, they are also frequently in a position to improve – at a cost – on their information before signing a contract offered to them by the conservation agency. When present, this asymmetry in the ability to gather information has important implications for contract design. This is because information collection by an agent before signing a contract gives rise to endogenous information structures that require additional features to be added in optimal contract design (Laffont and Martimort 2002, Crémer et al. 1998, Crémer and Khalil 1992).

In our view, it is a characteristic of a significant number of conservation contracting situations that both types of asymmetry described above will be present at once. This will be true particularly in settings where conservation contracts are either a novel instrument or exhibit significant heterogeneity. The reason is that while it is plausible, on the one hand, to assume that landowners will possess some superior information about the private cost of participating in a particular contract, they will, on the other hand, usually not find it economical to become perfectly informed about the exact cost of fulfilling their contractual commitments prior to a particular contract being offered. Once a specific contract can be considered by the landowner, however, it can be shown that there will be conditions under which it will be rational to improve on the informational status by gathering additional information.

Information gathering by landowners is welfare-relevant for at least three reasons: If the information so collected is productive, both conservation agency and landowner have a joint interest in it being collected to improve efficiency of production. Since information collection is usually costly, however, encouraging information collection is not always socially desirable. Thirdly, since information collection can usually not be observed and the landowner does not need to share new information with the conservation agency, information collection can increase the landowner's existing strategic advantage of pre-contractual information asymmetry and hence his ability to extract additional rents from the conservation agency. These three basic considerations point to the need to design the conservation contract in a way that efficiently manages the trade-off between encouraging and deterring information collection by the landowner after the contract has been offered. This paper provides a characterisation of the optimal contract in such a setting.

1.2. Contribution

Previous papers have considered the problem of information collection, both in the context of conservation contracting and more generally. Polasky and Doremus (1998) and Polasky (2001) consider the case of how conservation agencies can gather biological information on private lands to determine the optimal extent of restrictions on land use as well as the optimal level of compensation. In these models, agreeing to information collection is voluntary while participation in conservation is not. By contrast, in our setting the landowner 's participation in conservation is purely voluntary.

The general contracting literature has considered both the cases of strategic[1] (Crémer et al. 1996, Crémer and Khalil 1992) and productive[2] information gathering (Laffont and Martimort 2002, Crémer et al., 1998a, Lewis and Sappington 1997)[3]. Information is productive in our model, but we extend the existing literature by studying contracts that are also robust with respect to pre-contractual asymmetry. Specifically, we differ from Laffont and Martimort (2002, 395ff.) in considering a continuum of agents and a different timing of the game and from Lewis and Sappington (1988) by excluding ex-post cost observability. One restriction of the analysis is that it focuses on cases in which types are sufficiently distinct or – differently put – exogenous information asymmetry is 'large' relative to new information. We return to this point below.

By considering the – from our point of view, highly realistic – combination of information asymmetry and information gathering, our model is a first attempt to include endogenous information structures in the analysis of conservation contracts. As a result, we are able to study some interesting contract design problems that do not arise when information and ability asymmetry are analyzed in isolation.

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[1] Strategic information gathering refers to situations where the information is obtained freely after the contract is signed. Pre-signing information gathering is therefore carried out purely for bargaining reasons (see Crémer et al 1998a).

[2] Productive information gathering refers to situations where the information must be acquired for a cost even after signing the contract. (again, see Crémer et al, 1998a).

[3] Cremer et al. (1998a) analyse a continuous-type Baron and Myerson (1982) model with adverse selection and endogenize the regulator 's choice of whether to induce or deter costly information acquisition. They show that when information acquisition cost is high enough, regulator would deter information acquisition by offering a fixed-amount fixed-payment contract. Lewis and Sappington (1997) study contracts that encourage precontractual cost information collection in the two-type case with unobservable effort. They extend the standard procurement model to examine how an landowner is optimally induced to acquire information and show that concerns about information acquisition cause

What is the nature of the problem? From the point of view of the conservation agency, there are considerable benefits from inducing the landowner to collect information in order to improve production efficiency. As a complication, moral hazard problems arise since the action of information acquisition is unobservable by the agency. The contract needs to ensure therefore that it will be in the landowner's interest to collect information if that increases the efficiency of production. In our context, sufficient information rent has to be offered to compensate for the cost of information acquisition. In line with Cremer et al. (1998a), the optimal conservation contract balances the information rent, as a function of the cost of acquisition, and the improvement in efficiency.

The counterweight to the efficiency gains generated by information gathering is that in the absence of ex-post observability, the conservation agency has to design the contract in an incentive-compatible way in order to make landowners reveal their private cost of conservation. As information acquisition is not observable by the agency, information rents must be offered to overcome the implicit moral hazard problem. However, we find that – as a general rule – increasing information rents in the interest of encouraging information acquisition will worsen the adverse selection problem. Specifically, raising the information rent for low efficiency landowners makes it more attractive for high efficiency landowners to misreport their type.

The core contribution of this paper is to characterize the conservation contract that optimally trades off moral hazard and adverse selection when the landowner is both better informed and able to get better informed still. Depending on the cost of information acquisition, the optimal contract is designed to encourage the landowner to collect information when appropriate, while at the same time controlling the

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important changes in standard incentive contracts. Reward structures with extreme financial payoffs information rent to prevent untruthful revelation of the information. It turns out that the terms of such contract will differ significantly from contracts derived for exogenous information structures or for incentivizing information collection.

The structure of the paper is as follows: In the next section, we describe a simple model of endogenous information structures with precontractual information asymmetry. In section 3 we give as benchmarks special cases of our problem for which solutions already exist in the literature, then present and contrast with these solutions the main results of our generalized model. In section 4, we develop the specific contract terms given our contracting situation. In section 5, we discuss the main findings, suggest possible extensions and conclude.

2. The Model

2.1. Model set-up

The set-up of the model is similar to Cremer et. al. (1998a), but differs in its information structure. A risk-neutral conservation agency (thereafter, 'the regulator') contracts with a risk-neutral landowner for the production of a positive amount q of conservation effort, such as the amount of land retired. The amount produced $q \in [0,+\infty[$ is publicly observable.

The regulator. Net of transfer T to the agent, the regulator earns – ex post – a net benefit $G \equiv V(q) - T$. The benefit function V is concave and twice differentiable on $[0, +\infty[$ with $V' > 0$, $V'' < 0$, and $V''' > 0$ and satisfies Inada's conditions $[V'(0)=+\infty, V'(+\infty)=0]$.

The landowner. The landowner's net payoff U from accepting the contract is – ex post – the transfer T received from the regulator minus the cost of producing q, such

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arise, and super-high-powered contracts are coupled with contracts that entail pronounced cost sharing.

that $U \equiv T - Bq$. The payoff from not accepting the contract is zero. Information asymmetry arises from the fact that there are two types of agents in the market: high efficiency agents (type *H*) and low efficiency agents (type *L*). Let B_H (B_L) denote high (low) efficiency landowner's efficiency parameter in the cost function and $B_H < B_L$. There is a probability $\lambda \in [0,1]$ that the landowner is of the high efficiency type. The landowner's marginal cost B_i consists of two components: The first is the efficiency parameter β_i which is privately known to the landowner only. This gives rise to status asymmetry. The second is a parameter θ_i denoting the state of the world which is unknown to both regulator and landowner at the outset, but which the landowner can find out in return for paying *r*. This gives rise to ability asymmetry. The marginal cost is additive in both parameters such that $B_i = \beta_i + \theta_i$. For simplicity assume that θ_i is uniformly distributed $[\underline{\theta}, \overline{\theta}]$ with $E(\theta_i) = 0$. θ_H and θ_L are assumed to be drawn from the same distribution, so the subscripts are dropped subsequently. Note that even though the realization of state of world θ can be different for type *H* and type *L*, in the interest of tractability we restrict attention to a setting in which high and low efficiency agents are sufficiently distinct such that $\beta_L > \beta_H + \overline{\theta}$. This implies that a producer who observes his type to be *H* prior to collecting information will be more efficient under the worst case of the world than the average low-efficiency producer: Exogenous information asymmetry is – loosely speaking – 'important' relative to new information. We come back to this point in section 5.

2.2. Direct revelation game

Following Cremer et al. (1998a), we assume that if the regulator encourages acquisition of θ, he offers the landowner a schedule $T_i(q_i(\theta))$ that links payment to production, where $q_i(\theta)$ is a function of the true and known cost B_i, which includes information on both θ and β_i. On the other hand, if the regulator discourages the landowner from acquiring θ, the contract can be described by a pair (T_i, q_i), in which case production q_i is a function of type β_i only.

2.3. Information structure and timing

The timing is as in Crémer et al.(1998a), but has an endogenous information structure:

- At date 0, nature selects the marginal cost B_i, which consists of two components: β_i which is known to the landowner privately and θ, which is unknown to both at the outset. Recall that $B_i = \beta_i + \theta$.
- At date 1, the regulator offers a contract to the landowner. The form of the contract follows a direct revelation mechanism. If the regulator encourages information collection, the contract takes forms of $T_i(q_i(\theta))$ where the production and payment will relate to both β_i and θ. If the regulator discourages information collection, the contract will take form of (T_i, q_i) where production and payment are only based on β_i.
- At date 2, the landowner chooses whether or not to collect information. The cost of information collection, r, is common knowledge. Information collection is not observable by the regulator and therefore non-contractable.
- At date 3, the landowner decides whether to accept or refuse the contract. If the contract is refused, the game is over.
- At date 4, if the landowner accepts the contract, he chooses an output level q and receives the transfer T specified in the contract.

Note that the landowner has an opportunity to collect information θ (date 2) after the contract is offered (date 1) but before signing the contract (date 3) and producing (date 4). Knowledge of θ provides information about the true marginal cost before production, and therefore improves efficiency. In this sense, gathering information θ is "productive".

2.4. Strategies and payoffs

The regulator may or may not choose to induce information acquisition. If he does, output will be sensitive to the true cost of production $B_i = \beta_i + \theta$. Therefore with acquisition of θ, the landowner's and regulator's utilities are respectively:

$$U_i(\theta) \equiv T_i(q_i(\theta)) - B_i q_i(\theta) = T_i(\theta) - (\beta_i + \theta) q_i(\theta)$$
$$G_i(\theta) \equiv V(q_i(\theta)) - T_i(q_i(\theta)) = V(q_i(\theta)) - T_i(\theta)$$

On the other hand, if the landowner has been deterred from acquiring information, production will be independent of θ and therefore independent of B_i. The optimal contract can be described by a pair (T_i, q_i). Without information acquisition, the landowner's and government regulator 's utilities are respectively:

$$U_i \equiv T_i - B_i q_i$$
$$G_i \equiv V(q_i) - T_i$$

The contracts offered must be incentive compatible in the sense that - when offered $T_i(q_i(\theta))$- the landowner should prefer to become informed, and - when offered (T_i, q_i)- he should prefer not to become informed. It follows from the revelation principle that if the landowner has acquired information, the regulator will find it optimal to have the landowner announce the value of B_i, and to base the production and payment on this announcement.

3. Optimal Contract Choice

The specific set-up of our model suggests three special cases. The first is where $\theta \equiv 0$, the second is where $r \equiv 0$, and the third is where $\lambda \equiv 1$ or 0. For these special cases, the optimal contract terms are available from the literature. The first case is familiar as the simple version of precontractual information asymmetry with two discrete types of agents, also known as the 'basic' model in the textbook literature (Laffont and Martimore 2002, Laffont and Tirole 1993). In the second case, our model effectively collapses into the Baron-Myerson (1982) model (BM hereafter) with a continuum of agents. Lastly, in the third case the model is identical to the Cremer et. al.(1998a) model (CKR hereafter) where on the outset of contract both the regulator and the landowner are equally informed, but the landowner has better ability to collect information by incurring a cost *r*. These well-known results are important benchmarks against which we contrast our findings about what happens when pre-contractual asymmetry and costly information acquisition interact.

3.1. Benchmark Model 1: $\theta \equiv 0$

If $\theta \equiv 0$, the only information asymmetry remaining in the model is precontractual, which corresponds to a standard problem with two types of landowners. The optimal design of such a contract is the 'textbook' second best solution:

$$\begin{aligned} &V'(q_H^{**}) = \beta_H \\ &V'(q_L^{**}) = \beta_L + \frac{1-\lambda}{\lambda}(\beta_L - \beta_H) \\ &T_L^{**} = \beta_L q_L^{**} \\ &T_H^{**} = T_L^{**} - \beta_H q_L^{**} + \beta_H q_H^{**} \end{aligned} \tag{1}$$

The classic conclusion is that in this setting, the contract should be designed such that the low-efficiency landowner under-produces and receives no rent, while the high efficiency landowner produces at the efficient level and receives an information rent. We will make extensive use of the benchmark output contracted, q_L^{**} and q_H^{**}, below.

3.2. Benchmark Model 2: $r \equiv 0$

If information can be collected at zero cost, i.e. $r = 0$, our model collapses into the classic BM model. Consider the simplified case where there exists only one type of landowner, i.e. $\lambda = 1$ *or* 0. Like in BM therefore, the regulator faces a landowner of a continuous type (with unit costs between $\beta+\underline{\theta}$ and $\beta+\overline{\theta}$) with the true type private information of the landowner only. The solution to the BM model is:

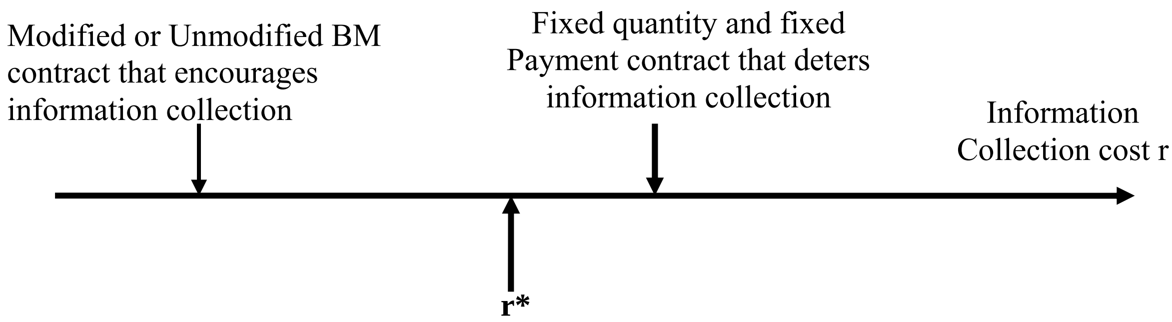
$$V'(q^{BM}(\theta)) = \beta + \theta + \frac{F(\theta)}{f(\theta)} \tag{2}$$

where $f(\theta)$ and $F(\theta)$ are the probability density and cumulative probability functions of θ. The BM contract is designed such that at the optimum the contracted production yields a marginal utility to the regulator which is equal to the marginal cost to the landowner ($\beta+\theta$) plus an information rent term $\frac{F(\theta)}{f(\theta)}$. So with the exception of the best state of the world, i.e. $\theta=\underline{\theta}$, the post-contractual situation is characterised by underproduction.

3.3. Benchmark Model 3: $\lambda = 1/0$

If $\lambda = 1$ or 0, there is no pre-contractual asymmetry, but only the landowner can collect information at cost r. This is the set-up in CKR's classic paper. Their conclusion is that depending on how costly it is to compensate the landowner for his effort in collecting information, the regulator might find optimal to offer either a fixed quantity - fixed payment (FQ-FP) contract (q,T) based on expected cost, which deters the landowner from collecting information, or a BM-type incentive contract with additional compensation for the landowner's information acquisition activity, which encourages information acquisition. Figure 1 illustrates their main result. When $r < r^*$, the optimal contract is a BM type incentive contract which encourages information collection and revelation. When $r > r^*$, the optimal contract to offer is a FQ-FP contract that deters information collection.

Figure 1: Ability Asymmetry: CKR Model



As we will show, this result only holds for the special case of one type of landowner. Adding a second type of landowner to the model makes substantial difference in terms of the types of contract offered as well as the specific contract terms. In CKR, the only rationale for the regulator to switch from encouraging to deterring information collection is that the landowner's information collection cost r is too high to compensate. In a generalized model, however, there are additional concerns about the choice of contract type. As we will show in detail later, encouraging information collection also encourages landowners, in particular high-efficiency landowners, to misreport their type. However, offering the high-efficiency landowner an incentive compatible contract for revealing his true type is much more costly if the low efficiency landowner is encouraged to collect information. In a generalized model, these potential interactions between two types of agents compound the information collection cost in driving the regulator's choice between contract types. We demonstrate this in the following subsection.

3.4. Main result

Under precontractual asymmetry and endogenous information structures, there are four types of contracts available to the principal. The first is a contract type that deters both types of agents from collecting information and is denoted as P_{NN}. The second type induces both types of agents to collect information, a problem referred to as $P_{II.}$ The third types induces only the high-efficiency landowner to collect information, a problem denoted by P_{NI}. The last type of contract induces only the low-efficiency landowner to collect information, a problem denoted by P_{IN}. The regulator 's utility in offering four types of contracts is denoted by G_{NN}, G_{II}, G_{NI}, and G_{IN} respectively. Here we characterize the regulator's optimal choice across the four different types of contracts. Section 4 discusses the optimal terms of these contracts.

The first result, contained in Lemma 1, states that only three of the four possible contract types will ever be considered by the regulator.

Lemma 1: For each given information collection cost r, there exists a feasible contract P_{NI} that is preferable to P_{IN} by the principal.

Proof: See Appendix A.

The intuition for Lemma 1 lies in the asymmetric nature of the "information rent effect". The information rent is the rent that the regulator has to pay to encourage the landowner to collecting information. This rent is different for type *H* and type *L*: For contract type P_{NI}, the terms only have to ensure that the information rent paid to type

H under the most unfavourable situation ($\beta_H + \overline{\theta}$) is incentive compatible with the transfer to type L (β_L). In other words, the information rent paid to type H under P_{NI} will generally not impact significantly on the size of the transfer (T_L) to type L. However, the converse does not hold for P_{IN}. Compared to $P_{NI,}$ P_{IN} generally leads to a significant increase in the information rent going to landowners because for the contract to be incentive compatible, it has to pay as much information rent for type H (β_H) as for type L under the most favourable situation ($\beta_L + \underline{\theta}$). This is to say, every penny paid as information rent to type L will increase the transfer (T_H) to type H. Therefore P_{NI}, the contract that induces type H to collect information, strictly dominates P_{IN}.

Given that only three contract types need ever be considered by Lemma 1, Proposition 1 contains the rule by which the regulator optimally chooses between the three contract types as a function of r.

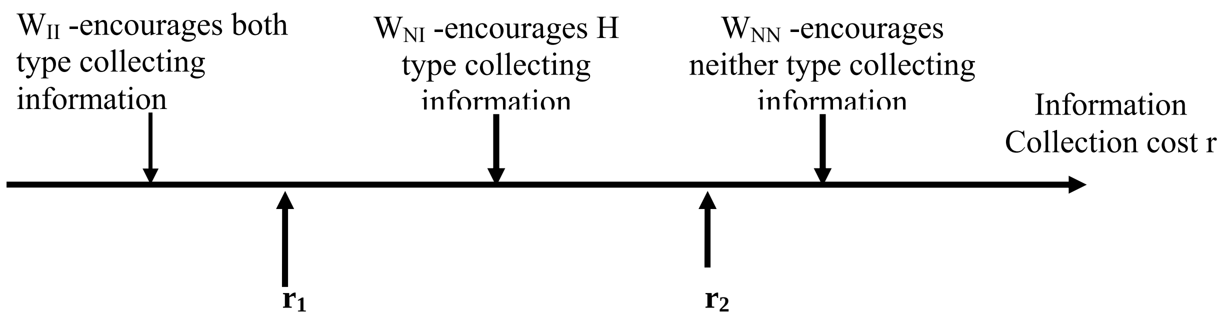
Proposition 1: Denote the regulator's optimal contract and associated utility as $G_{opt.}$ G_{opt} can be characterized by two critical levels of r: r_1 and r_2, where $r_2 \geq r_1$:

- *For $r < r_1$, $G_{opt} = G_{II}$*
- *For $r_1 \leq r \leq r_2$, $G_{opt} = G_{NI}$*
- *For $r > r_2$, $G_{opt} = G_{NN}$*

Proof: See Appendix A.

Proposition 1 shows that for a high information acquisition cost ($r > r_2$), it is optimal to offer both types of agents FQ-FP contracts that deter both from collecting information. For all $r_1 \leq r \leq r_2$, a FQ-FP contract is offered to type L to deter information acquisition and a BM contract to type H to encourage information collection. For $r < r_1$, BM contracts are offered to both types of agents to encourage information acquisition. We develop the specific terms of these contracts in the Section 4. The Figure 2 illustrates the essential features of the choice of contract types indexed by the cost of gathering information.

Figure 2: Dual Information Asymmetry



The difference between Proposition 1, illustrated in Figure 2, and the main results of CKR, illustrated in Figure 1, can be understood in two ways. First, in contrast with CKR's result where choice of the contract type depends exclusively on the information collection cost *r*, in the more general setting it also depends on landowner's efficiency type. For intermediate information collection cost, the regulator encourages information collection by type *H* and deters that activity by type *L*. There are two reasons for this asymmetric treatment: First of all, type *H* has greater use for the information since it can be used both to misreport its type and to decide on the rejection of the contract. By comparison, type *L* can use the information only to reject the contract (as he would never have incentive to misreport his type and to understate his marginal cost!). It is therefore more difficult to deter type *H* from collecting information. Secondly, any information rent paid to type *L* requires the information rent paid to type *H* to increase to prevent misreporting by the latter. The converse, however, is not true. This makes inducing the less efficient agent to collect information particularly unattractive from the regulator's point of view.

Second, the threshold level of r^* at which the optimal contract type is switched in CKR becomes very different when there is more than one type of landowner. Due to the "information rent effect", this threshold point is further pushed toward the direction of zero (infinity) if there exists a more (less) efficient agent. In other words, if there exists a more efficient type of agent, this threshold is pushed toward zero and a FQ-FP contract is more plausible. Conversely, the threshold is pushed toward the direction of infinity and an incentive contract that encourages information acquisition is more plausible when there possibly exists a less efficient type agent.

After having characterized the optimal choice across contract types as a functon of *r*, we now study the precise terms of the contract types on offer.

4. Optimal Contracts with Information Acquisition Constraints

Proposition 1 specifies three types of contracts indexed by information collection cost r under dual information asymmetry. In this section we derive the optimal contract terms for each type, P_{NN}, P_{II} and P_{NI}, in the presence of both precontractual information asymmetry and endogenous information structures. In the interest of tractability and illustration and without loss of generality, we make several simplifications by assuming: $\lambda = ½$, $V(q) = q^{\alpha}$ where $\alpha \in (0,1)$, and θ_i is uniformly distributed.

4.1 P_{NN}: Contracts that Deter Information Acquisition from Both Agents

We first consider the terms of the contract type that the regulator uses to deter information collection by both types of landowners. In this case, the regulator benefits from the fact that he does not need to ensure a positive utility of the landowner in every state of world. The landowner saves information collection expenses but possibly commits to a contract that he would not commit to if he knew the true state of world. Since the landowner does not gather information, production will be independent of θ and the optimal contract menu can be described as (T_H, q_H) and (T_L, q_L) for β_H and β_L respectively. The optimal contract that deters information acquisition is the solution to the problem P_{NN}:

$$Max \quad \frac{1}{2}[V(q_H)-T_H]+\frac{1}{2}[V(q_L)-T_L]$$

s.t.

$$(1) \quad E(U_L)=T_L-\beta_L q_L \geq 0$$

$$(2) \quad E(U_H)=T_H-\beta_H q_H \geq 0$$

$$(3) \quad T_L-\beta_L q_L \geq T_H-\beta_L q_H$$

$$(4) \quad T_H-\beta_H q_H \geq T_L-\beta_H q_L$$

$$(5) \quad \int_{\underline{\theta}}^{\theta''}(T_L-(\beta_L+\theta))f(\theta)d\theta-(T_L-\beta_L q_L)\leq r$$

$$where \quad T_L-(\beta_L+\theta'')q_L=0 \quad i.e.\theta''=\frac{T_L}{q_L}-\beta_L$$

$$(6) \quad \int_{\underline{\theta}}^{\theta'}(T_H-(\beta_H+\theta)q_H)f(\theta)d\theta+\int_{\theta'}^{\bar{\theta}}(T_L-(\beta_H+\theta)q_L)f(\theta)d\theta-(T_H-\beta_H q_H)\leq r$$

$$where \quad T_L-(\beta_L+\theta')q_L=T_H-(\beta_H+\theta')q_H \quad i.e. \quad \theta'=\frac{T_L-T_H}{q_L-q_H}-\beta_H$$

$$(7) \quad \int_{\underline{\theta}}^{\theta'''}(T_H-(\beta_H+\theta)q_H)f(\theta)d\theta-(T_H-\beta_H q_H)\leq r$$

$$where \quad T_H-(\beta_H+\theta''')q_H=0 \quad i.e.\theta'''=\frac{T_H}{q_H}-\beta_H$$

The objective function in P_{NN} reflects the regulator's desire to maximize the expected net return from the policy when he deters information collection from either landowner by offering two pairs of (T_i, q_i). Conditions (1) to (4) are standard. (1) and (2) are individual rationality constraints (IRs), ensuring the expected utility of each landowner is non-negative. Condition (3) and (4) are incentive compatibility constraints (ICs) that ensure truthful reporting of the efficiency type. Condition (5), (6) and (7) are information acquisition constraints (IAs) that ensure that agents prefer to stay uninformed about θ given information collection costs r.

It is essential to observe that the information acquisition constraints (IAs) are different for high and low efficiency agents. For type L, the benefit of knowing θ is the ability to turn down the contract when true marginal cost is so high that the contract yields negative payoff (i.e. $\theta > \theta''$ where θ'' is the zero-profit state of world). If information collection costs r outweigh expected benefits, as shown in condition (5), the landowner will choose to stay uninformed. For *type H*, on the other hand, the benefit of collecting information is twofold. (7) shows that he can use this information to turn down the contract if the state of world is unfavourable (i.e. $\theta > \theta'''$ where θ''' is the zero-profit state of world). This option is similar to type L in condition (5). In addition, however, as shown by condition (6), he can also use this information to misreport his efficiency type if the state of world is unfavourable ($\theta > \theta'$, where θ' is the state of world where he is indifferent between truly and falsely reporting his type). The first two terms of the left-hand side of (6) are the expected income after information acquisition and the third term is his expected income without information acquisition. If the difference between them is smaller than information collection cost r, no information acquisition will occur.

The contract terms when information collection is deterred are best understood when compared to benchmark model I, the ‘textbook’ contract that might be offered when the endogeneity of the information structure is not explicitly considered.

Proposition 2, therefore, contrasts the solution to P_{NN} against the 'textbook' second-best solution shown in Equation (1).

Proposition 2: If information collection is deterred from both agents, two fixed-quantity fixed-payment contracts will be offered. Denote q_i^{NN} the optimal production contracted and q_i^{**} the standard second best contract shown in Equation (1). The optimal contract has the following properties: Assuming $\beta_L \geq \frac{(2^{\alpha-1}+1)}{2^{\alpha}}\beta_H$ [4], there exist two critical levels r_A^{NN} and r_B^{NN} , $r_A^{NN} \leq r_B^{NN}$

- *For all $r \geq r_B^{NN}$, $q_i^{NN} = q_i^{**}$.*
- *For all $r < r_B^{NN}$, $q_H^{NN}(r) < q_H^{**}$, $\partial q_H^{NN}(r)/\partial r > 0$; $q_L^{NN}(r) > q_L^{**}$*, and $\partial q_L^{NN}(r)/\partial r < 0$. $\partial q_L^{NN}(r)/\partial r \mid r \in (r_A^{NN}, r_B^{NN}) < \partial q_L^{NN}(r)/\partial r \mid r \in (0, r_A^{NN})$.

Proof: See Appendix B.

Proposition 2 is illustrated by Figure 3[5]. Only in the case of $r > r_B^{NN}$ is the conventional second-best contract design based on expectation efficient. For $r_A^{NN} < r < r_B^{NN}$, the contracts intended for both agents need to be modified. Within this cost range, a landowner of type *H* will be tempted to collect θ. This information is of value to type *H* because it can be used either to reject the contract or to misreport the efficiency parameter β_H. As a remedy, the regulator has to decrease the quantity contracted from type *H* (q_H) and to increase it from type *L* (q_L), which partially

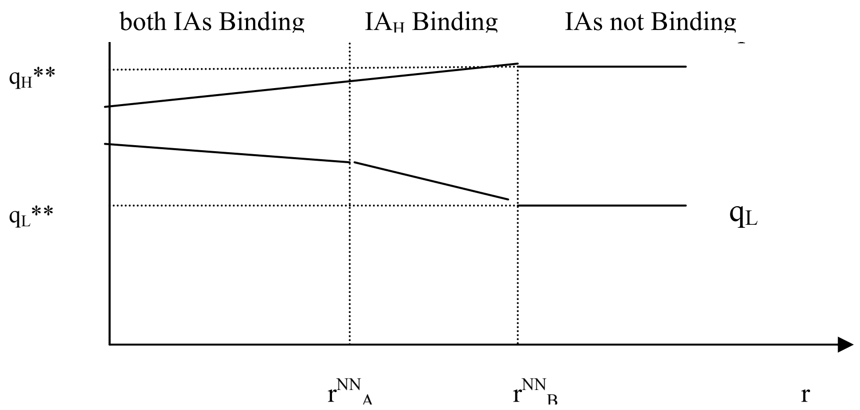
[4] More general solution to this is $V'^{-1}(\beta_H) \geq 2\, V'^{-1}[\beta_L + (\beta_L - \beta_H)(1-\lambda)/\lambda]$. This is to assume there exist significant efficiency difference between two types of agents. α is the Cobb-Douglas coefficient and measures the concavity of regulator 's utility function. The larger α is, the smaller difference between β_H and β_L is required for the result to hold. For linear utility G=q, $\beta_L \geq \beta_H$ is sufficient.

[5] We illustrate in the graph the change of contracted quantities responding to the change of r. We show the change in a linear fashion, but it does not have to be linear. Same applies to Figure 4 and 5.

eliminates the information value of θ. This means that compared *to the second-best situation, less production is contracted for type H and more production for type L.*

When $r \leq r_A^{NN}$, not only type *H*, but also type *L* will find it desirable to acquire θ under the conventional second-best contract because he can use this information to evaluate the option of accepting (or rejecting) the contract. Thus the information acquisition constraints bind more strongly and the contract terms need to be modified further, as shown in Figure 3. As a consequence, *for* $r \leq r_A$, *production contracted from type H decreases and the rate of production growth decreases for type L as* r *decreases.*

Figure 3: Optimal Contract under Information Collection Deterrence



The differences between the 'textbook' contract and the terms of P_{NN} highlight that information acquisition constraints should play an important role in contract design. When the regulator tries to deter both types of landowners from collecting information, the conventional second-best contract is only valid when information collection costs are high. For low information collection cost, the contract terms have to be altered in a way that reduces agents' incentive to collect information. The optimal contract achieves this by decreasing the difference between the type-specific contract quantities. As a result, the regulator's welfare decreases as the contract terms are modified away from the conventional second best solutions and the regulator's welfare is non-decreasing in *r*.

4.2 Contracts that Induce Both Types of Agents to Collect Information

If the regulator wants to induce both types of landowners to collect information, the appropriate instrument is for the regulator to offer both BM-style incentive contracts, ensuring a higher level of rent for type *H*. Schedules $T_H(\theta)$ and $T_L(\theta)$ are offered to type *H* and *L*, respectively. The optimal contract is the solution to problem P_{II}:

$$Max \quad \frac{1}{2}\int_{\underline{\theta}}^{\bar{\theta}}[V(q_H(\theta)) - T_H(\theta)]f(\theta)d\theta + \frac{1}{2}\int_{\underline{\theta}}^{\bar{\theta}}[V(q_L(\theta)) - T_L(\theta)]f(\theta)d\theta$$

s.t.

(1) $U_L(\theta) = T_L(\theta) - (\beta_L + \theta)q_L(\theta) \geq 0 \quad \forall\theta$

(2) $U_H(\theta) = T_H(\theta) - (\beta_H + \theta)q_H(\theta) \geq 0 \quad \forall\theta$

(3) $T_L(\theta) - (\beta_L + \theta)q_L(\theta) \geq T_L(\theta') - (\beta_L + \theta)q_L(\theta') \quad \forall\theta \ \theta'$

(3*a*) $T_L(\theta) - (\beta_L + \theta)q_L(\theta) \geq T_H(\theta') - (\beta_L + \theta)q_H(\theta') \quad \forall\theta \ \theta'$

(4) $T_H(\theta) - (\beta_H + \theta)q_H(\theta) \geq T_H(\theta') - (\beta_H + \theta)q_H(\theta') \quad \forall\theta \ \theta'$

(4*a*) $T_H(\theta) - (\beta_H + \theta)q_H(\theta) \geq T_L(\theta') - (\beta_H + \theta)q_L(\theta') \quad \forall\theta \ \theta'$

(5) $\int_{\underline{\theta}}^{\bar{\theta}}[T_L(\theta) - (\beta_L + \theta)q_L(\theta)]f(\theta)d\theta - \int_{\underline{\theta}}^{\bar{\theta}}(T_L(0) - (\beta_L + \theta)q_L(0)]f(\theta)d\theta \geq r$

(6) $\int_{\underline{\theta}}^{\bar{\theta}}[T_H(\theta) - (\beta_H + \theta)q_H(\theta)]f(\theta)d\theta - \int_{\underline{\theta}}^{\bar{\theta}}[T_H(0) - (\beta_H + \theta)q_H(0)]f(\theta)d\theta \geq r$

The objective function in P_{II} is the regulator's expected payoff. Conditions (1) and (2) are individual rationality constraints (IRs), ensuring the *actual* utility of both types under all possible states of the world is non-negative. Conditions (3), (3a), (4) and (4a) are incentive compatibility constraints (ICs): (3) ensures that type *L* will not find it profitable to misreport θ whatever the state of the world (i.e. pretending to be θ') while truthfully reporting his type β_L (by choosing $T_L(\theta)$ and $q_L(\theta)$). (3a) on the other hand ensures type *L* will not find it attractive to misreport θ even when misreporting his type (by choosing $T_H(\theta)$ and $q_H(\theta)$). Conditions (4) and (4a) are analogous for type *H*. Conditions (5) and (6) are information acquisition constraints (IAs) for type *L* and *H* respectively. The left-hand sides of (5) and (6) are the expected gain of collecting information, i.e. the difference between the landowner's expected utility with (first term) and without information (second term). The right-hand sides are the cost, *r*, of collecting information. Here, both agents have incentives to collect information. We no longer consider in IAs the potential gain of type *H* misreporting his type because IC (4a) eliminates the possibility. We can therefore proceed to state Proposition 3, again contrasted against the appropriate benchmark of a standard BM contract.

Proposition 3: If both agents are encouraged to collect information, the optimal contracts are two incentive contracts. Denote the optimal production with q_i^{II} and the standard BM contract q_i^{BM} as shown in Equation (2), the optimal contract has the following properties: There exist two critical levels r_A^{II} and r_B^{II} , $r_A^{II} \leq r_B^{II}$

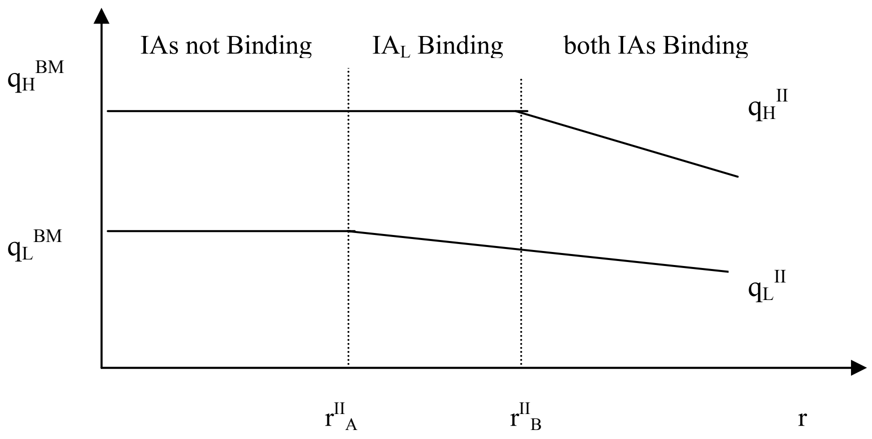
- *For all $r \leq r_A^{II}$, $q_i^{II} = q_i^{BM}$.*
- *For all $r_A^{II} < r < r_B^{II}$,*
    - *when a positive θ is realized $q_L^{II}(r) < q_L^{BM}$ and $\partial q_L^{II}(r)/\partial r<0$*
    - *when a negative θ is realized $q_L^{II}(r) > q_L^{BM}$ and $\partial q_L^{II}(r)/\partial r>0 q_L^{II}(r)$*
    - *$q_H^{II} = q_H^{BM}$.*
- *For all $r \geq r_B^{II}$, and i=L, H*
    - *when a positive θ is realized, $q_i^{II}(r) < q_i^{BM}$ and $\partial q_i^{II}(r)/\partial r<0$*

- *when a negative θ is realized, $q_i^{II}(r) > q_i^{BM}$ and $\partial q_i^{II}(r)/\partial r > 0$*

Proof: See Appendix C.

Figure 4 shows how the contract design has to deviate from the standard BM results when a positive θ is reported. Only for low information acquisition cost (r ≤ r_A^{II}) is the contract design problem equivalent to two separate and standard BM contracts. For acquisition costs in the interval [r_A^{II}, r_B^{II}], the IA constraint for type *L* becomes binding and its incentive contract requires modification. The contracted quantity decreases in unfavourable (*$\theta > 0$*) and increases in favourable situations (*$\theta < 0$*).

Figure 4: Optimal Contract When Both Agents Are Encouraged to Collect Information (θ>0)



The intuition for modifying the contract term in this particular way is that – since the IA constraint becomes binding – the terms have to be conducive to type *L*'s information collection. This is achieved by making that type, after collecting, choose a smaller production when the marginal cost is higher than expected (*$\theta > 0$*) and a greater production when the marginal cost is smaller than expected (*$\theta < 0$*).

For higher information acquisition costs (r ≥ r_B^{II}), the incentive contracts offered to both types of landowners need to deviate further still from standard BM incentive contracts. Because the regulator's welfare decreases with the addition of new IA constraints, the regulator's welfare is non-increasing in *r*.

4.3 Contracts that Induce Only One Landowner to Collect Information

For P_{NI}, the regulator will offer type *H* a schedule $(q_H(\theta),T_H(\theta))$ while offering a FQ-FP contract (T_L,q_L) to type *L*. The optimal contract is the solution to the problem $P_{NI:}$

$$Max \quad \frac{1}{2}[V(q_L)-T_L]+\frac{1}{2}\int_{\underline{\theta}}^{\overline{\theta}}[V(q_H(\theta))-T_H(\theta)]f(\theta)d\theta \text{ subject to}$$

(1) $E(U_L)\equiv T_L-\beta_L q_L\geq 0$

(2) $U_H(\theta)\equiv T_H(\theta)-(\beta_H+\theta)q_H(\theta)\geq 0 \quad \forall\theta$

(3) $T_L-\beta_L q_L\geq T_H(\theta)-\beta_L q_H(\theta) \qquad \forall\theta$

(4) $T_H(\theta)-(\beta_H+\theta)q_H(\theta)\geq T_H(\theta')-(\beta_H+\theta)q_H(\theta') \quad \forall\theta\ \ \theta'$

(4*a*) $T_H(\theta)-(\beta_H+\theta)q_H(\theta)\geq T_L-(\beta_H+\theta)q_L \quad \forall\theta\ \theta'$

(5) $-\int_{\theta''}^{\overline{\theta}}(T_L-(\beta_L+\theta)q_L)f(\theta)d\theta\leq r \ \ where\ \theta''=\frac{\mathrm{T_L}}{\mathrm{q_L}}-\beta_H$

(6) $\int_{\underline{\theta}}^{\overline{\theta}}(T_H(\theta)-(\beta_H+\theta)q_H(\theta))f(\theta)d\theta-\int_{\underline{\theta}}^{\overline{\theta}}(T_H(0)-\beta_H q_H(0))f(\theta)d\theta\geq r$

The objective function and the constraints in P_{NI} are similar to previous problems. Information acquisition constraints (5) and (6) ensure type *L* will have no incentive to collect information while type *H* will. The detailed analysis provided in appendix D gives rise to the following proposition.

Proposition 4: If only one type of landowner is encouraged to collect information, the optimal contract offers the high efficiency landowner a BM type incentive contract and the low efficiency landowner a fixed quantity – fixed payment contract.

There exist two critical levels r_A^{NI} *and* r_B^{NI} *such that* $r_A^{NI} \leq r_B^{NI}$ *for* $\beta_L \gg \beta_H$ [6]*.*

Denoting the optimal production with q_i^{NI}*, and a* q_L^{***} *satisfying*

$V'(q_L^{***}) = 2\beta_H - \beta_L - \overline{\theta}$ such that $q_L^{**} \leq q_L^{***}$

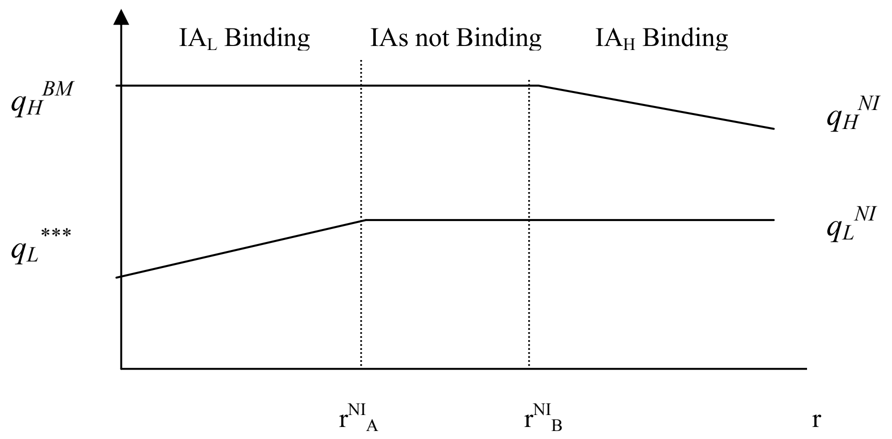
- *For* $r_A^{NI} \leq r \leq r_B^{NI}$ $q_L^{NI} = q_L^{***}$*;* $q_H^{NI} = q_H^{BM}$
- *For* $r < r_A^{NI}$*,*
  - $q_L^{NI} < q_L^{***}$ $\partial q_L^{NI} / \partial r > 0$
  - $q_H^{NI} = q_H^{BM}$.
- *For* $r > r_B^{NI}$*,*
  - $q_L^{NI} = q_L^{***}$*;*
  - $q_H^{NI} < q_H^{BM}$ *and* $\partial q_H^{NI} / \partial r < 0$ *for* $\theta > 0$*;*
  - $q_H^{NI} > q_H^{BM}$ *and* $\partial q_H^{NI} / \partial r > 0$ *for* $\theta < 0$*.*

Proposition 4 distinguishes between three cases. For intermediate acquisition costs ($r_A^{NI} \leq r \leq r_B^{NI}$), the contract designed for type *L* involves a fixed production above the level implied by the second-best solution and the contract designed for type *H* is a BM incentive contract. The IA constraint becomes binding for type *L* for $r < r_A^{NI}$ and as a result, a smaller production is contracted. This decreases type *L*'s total gain from resolving the marginal cost uncertainty and thus deters him from collecting information. For type *H,* the IA constraint becomes binding for $r > r_B^{NI}$. In that case, the incentive contract needs to be modified. Analogous to the reasoning underpinning the solution to P_{II} in 4.2, a larger production is contracted for in favourable situations

[6] The general expression is that β_L is sufficiently greater than β_H such that
$$\frac{1}{2\Delta\theta}\overline{\theta}^2\left[\frac{1}{\alpha}(2\beta_H - \beta_L - \overline{\theta})\right]^{\frac{1}{\alpha-1}} < \int_{\underline{\theta}}^{\overline{\theta}} F(\theta)\left[\frac{1}{\alpha}(\beta_H + 2\theta + \overline{\theta})\right]^{\frac{1}{\alpha-1}} d\theta - \int_0^{\overline{\theta}}\left[\frac{1}{\alpha}(\beta_H + 2\theta + \overline{\theta})\right]^{\frac{1}{\alpha-1}} d\theta$$

($\theta < 0$) and a smaller production in unfavourable situations ($\theta > 0$). Figure 5 illustrates the results

Figure 5: Optimal Contract When One Agent Is Encouraged to Collect Information (θ>0)



5. Concluding Discussion

In this paper, we extend the literature on conservation contracting to contracting situations with endogenous information structures. In concrete terms, we examine a setting in which the landowner can collect contract-relevant information after being offered, but before signing the contract. We believe this situation is frequently encountered in practice and show that it requires additional contract features in order to manage the agency-landowner relationship efficiently, even if – such as in our case – precontractual information asymmetry is 'large' relative to additional information. Since the regulator has to rely on the landowner to acquire information, the welfare-improving effect of enhancing production efficiency through additional information is counteracted by the potential gain in the landowner's ability to extract additional rents out of the contract. The reason is that the landowner is not only potentially better informed about his cost, he is also the only party that knows whether additional information has in fact been acquired. If landowners' information acquisition is relevant, therefore, the efficient contract must incorporate the information acquisition constraints in operation.

Analytically, our approach generalizes the previous contracting literature and we are able to replicate the results of Cremer et al (1998a), Baron-Meyerson (1982) and the 'textbook' model of precontractual information asymmetry with two types as special cases. In our mixed case, both moral hazard and adverse selection problems are present and the trade-off between these two problems poses an interesting problem to the principal. As the landowner's action of collecting information is not observable by the regulator, an information rent has to be offered to overcome the moral hazard problem. However, encouraging a landowners to learn about the state of the world also raises the landowner's incentive to misreport his type. We show that the optimal contract terms are significantly altered relative to the special cases considered.

A number of extensions and generalizations are possible. One obvious generalization is to extend the model to one where endogenous information can outweigh exogenous information. Another is to acknowledge that regulators usually have partial control over the information acquisition costs faced by the landowner by being able to specify a deadline for signing the contract. Does this improve the bargaining position of the conservation agency and if so, can it credibly commit to a deadline? Lastly, a regulator may decide to offer to acquire the information itself. When is it optimal to offer this and does this in any way improve on the contract terms presented here, which are compliant with the information acquisition constraints of the problem. These extensions would help us arrive at a richer analysis of the full strategy set available to conservation agencies.

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Appendices

Appendix A: Proof of Proposition 1

The existence of at least one threshold level r_z that alternate optimal choices between G_{NN} (for $r > r_z$) and G_{II} (for $r > r_z$) is easy to prove with the monotonic non-decreasing and non-increasing properties of G_{NN} and G_{II} respectively.

Now suppose schedule $[T^Z{}_H(\theta),q^Z{}_H(\theta)]$ and $[T^Z{}_L(\theta), q^Z{}_L(\theta)]$ is the optimal Baron-Myerson type contract offered when $r= r_z$ while the optimal FQ-FP contract offered is $[T^Z{}_H,q^Z{}_H]$ and $[T^Z{}_L, q^Z{}_L]$.

$$G^{II}(r=r^z)=\lambda\int_{\underline{\theta}}^{\bar{\theta}}[V(q_H^Z(\theta))-T_H^Z(\theta)]f(\theta)d\theta+(1-\lambda)\int_{\underline{\theta}}^{\bar{\theta}}[V(q_L^Z(\theta))-T_L^Z(\theta)]f(\theta)d\theta$$

$$G^{NN}(r=r^z)=\lambda[V(q_H^Z)-T_H^Z]+(1-\lambda)[V(q_H^Z)-T_H^Z]$$

$$and \qquad \mathrm{G}^{II}(r=r^z)=G^{NN}(r=r^z)$$

It is very straightforward to see if the regulator instead offer either a P_{NI} contract as follow: $\{[T^Z{}_L, q^Z{}_L], [T^Z{}_H(\theta),q^Z{}_H(\theta)]\}$ or a P_{IN} contract as follow: $\{[T^Z{}_H,q^Z{}_H]$, $[T^Z{}_L(\theta), q^Z{}_L(\theta)]\}$, either contract will satisfy their IR, IC and IA conditions. Denote the welfare that regulator derives from these two contracts are G^{NI} and G^{IN} respectively.

So

$$G^{II}(r=r^z)+G^{NN}(r=r^z)$$

$$=\{\lambda[V(q_H^Z)-T_H^Z]+(1-\lambda)\int_{\underline{\theta}}^{\bar{\theta}}[V(q_H^Z(\theta))-T_H^Z(\theta)]f(\theta)d\theta\}$$

$$+\{\lambda[V(q_H^Z)-T_H^Z]+(1-\lambda)\int_{\underline{\theta}}^{\bar{\theta}}[V(q_L^Z(\theta))-T_L^Z(\theta)]f(\theta)d\theta\}$$

$$=G^{NI}+G^{IN}$$

Denote $G^{NI}(r=r^Z)$ the optimal contract that induce *type H* only collecting information at $r=r^Z$. Naturally $G^{NI}(r=r^Z)\geq G^{NI}$ (optimal contract is no worse than any feasible contract of the same type at this point) and $G^{NI}(r=r^Z) > G^{IN}$ (Lemma 1). So we get,

$$2\mathrm{G}^{NI}(r=r^z)>G^{II}(r=r^z)+G^{NN}(r=r^z)$$

$$G^{NI}(r=r^z)>G^{II}(r=r^z)$$

$$G^{NI}(r=r^z)>G^{NN}(r=r^z)$$

which mean at least at r^Z, the regulator would be able to find a W^{NI} contract that is strictly better than W^{NN} and W^{II}.

QED.

Appendix B: Solution to P_{NN}

$$Max \quad \frac{1}{2}[V(q_H)-T_H]+\frac{1}{2}[V(q_L)-T_L]$$

s.t.

$(B1) \quad E(U_L) = T_L - \beta_L q_L \geq 0$

$(B2) \quad E(U_H) = T_H - \beta_H q_H \geq 0$

$(B3) \quad T_L - \beta_L q_L \geq T_H - \beta_L q_H$

$(B4) \quad T_H - \beta_H q_H \geq T_L - \beta_H q_L$

$$(B5) \quad \int_{\underline{\theta}}^{\theta''} (T_L - (\beta_L + \theta) q_L) f(\theta) d\theta - (T_L - \beta_L q_L) \leq r$$

$$where \quad T_L - (\beta_L + \theta'') q_L = 0 \quad i.e. \theta'' = \frac{T_L}{q_L} - \beta_L$$

$$(B6) \quad \int_{\underline{\theta}}^{\theta'} (T_H - (\beta_H + \theta) q_H) f(\theta) d\theta + \int_{\theta'}^{\overline{\theta}} (T_L - (\beta_H + \theta) q_L) f(\theta) d\theta - (T_H - \beta_H q_H) \leq r$$

$$where \quad T_L - (\beta_L + \theta') q_L = T_H - (\beta_H + \theta') q_H \quad i.e. \quad \theta' = \frac{T_L - T_H}{q_L - q_H} - \beta_H$$

$$(B7) \quad \int_{\underline{\theta}}^{\theta'''} (T_H - (\beta_H + \theta) q_H) f(\theta) d\theta - (T_H - \beta_H q_H) \leq r$$

$$where \quad T_H - (\beta_H + \theta''') q_H = 0 \quad i.e. \theta''' = \frac{T_H}{q_H} - \beta_H$$

Step 1: Condition (B1) implies that $\theta'' \geq 0$. Condition (B2) can be ignored if (B1) and (B4) are satisfied.

(B7) ensures the benefits that *type H* receives by rejecting contract after learning the true state of world information will not exceed the information collection cost r. The first term on the left hand side is the expected return after rejecting contracts under some unfavourable true state of world. (B7) can be ignored with condition (B1) and assumption $\beta_L > \beta_H + \overline{\theta}$ satisfied because:

$T_L - (\beta_H + \overline{\theta}) q_L > T_L - \beta_L q_L \geq 0$

This means even the worst state of world, *type H* will gain non-negative utility by choosing contract intended for type L, so he will never reject the contract after discovering the true state of world.

Step 2:

Condition (B5) is rewritten as :

$$\varpi(B5) \equiv \int_{\theta''}^{\bar{\theta}} (T_L - (\beta_L + \theta)q_L) f(\theta) d\theta + r \geq 0$$

$$\varpi(B5) = \Delta\theta r + T_L\bar{\theta} - \beta_L\bar{\theta}q_L - \frac{T_L^2}{q_L} + 2\beta_L T_L - \beta_L^2 q_L - 0.5q_L\bar{\theta}^2 + 0.5\frac{T_L^2}{qL} + 0.5q_L\beta_L^2 - T_L\beta_L \geq 0$$

where $\Delta\theta = \bar{\theta} - \underline{\theta}$

$$(B5.1)\frac{\partial\varpi(B5)}{\partial q_L} = 0.5\frac{T_L^2}{q_L^2} - 0.5\beta_L^2 - \beta_L\bar{\theta} - 0.5\bar{\theta}^2$$

$$(B5.2)\frac{\partial\varpi(B5)}{\partial T_L} = -\frac{T_L}{q_L} + \beta_L + \bar{\theta}$$

Step 3:

Condition (B6) is rewritten as:

$$\varpi(B6) \equiv r - \frac{1}{\Delta\theta}\int_{\theta'}^{\bar{\theta}} (T_L - (\beta_L + \theta)q_L - T_H + (\beta_H + \theta)q_H) d\theta = r - \frac{1}{2\Delta\theta}(\bar{\theta} - \theta')^2 (q_H - q_L) \geq 0$$

$$(B6.1) - \frac{\partial\varpi(B6)}{\partial T_L} = \frac{\partial\varpi(B6)}{\partial T_H} = (\bar{\theta} - \theta')\frac{1}{\Delta\theta}$$

$$(B6.2)\frac{\partial\varpi(B6)}{\partial q_L} = -\frac{\partial\varpi(B6)}{\partial q_H} = [0.5(\bar{\theta} - \theta')^2 + (\bar{\theta} - \theta')\frac{T_L - T_H}{q_L - q_H}]\frac{1}{\Delta\theta}$$

Step 4:

The lagrangian function of P_{NN} becomes:

$$Max \quad L \equiv \frac{1}{2}[V(q_H) - T_H] + \frac{1}{2}[V(q_L) - T_L] + \varphi_1(T_L - \beta_L q_L) + \varphi_3(T_L - \beta_L q_L - T_H + \beta_L q_H)$$

$$+\varphi_4(T_H - \beta_H q_H - T_L + \beta_H q_L) + \varphi_5\varpi(B5) + \varphi_6\varpi(B6)$$

where φ_i are Lagrangian coefficients

We first consider the case that both condition (B5) and (B6) are non-binding. P_{NN} boils down to standard hidden information model and the optimal solution is characterized as following:

$$V'(q_H^{**}) = \beta_H$$

$$V'(q_L^{**}) = 2\beta_L - \beta_H$$

$$T_L^{**} = \beta_L q_L^{**}$$

$$T_H^{**} = T_L^{**} - \beta_H q_L^{**} + \beta_H q_H^{**}$$

It tells the conventional story that at second best solution *type H* produces efficient amount with a rent, while type L under-produces with zero rent. Substituting this back to ϖ(B5) and ϖ (B6), we get

$$(B5.3)\quad r \geq \frac{1}{\Delta\theta}\bullet\frac{1}{2}\bullet q_L^{**}\overline{\theta}^2 \equiv r_A$$

$$(B6.3)\quad r \geq \frac{1}{\Delta\theta}\bullet\frac{1}{2}\bullet(q_H^{**}-q_L^{**})\overline{\theta}^2 \equiv r_B$$

Therefore second best contract is only good when r is higher than both r_A and r_B under our setting. For relatively large difference between β_H and β_L[7], we find r_B is greater than r_A. Therefore for $r \in [r_A, r_B]$, (B6) is binding while (B5) is not. For r smaller than both r_B and r_A, both (B5) and (B6) are binding. In each case, modifications need to be made to the contract which we are going to explore in the following steps.

Step 5:

We examine the situation when (B6) is binding and (B5) is slack (for $r \in [r_A, r_B]$). First order condition of Lagrangian function is

$$\frac{\partial L}{\partial T_L} = -\frac{1}{2}+\varphi_1+\varphi_3-\varphi_4-\varphi_6\frac{\partial\varpi(B6)}{\partial T_L}=0\quad(B7)$$

$$\frac{\partial L}{\partial q_L} = \frac{1}{2}V'(q_L)-\varphi_1\beta_L-\varphi_3\beta_L+\varphi_4\beta_H+\varphi_6\frac{\partial\varpi(B6)}{\partial q_L}=0\quad(B8)$$

$$\frac{\partial L}{\partial T_H} = -\frac{1}{2}-\varphi_3+\varphi_4+\varphi_6\frac{\partial\varpi(B6)}{\partial T_H}=0\quad(B9)$$

$$\frac{\partial L}{\partial q_H} = \frac{1}{2}V'(q_H)+\varphi_3\beta_L-\varphi_4\beta_H+\varphi_6\frac{\partial\varpi(B6)}{\partial q_H}=0\quad(B10)$$

Adding (B7) and (B9) we get $\varphi_1=1>0$ (condition B1 is binding), thus θ"=0. Given assumption $\beta_L>\beta_H+\overline{\theta}$, we get $\varphi_3=0$ (Condition B3 is non-binding)[8], therefore by (B8),(B9) and (B10) we have:

$$(A11)\quad r = \frac{(\overline{\theta}^2-\theta'^2)}{2}(q_H-q_L)>0$$

$$(A12)\quad V'(q_H)=\beta_H+\frac{\varphi_6(\overline{\theta}^2-\theta'^2)}{\Delta\theta}>\beta_H$$

$$(A13)\quad V'(q_L)=2\beta_L-\beta_H-\frac{\varphi_6(\overline{\theta}^2-\theta'^2)}{\Delta\theta}<2\beta_L-\beta_H$$

[7] (restate from footnote 1 in the text) If $V=q^\alpha$ ($\alpha\in(0,1)$) as assumed, this condition is equivalent to $\beta_L>[1+0.5(2^{1-\alpha}-1)]\beta_H$. Therefore for sufficient large difference between β_H and β_L, $q_L^{**}>2q_H^{**}$.

[8] If (A3) is binding, $\beta_L=\beta_H+\theta'$, which contradicts to $\beta_L>\beta_H+\overline{\theta}$

From (B12-13), we conclude that when r $\in[r_{A,}\ r_B]$ (i.e. constraint B5 is slack while B6 binding), high efficiency producer under produces and low efficiency producer increases her production compared to conventional second best contracts. Since it is easy to see that φ_6 is a decreasing function of r, this over production and under production deteriorate with r decreasing from r_B to r_A.

Step 6:

Now we examine the situation when both (B5) and (B6) are binding (for r $\in[0, r_A]$). First order condition of Lagrangian function is further complicated to:

$$\frac{\partial L}{\partial T_L} = -\frac{1}{2} + \varphi_1 + \varphi_3 - \varphi_4 + \varphi_5 \frac{\partial \varpi(B5)}{\partial T_L} - \varphi_6 \frac{\partial \varpi(B6)}{\partial T_L} = 0 \quad (B14)$$

$$\frac{\partial L}{\partial q_L} = \frac{1}{2} V'(q_L) - \varphi_1 \beta_L - \varphi_3 \beta_L + \varphi_4 \beta_H + \varphi_5 \frac{\partial \varpi(B5)}{\partial q_L} + \varphi_6 \frac{\partial \varpi(B6)}{\partial q_L} = 0 \quad (B15)$$

$$\frac{\partial L}{\partial T_H} = -\frac{1}{2} - \varphi_3 + \varphi_4 + \varphi_6 \frac{\partial \varpi(B6)}{\partial T_H} = 0 \quad (B16)$$

$$\frac{\partial L}{\partial q_H} = \frac{1}{2} V'(q_H) + \varphi_3 \beta_L - \varphi_4 \beta_H + \varphi_6 \frac{\partial \varpi(B6)}{\partial q_H} = 0 \quad (B17)$$

Solving (B14)-(B17), we get:

$$(A18) \quad r = \frac{(\overline{\theta}^2 - \theta'^2)}{2\Delta\theta}(q_H - q_L) = \frac{(\overline{\theta}^2 - \theta''^2)}{2\Delta\theta} q_L > 0$$

$$(A19) \quad V'(q_H) = \beta_H + \frac{\varphi_6(\overline{\theta}^2 - \theta'^2)}{\Delta\theta}$$

$$(A20) \quad V'(q_L) = 2\beta_L - \beta_H - \frac{\varphi_6(\overline{\theta}^2 - \theta'^2)}{\Delta\theta} + \frac{\varphi_5(\overline{\theta}^2 - \theta''^2)}{\Delta\theta}$$

It shows that contract for *type H* behaves as shown in previous step 5, while type L further under-produces as the last term of (B20) is positive (φ_5 is a positive and decreasing function of r). (B18)-(B20), together with

$$\theta' = \frac{T_H - T_L}{q_H - q_L} - \beta_H = \beta_L - \beta_H, \quad \theta'' = \frac{T_L}{q_L} - \beta_L, \quad \varphi_1 \begin{cases} = 0 \Rightarrow \varphi_5 = \dfrac{1}{\overline{\theta} - \theta''} \\ > 0 \Rightarrow \theta'' = 0 \end{cases}$$

implicitly defines the general solution to P_{NN}.

Appendix C: Solution to P_{II}

Before we solve for P_{II}, we first prove two lemmas for condition 3a and 4a.

Lemma 2: Condition 3a is satisfied if and only if:

$$T_L(\underline{\theta}) - (\beta_L + \underline{\theta})q_L(\underline{\theta}) \geq T_H(\overline{\theta}) - (\beta_L + \underline{\theta})q_H(\overline{\theta}) \qquad (3a')$$

Lemma 3: Condition 4a is satisfied if and only if:

$$T_H(\overline{\theta}) - (\beta_H + \overline{\theta})q_H(\overline{\theta}) \geq T_L(\underline{\theta}) - (\beta_H + \overline{\theta})q_L(\underline{\theta}) \qquad (4a')$$

Lemma 2 states that type L will never misreport his type if his pay-off under the best state of the world is greater than his pay-off when misreporting under the worst state of the world, i.e. condition 3a is satisfied. Lemma 3 states that type H will never misreport his type if his pay-off under the best state of the world is higher than his pay-off when misreporting his type under the best state of world, i.e. condition 4a is satisfied. Lemma 2 and Lemma 3 together say that if type H under the worst state of world and type L under the best state of world have no interest pretending to be each other, they would not lie about their type in any realization of the state of world.

Proof of Lemma 2:

Lemma 2: This is to prove (3a') is sufficient and necessary condition to (3a)

$$(3a) \quad T_L(\theta) - (\beta_L + \theta)q_L(\theta) \geq T_H(\theta') - (\beta_L + \theta)q_H(\theta') \quad \forall \theta \;\; \theta'$$
$$(3a') \quad T_L(\underline{\theta}) - (\beta_L + \underline{\theta})q_L(\underline{\theta}) \geq T_H(\overline{\theta}) - (\beta_L + \underline{\theta})q_H(\overline{\theta})$$

Necessary condition is straightforward to see. Following we prove (3a') is sufficient condition of (3a) as well.

Step 1: Observation 1: "Type L under most favourable state of world situation is most likely to lie". Precisely, if there is any θ such that:
$$T_L(\theta) - (\beta_L + \theta)q_L(\theta) < T_H(\overline{\theta}) - (\beta_L + \theta)q_H(\overline{\theta})$$
Then we can prove
$$T_L(\underline{\theta}) - (\beta_L + \underline{\theta})q_L(\underline{\theta}) < T_H(\overline{\theta}) - (\beta_L + \underline{\theta})q_H(\overline{\theta})$$

$$T_H(\overline{\theta}) - (\beta_H + \theta)q_H(\overline{\theta}) > T_L(\theta) - (\beta_L + \theta)q_L(\theta) \geq T_L(\underline{\theta}) - (\beta_L + \theta)q_L(\underline{\theta})$$
$$T_H(\overline{\theta}) - T_L(\underline{\theta}) > (\beta_L + \theta)[-q_L(\underline{\theta}) + q_H(\overline{\theta})] \geq (\beta_L + \underline{\theta})[-q_L(\underline{\theta}) + q_H(\overline{\theta})] \quad proved.$$

Step 2: Observation 2: "Type L will not lie if she finds no interest pretending to be *type H* under the most unfavourable state of world condition". Precisely, if there is

$$T_L(\underline{\theta}) - (\beta_L + \underline{\theta})q_L(\underline{\theta}) < T_H(\theta') - (\beta_L + \underline{\theta})q_H(\theta')$$
any θ' such that:
Then we can prove
$$T_L(\underline{\theta}) - (\beta_L + \underline{\theta})q_L(\underline{\theta}) < T_H(\overline{\theta}) - (\beta_L + \underline{\theta})q_H(\overline{\theta})$$

$$T_H(\overline{\theta}) - (\beta_H + \overline{\theta})q_H(\overline{\theta}) \geq T_H(\theta') - (\beta_H + \overline{\theta})q_H(\theta')$$
$$T_H(\overline{\theta}) - T_H(\theta') \geq (\beta_H + \overline{\theta})[q_H(\overline{\theta}) - q_H(\theta')] > (\beta_L + \underline{\theta})[q_L(\overline{\theta}) - q_H(\theta')] \quad proved.$$

Step 1 and 2 together prove the sufficient condition.

Proof of Lemma 3

This is to prove (4a') is sufficient and necessary condition of (4a).

$$(4a) \quad T_H(\theta) - (\beta_H + \theta)q_H(\theta) \geq T_L(\theta') - (\beta_L + \theta)q_L(\theta') \quad \forall \theta \;\; \theta'$$
$$(4a') \quad T_H(\overline{\theta}) - (\beta_H + \overline{\theta})q_H(\overline{\theta}) \geq T_L(\underline{\theta}) - (\beta_H + \overline{\theta})q_L(\underline{\theta})$$

Necessary condition is straightforward to see. Following we prove (4a') is sufficient condition of (4a) as well.

Step 1: Observation 1: "*Type H* under the most unfavourable state of world situation is most likely to lie". Precisely, if there is any θ such that:
$$T_H(\theta) - (\beta_H + \theta)q_H(\theta) < T_L(\underline{\theta}) - (\beta_H + \theta)q_L(\underline{\theta})$$
Then we can prove
$$T_H(\overline{\theta}) - (\beta_H + \overline{\theta})q_H(\overline{\theta}) < T_L(\underline{\theta}) - (\beta_H + \overline{\theta})q_L(\underline{\theta})$$

$$T_L(\underline{\theta}) - (\beta_H + \theta)q_L(\underline{\theta}) > T_H(\theta) - (\beta_H + \theta)q_H(\theta) > T_H(\overline{\theta}) - (\beta_H + \theta)q_H(\overline{\theta})$$
$$T_L(\underline{\theta}) - T_H(\overline{\theta}) > (\beta_H + \theta)[q_L(\underline{\theta}) - q_H(\overline{\theta})] \geq (\beta_H + \overline{\theta})[q_L(\underline{\theta}) - q_H(\overline{\theta})] \quad proved.$$

Step 2: Observation 2: "*Type H* will not lie if she finds no interest pretending to be type L under the most favourable state of world condition". Precisely, if there is any

$$T_H(\overline{\theta}) - (\beta_H + \overline{\theta})q_H(\overline{\theta}) < T_L(\theta') - (\beta_H + \overline{\theta})q_L(\theta')$$
θ' such that:
Then we can prove

$$T_H(\bar{\theta}) - (\beta_H + \bar{\theta}) q_H(\bar{\theta}) < T_L(\underline{\theta}) - (\beta_H + \bar{\theta}) q_L(\underline{\theta})$$

$$T_L(\underline{\theta}) - (\beta_L + \underline{\theta}) q_L(\underline{\theta}) \geq T_L(\theta') - (\beta_H + \underline{\theta}) q_L(\theta')$$
$$T_L(\underline{\theta}) - T_H(\theta') \geq (\beta_L + \underline{\theta})[q_L(\underline{\theta}) - q_L(\theta')] > (\beta_H + \bar{\theta})[q_L(\underline{\theta}) - q_H(\theta')] \quad \textit{proved}.$$

Step 1 and 2 together prove the sufficient condition. Q.E.D.

It is well known (Baron-Myerson, 1982, Rochet 1985) that conditions (3) and (4) are satisfied if and only if :

$$T_L(\theta) - (\beta_L + \theta) q_L(\theta) = T_L(\bar{\theta}) - (\beta_L + \bar{\theta}) q_L(\bar{\theta}) + \int_{\theta}^{\bar{\theta}} q_L(\theta) d\theta \quad \forall \theta$$

Since at optimum low efficient agent in the most unfavourable state of world receives reservation utility[2] $: U_L(\bar{\theta}) \equiv T_L(\bar{\theta}) - (\beta_L + \bar{\theta}) q_L(\bar{\theta}) = 0$

(3') $T_L(\theta) - (\beta_L + \theta) q_L(\theta) = \int_{\theta}^{\bar{\theta}} q_L(\theta) d\theta \quad \forall \theta$

and $q_L(\theta)$ is nondecreasing.

(4') $T_H(\theta) - (\beta_H + \theta) q_H(\theta) = T_H(\bar{\theta}) - (\beta_H + \bar{\theta}) q_H(\bar{\theta}) + \int_{\theta}^{\bar{\theta}} q_H(\theta) d\theta \quad \forall \theta$

and $q_H(\theta)$ is nondecreasing.

(3') and (4') show that the landowner's rent can be reduced either by lowering $U_i(\bar{\theta})$ or reducing $q_i(\theta)$ (see Crèmer et. al. 1998a for further discussions).

Therefore we can rewrite problem P_{II} as:

$$Max \quad \frac{1}{2}\int_{\underline{\theta}}^{\bar{\theta}} [V(q_H(\theta)) - T_H(\theta)] f(\theta) d\theta + \frac{1}{2}\int_{\underline{\theta}}^{\bar{\theta}} [V(q_L(\theta)) - T_L(\theta)] f(\theta) d\theta$$

$$Max \quad \frac{1}{2}\int_{\underline{\theta}}^{\bar{\theta}} [V(q_H(\theta)) - T_H(\theta)] f(\theta) d\theta + \frac{1}{2}\int_{\underline{\theta}}^{\bar{\theta}} [V(q_L(\theta)) - T_L(\theta)] f(\theta) d\theta$$

s.t.

$(C1') \quad T_L(\overline{\theta})-(\beta_L+\overline{\theta})q_L(\overline{\theta})\geq 0$

$(C2') \quad T_H(\overline{\theta})-(\beta_H+\overline{\theta})q_H(\overline{\theta})\geq 0$

$(C3') \quad T_L(\theta)-(\beta_L+\theta)q_L(\theta)=T_L(\overline{\theta})-(\beta_L+\overline{\theta})q_L(\overline{\theta})+\int_{\theta}^{\overline{\theta}}q_L(s)ds \quad \forall\theta$

and $q_L(\theta)$ is nondecreasing

$(C3a') \quad T_L(\underline{\theta})-(\beta_L+\underline{\theta})q_L(\underline{\theta})\geq T_H(\overline{\theta})-(\beta_L+\underline{\theta})q_H(\overline{\theta})$

$(C4') \quad T_H(\theta)-(\beta_H+\theta)q_H(\theta)=T_H(\overline{\theta})-(\beta_H+\overline{\theta})q_H(\overline{\theta})+\int_{\theta}^{\overline{\theta}}q_H(s)ds \quad \forall\theta$

and $q_H(\theta)$ is nondecreasing

$(C4a') \quad T_H(\overline{\theta})-(\beta_H+\overline{\theta})q_H(\overline{\theta})\geq T_L(\underline{\theta})-(\beta_H+\overline{\theta})q_L(\underline{\theta})$

$(C5) \quad \int_{\underline{\theta}}^{\overline{\theta}}(T_L(\theta)-(\beta_L+\theta)q_L(\theta))f(\theta)d\theta-\int_{\underline{\theta}}^{\overline{\theta}}(T_L(0)-\beta_L q_L(0))f(\theta)d\theta\geq r$

$(C6) \quad \int_{\underline{\theta}}^{\overline{\theta}}(T_H(\theta)-(\beta_H+\theta)q_H(\theta))f(\theta)d\theta-\int_{\underline{\theta}}^{\overline{\theta}}(T_H(0)-\beta_H q_H(0))f(\theta)d\theta\geq r$

Step 1: According to the parameter assumption $\beta_L > \beta_H + \overline{\theta}$, constraint C2' is ignored if C1' and C4a' are satisfied.

Step 2: Constraint C1' is binding at optimum.

Step3: Integrate (C3') by part and take expectation, we get:

$$E(T_L(\theta)-(\beta_L+\theta)q_L(\theta))=\int_{\underline{\theta}}^{\overline{\theta}}q_L(\theta)F(\theta)ds$$

This is the first term of constraint C5. Therefore C5 and C6 can be rewritten as:

$$\varpi(C5)\equiv\int_{\underline{\theta}}^{\overline{\theta}}F(\theta)q_L(\theta)d\theta-\int_0^{\overline{\theta}}q_L(\theta)d\theta-r\geq 0 \quad (C5')$$

$$\varpi(C6)\equiv\int_{\underline{\theta}}^{\overline{\theta}}F(\theta)q_H(\theta)d\theta-\int_0^{\overline{\theta}}q_H(\theta)d\theta-r\geq 0 \quad (C6')$$

Step 4: Substitute (C3') and (C4') into the objective function we get

$$\frac{1}{2}\int_{\underline{\theta}}^{\overline{\theta}}[V(q_L(\theta))-(\beta_L+\theta+\frac{F(\theta)}{f(\theta)})q_L(\theta)]f(\theta)d\theta$$
$$+\frac{1}{2}\int_{\underline{\theta}}^{\overline{\theta}}[V(q_H(\theta))-(\beta_H+\theta+\frac{F(\theta)}{f(\theta)})q_H(\theta)]f(\theta)d\theta-\frac{1}{2}[T_H(\overline{\theta})-(\beta_H+\overline{\theta})q_H(\overline{\theta})] \quad (C7)$$

Step5: Write Lagrangian function:

$$L\equiv\frac{1}{2}\int_{\underline{\theta}}^{\overline{\theta}}[V(q_L(\theta))-(\beta_L+\theta+\frac{F(\theta)}{f(\theta)})q_L(\theta)]f(\theta)d\theta$$
$$+\frac{1}{2}\int_{\underline{\theta}}^{\overline{\theta}}[V(q_H(\theta))-(\beta_H+\theta+\frac{F(\theta)}{f(\theta)})q_H(\theta)]f(\theta)d\theta-\frac{1}{2}[T_H(\overline{\theta})-(\beta_H+\overline{\theta})q_H(\overline{\theta})]$$
$$+\varphi_3[T_L(\underline{\theta})-(\beta_L+\underline{\theta})q_L(\underline{\theta})-T_H(\overline{\theta})+(\beta_L+\underline{\theta})q_H(\overline{\theta})]$$
$$+\varphi_4[T_H(\overline{\theta})-(\beta_H+\overline{\theta})q_H(\overline{\theta})-T_L(\underline{\theta})+(\beta_H+\overline{\theta})q_L(\underline{\theta})]+\varphi_5\varpi(C5)+\varphi_6\varpi(C6)$$

First order condition of L yields:

$$\frac{\partial L}{\partial q_L(\theta)} = 0.5V'(q_L(\theta)) - 0.5(\beta_L + \theta + \frac{F(\theta)}{f(\theta)}) + \varphi_5 \frac{\partial \varpi(C5)}{\partial q_L(\theta)} = 0 \quad (C8)$$

$$\frac{\partial L}{\partial q_H(\theta)} = 0.5V'(q_H) - 0.5(\beta_H + \theta + \frac{F(\theta)}{f(\theta)}) + \varphi_6 \frac{\partial \varpi(C6)}{\partial q_H(\theta)} = 0 \quad (C9)$$

$$V'(q_H(\theta)) = (\beta_H + 2\theta - \underline{\theta}) - 2\varphi_6 \{\frac{\partial \varpi(C6)}{\partial q_H(\theta)}\} \quad (C10)$$

$$V'(q_L(\theta)) = (\beta_L + 2\theta - \underline{\theta}) - 2\varphi_5 \{\frac{\partial \varpi(C5)}{\partial q_L(\theta)}\} \quad (C11)$$

$$Where \quad \frac{\partial \varpi(C5)}{\partial q_L(\theta)} = \frac{\partial \varpi(C6)}{\partial q_H(\theta)} = \frac{F(\theta)}{f(\theta)} = \theta - \underline{\theta} \geq 0 \quad if\, \theta < 0$$

$$\frac{\partial \varpi(C5)}{\partial q_L(\theta)} = \frac{\partial \varpi(C6)}{\partial q_H(\theta)} = \frac{F(\theta) - 1}{f(\theta)} = \theta - \overline{\theta} \leq 0 \quad if\, \theta \geq 0$$

$$\varphi_3 = 0 \quad \varphi_4 > 0$$

$$\varphi_5 = 0 \quad or \quad \int_{\underline{\theta}}^{\overline{\theta}} F(\theta) q_L(\theta) d\theta - \int_0^{\overline{\theta}} q_L(\theta) d\theta = r \quad (C5')$$

$$\varphi_6 = 0 \quad or \quad \int_{\underline{\theta}}^{\overline{\theta}} F(\theta) q_H(\theta) d\theta - \int_0^{\overline{\theta}} q_H(\theta) d\theta = r \quad (C6')$$

In (C10), the first term is standard Baron-Myerson solution. The second term, which represents the information acquisition constraint, is positive when positive θ is realized and negative when negative θ is realized. Therefore for negative θs, production is going to be greater than Baron-Myerson; for positive θs production is smaller than Baron-Myerson type contract; and there is a discontinuity at $\theta=0$. This result corresponds to Cremer et. al. (1998a).

Condition (C4a) is binding ($\varphi_4>0$) which shows that for the optimal contract, *type H* should find herself indifferent between contract intended for type L under the most favourable state of world condition and contract for herself when the state of world situation turns out to be the most unfavourable.

Now let us categorise the solution with different ranges of information collection cost r. The threshold points are r_A and r_B defined as following:

$$\int_{\underline{\theta}}^{\bar{\theta}} F(\theta) q_L(\theta) d\theta - \int_0^{\bar{\theta}} q_L(\theta) d\theta \equiv rA \quad (C5'')$$

$$\int_{\underline{\theta}}^{\bar{\theta}} F(\theta) q_H(\theta) d\theta - \int_0^{\bar{\theta}} q_H(\theta) d\theta \equiv rB \quad (C6'')$$

Where r_A is smaller than r_B[9] (See footnote for proof). When $r \in [0, r_A]$, both condition (5) and (6) are nonbinding, both of agents get Baron Myerson contracts. When $r \in [r_A, r_B]$, condition (5) is binding while (6) is not, which means contracts for type L needs to be modified in Cremer sense to induce him to collect the information. When $r \in [\, r_B, +\infty]$, both condition (5) and (6) are binding and both agents get modified Baron Myerson contracts.

That r_B is greater than r_A implies it is easier to induce *type H* to collect information than type L. When $r \in [r_A, r_B]$, without additional incentive provided by distorting the Baron-Myerson contract, *type H* would collect information while type L would not.

[9] Let $Q(\theta) = q_L(\theta) - q_H(\theta)$. $r_A - r_B =$

$\int_{\underline{\theta}}^{0} F(\theta) Q(\theta) d\theta + \int_0^{\bar{\theta}} [F(\theta) - 1] Q(\theta) d\theta = \int_{\underline{\theta}}^{0} F(\theta)[Q(\theta) - Q(-\theta)] d\theta$. The second equation is derived using change of variable. The question now boils down to check the monotonicity of $Q(\theta)$ within $[\underline{\theta}, 0]$ as $-\theta$ is always greater than θ on $[\underline{\theta}, 0]$.

Let's write W as the inverse function of V'. So $q(\theta) = W(\beta + 2\theta - \underline{\theta})$. $Q'(\theta) = W'(\beta_L + 2\theta - \underline{\theta}) - W'(\beta_H + 2\theta - \underline{\theta}) = 1/V''(q_L) - 1/V''(q_H)$. From the assumption of positive V''', we have increasing V'', therefore $Q'(\theta)$ is positive, which implies $Q(\theta)$ increasing. Therefore rA-rB is negative.

Appendix D: Solution to P_{NI}

$$Max \quad \frac{1}{2}[V(q_L) - T_L] + \frac{1}{2}\int_{\underline{\theta}}^{\bar{\theta}}[V(q_H(\theta)) - T_H(\theta)]f(\theta)d\theta$$

s.t.

$$(D1) \quad T_L - \beta_L q_L \geq 0$$

$$(D2) \quad T_H(\theta) - (\beta_H + \theta)q_H(\theta) \geq 0 \quad \forall\theta$$

$$(D3') \quad T_L - \beta_L q_L \geq T_H(\bar{\theta}) - \beta_L q_H(\bar{\theta})$$

$$(D4') \quad T_H(\theta) - (\beta_H + \theta)q_H(\theta) = T_H(\bar{\theta}) - (\beta_H + \bar{\theta})q_H(\bar{\theta}) + \int_{\theta}^{\bar{\theta}} q_H(\theta)d\theta \quad \forall\theta$$

and $q_H(\theta)$ is nondecreasing

$$(D4a') \quad T_H(\bar{\theta}) - (\beta_H + \bar{\theta})q_H(\bar{\theta}) \geq T_L - (\beta_H + \bar{\theta})q_L$$

$$(D5) \quad -\int_{\theta''}^{\bar{\theta}}(T_L - (\beta_L + \theta)q_L)f(\theta)d\theta \leq r \quad where \ \theta'' = \frac{T_L}{q_L} - \beta_L$$

$$(D6) \quad \int_{\underline{\theta}}^{\bar{\theta}}(T_H(\theta) - (\beta_H + \theta)q_H(\theta))f(\theta)d\theta - \int_{\underline{\theta}}^{\bar{\theta}}(T_H(0) - \beta_H q_H(0))f(\theta)d\theta \geq r$$

Step 1: According to the parameter assumption $\beta_L > \beta_H + \bar{\theta}$, constraint D2 is ignored if D1 and D4a' are satisfied.

Step 2: As previously shown, constraint D3 is non-binding.

Step3: Rewrite Constraint D5 and D6 into

$$\varpi(D5) \equiv r + \int_{\theta''}^{\bar{\theta}}(T_L - \tilde{\beta}_L q_L)f(\theta)d\theta \geq 0 \quad (D5')$$

$$\varpi(D6) \equiv \int_{\underline{\theta}}^{\bar{\theta}} F(\theta)q_H(\theta)d\theta - \int_0^{\bar{\theta}} q_H(\theta)d\theta - r \geq 0 \quad (D6')$$

Step 4: Substitute (D4') into the objective function and write the Lagrangian as

$$\begin{aligned} L \equiv & \frac{1}{2}[V(q_L) - T_L] + \frac{1}{2}\int_{\underline{\theta}}^{\bar{\theta}}[V(q_H(\theta)) - (\beta_H + \theta + \frac{F(\theta)}{f(\theta)})q_H(\theta)]f(\theta)d\theta - \frac{1}{2}[T_H(\bar{\theta}) - (\beta_H + \bar{\theta})q_H(\bar{\theta})] \\ & + \varphi_3[T_L - \beta_L q_L - T_H(\bar{\theta}) + \beta_L q_H(\bar{\theta})] + \varphi_4[T_H(\bar{\theta}) - (\beta_H + \bar{\theta})q_H(\bar{\theta}) - T_L + (\beta_H + \bar{\theta})q_L] \\ & + \varphi_5\varpi(D5) + \varphi_6\varpi(D6) \end{aligned} \quad (D7)$$

Step5: First order condition for Lagrangian function of D7 yields:

$$\frac{\partial L}{\partial T_L} = -\frac{1}{2} + \varphi_1 + \varphi_3 - \varphi_4 + \varphi_5 \frac{\partial \varpi(D5)}{\partial T_L} = 0 \quad (D8)$$
$$\frac{\partial L}{\partial q_L} = \frac{1}{2} V'(q_L) - \varphi_1 \beta_L - \varphi_3 \beta_L + \varphi_4 (\beta_H + \bar{\theta}) + \varphi_5 \frac{\partial \varpi(D5)}{\partial q_L} = 0 \quad (D9)$$
$$\frac{\partial L}{\partial T_H(\bar{\theta})} = -\frac{1}{2} - \varphi_3 + \varphi_4 = 0 \quad (D10)$$
$$\frac{\partial L}{\partial q_H(\theta)} = \frac{1}{2} V'(q_H) - \frac{1}{2}(\beta_H + \theta + \frac{F(\theta)}{f(\theta)}) + \varphi_6 \frac{\partial \varpi(D6)}{\partial q_H} = 0 \quad (D11)$$

Therefore we derive the solution as following:

$$V'(q_H) = (\beta_H + 2\theta - \underline{\theta}) - 2\varphi_6 \frac{\partial \varpi(D6)}{\partial q_H(\theta)} \quad (D12)$$

where $\frac{\partial \varpi(D6)}{\partial q_H(\theta)} = \begin{cases} \frac{F(\theta)}{f(\theta)} = \theta - \underline{\theta} \geq 0 & if\, \theta < 0 \\ \frac{F(\theta) - 1}{f(\theta)} = \theta - \bar{\theta} \leq 0 & if\, \theta \geq 0 \end{cases}$

$$V'(q_L) = 2\beta_L - \beta_H + \bar{\theta} + \frac{1}{\Delta\theta} \varphi_5 [\bar{\theta}^2 - \theta''^2] \quad (D13)$$
$$\varphi_5 = 0 \quad or \quad -\int_{\theta''}^{\bar{\theta}} (T_L - (\beta_L + \theta) q_L) f(\theta) d\theta = r \quad where\ \theta'' = \frac{T_L}{q_L} - \beta_L (D5)$$
$$\varphi_6 = 0 \quad or \quad \int_{\underline{\theta}}^{\bar{\theta}} F(\theta) q_H(\theta) d\theta - \int_0^{\bar{\theta}} q_H(\theta) d\theta = r \quad (D6')$$

In (D12), the first term is standard Baron-Myerson solution. The second term, which represents the information acquisition constraint, is positive when positive θ is realized and negative when negative θ is realized. Therefore for negative θs, production is going to be greater than Baron-Myerson; for positive θs production is smaller than Baron-Myerson type contract; and there is a discontinuity at θ=0.

Condition (D4) is binding (φ_4>0) which shows that for the optimal contract, *type H* should find her indifferent between the FQ-FP contract intended for type L and the incentive contract when the state of world situation turns out to be the most unfavourable. The first two terms of (D13) correspond to this point. However, when the information constraint comes into play (φ_5>0), under-production problem is deteriorated, which is shown by positive sign of the last term in (D13).

Now let us categorise the solution with different ranges of information collection cost r. The threshold points are rA and rB defined as following[10]:

[10] This is calculated as previous by setting φ5=0 φ6=0. By (D8) and (D10), we have φ1=1>0 therefore θ''=0.. r_B is the same as (B6'').

$$r_A \equiv \frac{1}{2\Delta\theta}\bar{\theta}^2 q_L$$
$$r_B \equiv \int_{\underline{\theta}}^{\bar{\theta}} F(\theta) q_H(\theta) d\theta - \int_0^{\bar{\theta}} q_H(\theta) d\theta$$

Where r_A is smaller than r_B when β_L is sufficiently larger than β_H[11] (See footnote for proof). When $r \in [r_A, r_B]$, both condition (5) and (6) are nonbinding, *type H* gets standard Baron-Myerson type incentive contract and type L receives a FQ-FP contract. When $r \in [0, r_A]$, condition (5) becomes binding, which means contracts for type L needs to be modified by decreasing the contracted production (equation D13). When $r \in [r_B, +\infty]$, condition (6) becomes binding and *type H*'s contract needs to be modified depending on the realization of θ - positive θ implies less contracted production and negative θ implies more.

[11] When β_L is sufficiently greater than β_H, q_L is sufficiently smaller than q_H. r_A and r_B are non-decreasing functions of q_L and q_H, hence $r_B > r_A$.