PRIVATE RESOURCE MANAGEMENT AND PUBLIC TRUST: OPTIMAL RESOURCE CONSERVATION CONTRACTS UNDER ASYMMETRIC INFORMATION[*]

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ABSTRACT

We analyse efficiency problems of incentive-compatible contracts under moral hazard and/ or adverse selection in the context of private resource management. The paper contributes to defining the regulatory role in creating an optimal information environment between regulator and private resource managers to maximize welfare from a mixed public-private good. The optimal contract structures developed in a principal-agent framework induce self-selection and type-specific conservation efforts. The associated contracting inefficiencies, however, are increasing in the degree of information asymmetry across scenarios, the total costs of conservation, and the difference in conservation costs across types. The results of this study imply that conservation contracts to mitigate problems of moral hazard and adverse selection are welfare improving if efficiency gains from private management outweigh the inefficiencies associated with incentive compatible contract design. Alternatively, the regulator can choose to retain information on 'types' and 'effort' during institutional transformations.

INTRODUCTION

This paper addresses efficiency problems of incentive-compatible contracts under asymmetric information in the context of private resource management. While private decision-making in natural resources management internalizes external effects where open access leads to resource degradation and the dissipation of economic rents [1]; alleviates public deficits or borrowing requirements [31]; improves the livelihoods of local communities; and is often more efficient than management by cumbersome public bureaucracies [31], its drawbacks when used as an institutional choice deserve attention. In particular, the delegation of decision-making authority to private agents introduces an agency problem, when used to serve "legitimate public interest goals" [31]. The agency problem results as private agents, who are entrusted with the management of fisheries, forestry or wildlife for private and public benefits, are typically better informed about their (costly) compliance with relevant conservation measures, and the specific resource characteristics, hence the underlying conservation costs. Accordingly, the informational implications of private provision of goods and services, formerly provided by the public sector, have to be traded-off with potential efficiency gains from privatization.

The policy implications of informational problems when (hidden effort, hidden type) to regulate management behaviour are well recognised in both the general economic[1] as well as the environmental and natural resource economics[2] literature. The literature acknowledges that information is imperfect, costly to obtain, and asymmetrically distributed amongst interacting economic parties. It has made significant progress in identifying economic contexts with information asymmetries, designing incentive-compatible regulatory instruments for independent or interdependent individual decision-makers, and describing the analytical properties of incentive schemes and selection mechanisms, and their equilibria [36].[3] However, the applied information economics literature still provides little structured comparison of the extent of inefficiencies associated with different degrees of information asymmetries (i.e. different information environments). Moreover, little has been said about the informational implications for processes of institutional transformation from public to private provision of a public or mixed good. Here, the regulator has leverage in choosing the information environment, and confronts the task of trading-off efficiency gains through private resource management with the inefficiencies associated with incentive-compatible regulatory instruments. Thus, the

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1 See [2; 8-12; 17; 20; 23; 25; 27; 28; 32; 35].

2 See [3-7; 16; 18; 19; 21; 24; 26; 30; 33; 34; 38-40].

3 According to Stiglitz [36], the contributions on information asymmetries overturn conventional results in economics as mathematical restrictions that formed the basis of general equilibrium analysis become insufficient, the non-existence of market equilibrium becomes possible, and competitive markets may not be Pareto efficient.

efficiency gains from private decision-making net of associated contracting inefficiencies[4] need to be compared to a situation of retaining (or improving) the regulator's information about 'effort' and or on 'type' when choosing the degree of privatization. This paper contributes to filling this gap.

The purpose of this paper is to investigate efficiency problems of incentive-compatible contracts when agents are privately informed about actions (moral hazard) and/or characteristics (adverse selection) in the context of private natural resource management. In comparing the magnitude of the contracting inefficiencies associated with increasingly more complex information asymmetries, this study provides guidance for conservation policy design under asymmetric information. The paper contributes to the discussion about the regulatory role in creating an optimal information environment between regulator and private resource managers to maximize welfare from a mixed public-private good. Specifically, it develops increasingly more complex information scenarios, and addresses the problems of 'hidden effort' and 'hidden types' simultaneously in the contract design.

The paper proceeds as follows. It develops a principal-agent model to analyse a sequence of informational environments with different degrees of information asymmetry between one regulator and individual resource managers.[5] The sequence of models is based on Wu and Babcock [38; 39], but extends their work significantly by allowing for noisy observations of conservation outcome. It develops incentive compatible contracts to induce socially optimal and type-specific conservation efforts for increasing degrees of informational asymmetry, and analytically isolates the contracting inefficiencies. Using numerical simulations, the paper compares the magnitude of associated contracting inefficiencies across 'hidden effort only', 'hidden type only' and 'hidden effort - hidden type' to the first best outcome with full information. In addition, it analyzes the effects of differences in opportunity costs of conservation, and discusses the question of additivity of contracting inefficiencies when 'hidden effort' and 'hidden type' are addressed simultaneously in the contract design.[6]

The paper derives the following main results: The optimal contract structures induce self-selection and type-specific conservation efforts. The associated contracting inefficiencies are increasing in (i) the degree of information asymmetry across scenarios, (ii) the total opportunity costs of conservation, and (iii) the difference in conservation costs across types. Regarding the additivity of contracting inefficiencies, we find that contracts designed for firms, who manage sites with relatively low opportunity costs of conservation

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[4] The paper refers to *contracting inefficiencies* as the agency cost from risk premia and information rents.

[5] In focusing on problems of 'hidden effort' and 'hidden types', the paper abstracts from some other important realities of developing resource management contracts, such as (i) multiple-site management, (ii) multiple-agent management, and (iii) combining multiple signals, and (iv) possible effects of a dynamic contracting setting.

[6] According to Stewart [35], contracting inefficiencies are 'super-additive' when the sum of the inefficiencies resulting from the individual problems of 'hidden effort' plus 'hidden types' is smaller than the contracting inefficiency of the combined problem of 'hidden effort - hidden type'. In case of the converse, efficiencies are 'sub-additive'.

show super-additive contracting inefficiencies, while those designed for sites with relatively high opportunity costs of conservation are sub-additive. Consequently, whether or not the aggregate contracting inefficiencies are super- or sub- additive depends on the proportions of different types. For the design of conservation policies the results of this study imply that conservation contracts to address both types of information problems are warranted only if efficiency gains from private management override the inefficiencies associated with incentive compatible contract design. Depending on the specific information environment between a regulator and private resource managers, it might be advisable to retain information on 'types' and 'effort' on part of the regulator in phases of institutional transformation. Retrieving this information from the firms once the information environment has been altered might be prohibitively costly.

THE MODEL

Conservation and Production

The principal-agent model of optimal resource conservation contracts uses a forest management context. The results, however, are generally applicable to incentive problems of delegating management responsibilities from public to private managers. It is assumed that the regulator or the owner of the resource (principal) provides the institutional structure and contractual specifications by which a total of n forest companies (agents), each managing one forest site of standardized size, may use publicly owned resources to maximize profits. In delegating forest management responsibilities to individual firms, the regulator aims at jointly maximizing private and public net social forest benefits[7] minus program costs. To achieve this, the regulator offers conservation performance based tenure arrangements, also referred to in this paper as conservation contracts. [8] If timber is extracted from a forest site, it is socially optimal that the firm expend an *ex ante* known amount of conservation effort[9], which is determined by the habitat conservation value of each site.

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[7] *Public benefits* include all non-wood forest benefits derived from a standing forest, such as non-wood use values, option values of future and presently not-known uses and existences values of uncut timber. Some literature refers to these benefits as "non-timber benefits", which is imprecise in that it is the timber on the stand, which contributes non-productive forest benefits. A better term to use is *non-wood benefits* as suggested by [22; 29].

[8] *Conservation performance* is measured as the sum of public benefits provided per forest unit. The model assumes that it is possible to standardize and transform all public forest benefits into comparable units, so that P represents a single, objectively measurable conservation index.

Conservation contract refers to a bundle of observable expected conservation performance and an associated expected tax/ transfer (*incentive schedule*). The regulator offers a menu of contracts from which firms choose according to their underlying and privately known resource setting.

[9] *Conservation efforts* are all actions taken by the firms to mitigate public resource benefit loss. Whenever a site is logged, the model assumes that the firm fully or partly abates losses by expending effort. These actions comprise the protection of individual or a group of species of flora and fauna, as identified in a forest management plan.

The forest provides two stylized categories of goods and services: timber, q, representing the group of private goods, and conservation benefits, P, that comprise all public forest benefits. In the forestry context of this paper, P refers to habitat conservation benefits, which do not enhance the benefits from cut timber, from the standing forest. Cast within a discrete framework, the model assumes that all forest sites are identical in their production characteristics, but differ in terms of the sites' ability to provide habitat for a particular species ('type'). There exist *high* quality sites and *low* quality sites, denoted as $k = l, h$, which are determined by underlying sites characteristics, such as location, tree species composition, predators, etc. These characteristics, in turn, drive the marginal conservation cost per unit of P on each site, and, accordingly, the optimal conservation effort choice. Low conservation quality (*type l*) sites provide expected public good benefits at lower marginal and total conservation cost than high quality (*type h*) sites.

Each firm may choose one of three conservation effort levels, e_i, with $i = o, l, h$. Here, e_o denotes a level of conservation effort without regulation[10], while l and h denote *high* and *low* conservation effort, respectively. According to the equi-marginal principal, firms optimally expend high conservation effort levels on sites with high conservation quality, and low conservation effort levels on sites with low conservation quality,[11] unless program costs dictate otherwise, as will be discussed. Each firm's timber production technology is represented by

$$q = q(x, e_i) \qquad \textit{Eq. 1}$$

where q denotes the deterministic timber output of an individual site, the scalar value x represents a scalar value of production inputs and e_i denotes conservation effort. q is concave in x, with $\partial q/ \partial x > 0$ and $\partial^2 q/ \partial x^2 < 0$. Moreover q is assumed to be linearly decreasing in e_i, which implies that production output decreases at a constant rate as the firm increases its effort. Changes in the marginal products of x and e_i are assumed to be independent, i.e. $\partial^2 q/ \partial x\, \partial e = \partial^2 q/\partial e\, \partial x = 0$, which implies that x and e_i are chosen independently.

Public forest benefits, P (measured as conservation performance), flow from the standing forest. The firm's conservation technology is represented by

$$P = P(e_i, \varepsilon, k) \qquad \textit{Eq. 2}$$

which is a function of conservation effort, e_i, a type parameter, k, and a stochastic disturbance, ε. P is monotonically increasing and concave in e_i, where $\partial P/ \partial e_i > 0$ and $\partial^2 P/ \partial e_i^2 < 0$. Two random outcomes of public good benefits, P_o and P_z, are possible, where $P_0 <$

10 e_o is a base effort level, motivated by firms' self interest, or a widely accepted conservation practices.

11 A standard assumption in principal agent models is that the regulator knows the marginal trade-off between the goods (here: aggregated public and private forest values) at all effort levels for each forest site k, based on social public and private benefit values, and the probabilistic and type-specific relationship between effort and conservation outcome.

P_z. Each firm chooses its effort levels, e_i, to maximize profits. Random disturbances, however, affect P_j at all effort levels, e_i according to the type parameter $k = l$ or h.

Type differences are conceptualized as type-specific *expected* conservation technologies [13; 14]. In the discrete model, this translates into type-specific conditional probabilities of producing a given level of P, denoted throughout the paper as $\rho^k_{ji} = Pr(P^k_j| e_i)$. They represent the probabilities of observing a particular conservation performance, P_j, conditional on effort level, e_i, and the firm's type k. Each type can provide either P_0 or P_z, but higher quality sites have a higher conditional probability of yielding P_z at any effort level e_i, than *type l* sites. Consequently, *type h* sites show a higher expected value of public benefits $\overline{P}(e_i, k)$ for every level of e_i than *type l* sites. Higher quality sites show a higher conditional probability of yielding P_z at any effort level e_i, than *type l* sites. Moreover, ρ^k_{ji} is specified such that the following conditions hold: (i) stochastic dominance, i.e. the expected conservation performance is increasing in effort for both types $\rho^k_{zh} > \rho^k_{zl}$ for $k = l, h$; (ii) expected conservation outcome is increasing in type for all effort levels ($\rho^h_{zi} > \rho^l_{zi}$ for $i = o, l, h$); (iii) expected marginal productivity of effort is higher for *type h* sites than for *type l* sites at all effort levels ($\rho^h_{zl} - \rho^h_{z0} > \rho^l_{zl} - \rho^l_{z0}$ and $\rho^h_{zh} - \rho^h_{zl} > \rho^l_{zh} - \rho^l_{zl}$). We will subsequently show (see *proposition 1*) that the single crossing property holds: *Type h* sites achieve a given expected amount of P less costly than *type l* sites, implying less forgone production, q, and private profits. Without any production, i.e. at $q = 0$, conservation effort is $e_i = o$, as no public benefit loss is mitigated, and sites provide P according to their inherent expected potential, P^k. Each firm is required to take some preventative effort to avoid public benefits loss, but firms do so at different levels, according to the underlying habitat quality. Without any production, i.e. at $q = 0$, conservation effort is $e_i = 0$, as no public benefit loss is mitigated, and sites provide public benefits according to their inherent expected potential, P^{k_o}.

The Firm's Optimization Problem

Each firm maximizes expected utility of net revenues. They are risk-averse with a von-Neuman-Morgenstern expected utility function over lotteries of net revenues EU[.]. The unregulated firm maximizes utility of timber profits over its choice of inputs, x, and sets $e = e_0$. Without regulation, each individual firm solves

$$\max_x U[\pi_o(x)] = U_o[p\,q(x, e_o) - wx] \qquad \textit{Eq. 3}$$

where π_0 and U_0 denote the firm's reservation profit, and the corresponding reservation utility at e_0, respectively.[12] Accordingly, $x^* = argmax\,\{p\,q\,(x, e_0) - w\,x\}$ is the solution to the maximization problem. With v denoting cost per unit of effort, profits at effort levels e_l or e_h are

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[12] A firm chooses optimal input level, x^*, as a function of timber characteristics of the stand independently of conservation effort, which allows for treating the timber extraction decision as independent from the conservation decision. In response, conservation effort mitigates potential public good losses.

$$U[\pi_l (x^*, e_l)] \equiv U[p\, q(x^*, e_l) - wx^* - v\, e_l]$$

and *Eq. 4*

$$U[\pi_h (x^*, e_h)] \equiv U[p\, q(x^*, e_h) - wx^* - v\, e_h]$$

Total conservation costs comprise (i) reductions of timber production through the effects of e_i on q, and (ii) cost per unit of e_i, which will be normalized to v = 1. The difference between reservation profits and profits at e_i, for $i = l, h$ is given as

$$d(x^*, e_i) = \pi_o - \pi(x^*, e_i) = p\big(q(x^*, e_o) - q(x^*, e_i)\big) + e_i \qquad \textit{Eq. 5}$$

With concavity of q in e, it follows that $\pi(x^*, e_o) > \pi(x^*, e_l) > \pi(x^*, e_h)$, since $e_o < e_l < e_h$, and $\pi^l_0 = \pi^h_0 = \pi_0$ and $\pi_0 > \pi(x^*, e_l) \geq \pi(x^*, e_h)$. For notational clarity, let $d_i = d(x^*, e_i)$ and $\pi_i = \pi(x^*, e_i)$, where $d_h > d_l > d_0$ and $\pi_0 > \pi_l > \pi_h$.

Firm's Participation and Incentive Compatibility Constraint

The models of contract design with asymmetric information isolate the necessary deviations (contracting inefficiencies) from full information first best to induce optimal effort levels. Let the incentive schedule, i.e. the additional component to an existing stumpage scheme, be denoted by T = [t^k_o, t^k_z], where $t^k_j = t^k(P_j)$ is an individual transfer based on the observed conservation performance. Following a standard principal-agent approach, the firm's participation and its first-order conditions constrain the regulator's problem. To make conservation contracting attractive for the firms, the regulator offers a contract, which satisfies each firm's reservation utility, such that

$$EU^k[\pi_i, T^k] \geq U_0 \qquad \textit{Eq. 6}$$

Faced with performance-based contracts, each firm maximizes expected utility of net revenues over the choice of e_i in response to the contract specifications, t^k_j.[13] With firms on *type h* and *type l* sites optimally taking e_h and e_l, respectively, this generalizes to:

$$e_i^* = \underset{e\, \in e_0, e_l, e_h}{\text{argmax}} \;\; EU^k[\pi_i, T^k] = \left(1 - \rho^k_{ji}\right) U[\pi_i + t^k_0] + \rho^k_{ji}\, U[\pi_i + t^k_j] \qquad \textit{Eq. 7}$$

The optimality conditions define the incentive-compatibility constraint to the regulator's problem. To induce the socially optimal effort choice he incentive schedule must satisfy each firm's incentive compatibility constraint:

[13] With unobservable site types, the incentive schedules are type-unspecific, and the schedule is denoted t_j.

$$EU^k[\pi_{i=k}, T_j] \geq EU^k[\pi_{i\neq k}, T_j] \qquad with \qquad k = l, h \ \ and \ \ i = l, h \qquad Eq. 8$$

Expected Welfare Maximization with Information Costs

The regulator's objective function is composed of type-specific commercial profits, π_i, plus public good benefits, $P(e_i)$, which are weighted by the proportion of the respective site types, υ^k. Program costs, which comprise expenditures for the incentive scheme, $E[T]^k$,[14] and a fixed component , $C(M^s)$, for administration and enforcement, need to be subtracted. $C(M^s)$ denotes the regulator's expenditures for implementing a regulatory instrument, which vary with the information scenarios, *s*, under consideration.

Public resource management bears a positive information externality, in that the regulator remains well informed about the firm's compliance and the habitat characteristics of individual sites. This will be referred to as the full information environment, with perfectly observable conservation behaviour of each firm and their resource settings. As the regulator reduces own management responsibilities and the associated management expenditures, the information environment becomes increasingly asymmetric. Accordingly, $C(M^{fi}) > C(M^{he}) > C(M^{he/ht})$, where $s = fi$, he, he - ht refers to 'full (symmetric) information', 'hidden effort only', and 'hidden effort - hidden type', respectively.

Regulations are socially costly as they are financed by distortionary taxes, represented by λ[15] Since n, λ, υ^k and $C(M^s)$ are parameters and constants, respectively, these terms are omitted from the cost minimization problem, when determining the optimal incentive schedules. However, these parameters cannot be ignored altogether as they influence the magnitude of total program costs, and thus the economic feasibility of the conservation program. The specific formulation of the firm's participation and incentive-compatibility constraints and which of the constraints is binding depends on the particular information scenario. This will be developed further down.

Given that the regulator wishes to induce predetermined effort levels, the welfare maximization problem transforms into a program cost minimization problem. In most general terms for the sequence of models, the regulator solves:

$$\min_{E[T^k]} E[C(GP^s)] = \lambda \ n\{\upsilon^l E[T^l] + \upsilon^h E[T^h] + C(M^s)\} \qquad Eq. 9$$

$$s.t \qquad EU^k[\pi_{i=k}, T^k] \geq U_o \qquad for\ k, i = l, h \qquad Eq. 10$$

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[14] $E[T^k]$, with $E[T]^k = \Sigma_j(\rho^k_{j,i=k} * t_j)$ for k, $i = l, h$, and $j = z, o$, denotes expected incentive transfer conditional on signal j.

[15] The literature suggests a range of 0.2 to 0.5 for every tax dollar raised [38; 39].

$$EU^k[\pi_{i=k}, T^k] \geq EU^k[\pi_{i\neq k}, T^k] \qquad \textit{for } k, i = l, h \qquad \textit{Eq. 11}$$

A SEQUENCE OF OPTIMAL RESOURCE CONSERVATION CONTRACTS[16]

Full Information[17]

Both, regulator and firms have costless access to the same information set with equal beliefs about the conditional probabilities of observing P_j, with $j = o, z$ given e_i and type k. Thus, no incentive problem exists, and state-independent and site-specific contracts in terms of effort levels and transfers, $t^k(e_i)$, will induce efficient efforts. The choice of $t^k(e_i)$ must satisfy the participation constraints for each type, while inducing e_l and e_h. Formulating equations 9 to11 as

$$\min_{t(e_l),t(e_h)} C(T^{fi}) = \upsilon^l\{t^l(e_l)\} + \upsilon^h\{t^h(e_h)\} \qquad \textit{Eq. 12}$$

s.t. *PC type l* $\quad (1-\rho^l_{zl})U[\pi_l + t^l(e_l)] + \rho^l_{zl}U[\pi_l + t^l(e_l)] \geq U_o$ *Eq. 13*

PC type h $\quad (1-\rho^h_{zh})U[\pi_h + t^h(e_h)] + \rho^h_{zh}U[\pi_h + t^h(e_h)] \geq U_o$ *Eq. 14*

minimizes program costs when both participation constraints hold with equality.[18]

Standard theory suggests [15; 27; 37] that with full information the incentive schedule is independent of observed conservation outcome. The risk-neutral principal shares risk optimally with each firm. It reimburses each for their cost, independent of the outcome, if $e_{i=k}$ is observed, but transfers nothing or imposes a fine for any other observation of effort. The resulting payment schedule for each type is:

Sites type l	$t^l(e_l) = d_l$	*and*	$t^l(e_{i\neq k}) \leq 0$	*Eq. 15*
Sites type h	$t^h(e_h) = d_h$	*and*	$t^h(e_{i\neq k}) \leq 0$	*Eq. 16*

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[16] This section characterises an incentive-compatible contract design with *full information, hidden effort only*, and *hidden effort - hidden type*. The results will then be used to isolate contracting inefficiencies, assess the implications of parameter changes, and provide policy guidance on the impact of information asymmetries, when delegating to contacting of private resource managers is used as a policy instrument.

[17] All relevant contract variables and parameters, such as each site's type, k (resource setting), each firm's conservation performances, P, the firm's individual efforts, e_i and the private and public values of each site are costlessly observable by the regulator and the firms.

[18] Note that $(1-\rho^l_{zl}) = \rho^l_{ol}$ and $(1-\rho^h_{zh}) = \rho^h_{oh}$. The notation $t^k(e_i)$ emphasizes the observability of effort.

Naturally, firms choose the optimal type-specific effort. Contracting costs plus monitoring costs are

$$C(GP^{fi}) = \upsilon^l d_l + \upsilon^h d_h + C(M^{fi}) \qquad \text{Eq. 17}$$

Contract Structures with Hidden Individual Conservation Effort

In this model, site types are observable, and the regulator offers site-specific contracts to each firm. With $t^k_j = t^k(P_j)$ the the pay-offs are strictly based on P_j, which is used as an observable signal indicative of each firm’s effort. Each individual firm's participation constraint is:

PC for type l $$(1-\rho^l_{zl})\,U[\pi_l + t^l_o] + \rho^l_{zl}\,U[\pi_l + t^l_z] \geq U[\ _o] \qquad \textit{Eq. 18}$$

PC for type h $$(1-\rho^h_{zh})\,U[\pi_h + t^h_o] + \rho^h_{zh}\,U[\pi_h + t^h_z] \geq U[\ _o] \qquad \textit{Eq. 19}$$

With three discrete effort levels, there exist two incentive compatibility constraints for each type. However, only one incentive compatibility constraint will be binding for each type, as type l must be prevented from taking e_o, while *type h* must be prevented from taking el or e_o.[19] To simplify the analytical set-up, but without any loss of generality, the model imposes $\rho^k_{zo} = 0$ for e_o, while for e_l or e_h it follows $\rho^k_{zi\neq o} \neq 0$ on both site types. Equation 11 becomes:

ICC for a type l site

$$(1-\rho^l_{zl})U[\pi_l + t^l_0] + \rho^l_{zl}\,U[\pi_l + t^l_z] \geq (1-\rho^l_{zo})U[\pi_o + t^l_o] + \rho^l_{zo}\,U[\pi_o + t^l_z] \qquad \textit{where} \quad \rho^l_{z0} = 0, \qquad \textit{Eq. 20}$$

and

ICC for a type h site

$$(1-\rho^h_{zh})U[\pi_h + t^h_0] + \rho^h_{zh}\,U[\pi_h + t^h_z] \geq (1-\rho^h_{zl})U[\pi_l + t^h_0] + \rho^h_{zl}\,U[\pi_l + t^h_z] \qquad \textit{where } \rho^h_{zl} > 0. \qquad \textit{Eq. 21}$$

The constraints implicitly define the conditions for the pay-off schedule for each type. While each firm's participation constraint determines the absolute magnitude of the

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[19] Notice that the incentive to prevent effort choice e_l nests prevention of effort choice e_o. If the incentive for *type h* is chosen large enough to prevent effort e_l, then it is also large enough to prevent choice e_o.

expected transfer, each incentive compatibility constraint controls the relative magnitude between t^k_0 and t^k_z.

Since individual group identities of each site are known, the regulator minimizes program costs separately for each type, $k = l, h$. The optimality conditions are derived separately for each site type by solving the respective first order conditions.

The cost minimization problem for *type l* sites is written as:

type l $$\min_{t_z^l, t_0^l} E[C^l(T^{he})] = \rho_{zl}^l\, t_z^l + (1-\rho_{zl}^l)\, t_0^l \qquad \textit{Eq. 22}$$

s.t. $$\rho_{zl}^l\{U[\pi_l + t_z^l] - U[\pi_l]\} = U_0 - U[\pi_l] \qquad \textit{Eq. 23}$$

For *type l* sites, the assumption $\rho^l_{z0} = 0$ implies $t^l_o = 0$,[20] such that t_z^{l*} remains the choice variable in this problem, and the participation and incentive-compatibility constraints for *type l* collapse into one equation.

For *type h* sites, the cost minimization problem becomes:

type h $$\min_{t_z^h, t_0^h} E[C^h(T^{he})] = \rho_{zh}^h\, t_z^h + (1-\rho_{zh}^h)\, t_0^h$$

s.t. $$\rho_{zh}^h\left\{U[\pi_h + t_z^h] - U[\pi_h + t_0^h]\right\} = U[\pi_0] - U[\pi_h + t_0^h] \qquad \textit{Eq. 24}$$

$$\rho_{zh}^h\left\{U[\pi_h + t_z^h] - U[\pi_h + t_0^h]\right\} - \rho_{zl}^h\left\{U[\pi_l + t_z^h] - U[\pi_l + t_0^h]\right\}$$

$$= U[\pi_l + t_0^h] - U[\pi_h + t_0^h] \qquad \textit{Eq. 25}$$

The fisrt order conditions, provided in appendix 1, yield the incentive compatible incentive schedule [t^k_z, t^k_o] for each type**.** Both of *type h*'s constraints are satisfied at minimum expenditure for the incentive schedule (i.e. a firm with a *type h* is just indifferent to taking e_h over any other effort level), if t_o^h and t_z^h are chosen such that the utility from taking e_l and producing a positive signal P_z with probability ρ^h_{zl} equals the difference in utility from taking e_l plus receiving t_0 and from taking e_0. The firm's expected marginal utility derived from choosing efficient effort (over any other effort level) equals the marginal forgone utility from doing so.

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20 t^k_0 and t^k_z will be greater than, equal to, or less than zero if $\rho^k_{zi} \neq 0$.

Risk exposure of a risk-averse firm, induced by a pay-off schedule which is conditional on conservation performance, necessitates the inclusion of a risk premium into the firm's pay-off.[21] This leaves the firm indifferent to accepting the contractual gamble for public benefit conservation, or not managing public lands. Accordingly, the expected minimum transfers to the firms of either site type can be parameterized as:

type l $$\rho_{zl}^{l} t_z^l + \left(1-\rho_{zl}^{l}\right) t_0^l = d_l + r^l$$ *Eq. 26*

type h $$\rho_{zh}^{h} t_z^h + \left(1-\rho_{zh}^{h}\right) t_0^h = d_h + r^h$$ *Eq. 27*

After re-arranging, the state-contingent transfers for each type are written as:

type l $$t_z^l = \frac{\left(d_l + r^l\right)}{\rho_{zl}^{l}} \quad \text{and} \quad t_0^l = 0$$ *Eq. 28*

type h $$t_z^h = \frac{\left(d_h + r^h\right) - \left(1-\rho_{zh}^{h}\right) t_0^h}{\rho_{zh}^{h}} \quad \text{and} \quad t_0^h = \frac{\left(d_h + r^h\right) - \rho_{zh}^{h} t_z^h}{\left(1-\rho_{zh}^{h}\right)}$$ *Eq. 29*

Total expected program costs are now:

$$E[C(GP^{he})] \equiv \quad \upsilon^l\left\{d^l + r^l\right\} + \upsilon^h\left\{d^h + r^h\right\} + C^{he}(M)$$ *Eq. 30*

Contract Structures with Hidden Effort and Hidden Site Types[22]

To clarify the regulatory problem of designing incentive compatible conservation contracts in the presence of hidden site types and unobservable effort levels, recall the conceptualisation of type differences as the sites' specific resource settings influencing the expected conservation function. Type differences are expressed in the conditional probabilities ρ^k_{ji}. If the regulator observes only the stochastic signal P_j, and firms are privately informed about type, firms who manage *type h* sites have an incentive to deliberately misrepresent their type as they are able to systematically increase their total pay-off. By choosing e_l, but being *type h*, the firms incur opportunity costs of d_l, but receive an expected transfer, which exceeds this conservation cost, because they consistently

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[21] The risk premium is the amount over and above the opportunity cost of $e_{i=k}$, to satisfy the firm's participation constraint.

[22] The sites' resource settings are privately known by firms, while the regulator monitors noisy conservation performance. The performance oriented incentive schedule induces firms with a type l site to prefer the expected utility from choosing $e = e_l$ over $e = e_0$ and the firms with a *type h* site to prefer the expected utility from choosing eh over e_l.

provide the signal P_z with a higher probability than anticipated by. To prevent type misrepresentation, firms need to reveal their type identity *a priori*.[23]

For the combined *hidden effort - hidden type* model, firms are assumed to be risk-neutral. This allows for providing an explicit analytical solution for the contract design with *hidden effort* and *hidden type*, and may also be a more realistic description of a firm's risk preferences.[24] The assumptions $\rho^k_{z0} = 0$ and ρ^k_{zl}, $\rho^k_{zh} > 0$ are maintained.

The regulator offers an incentive schedule which induces type-specific efficient effort levels on each site. Firms face identical offers contingent on the signal about their conservation performance, indicated by dropping superscript *k* on the payment schedule, t_j. The regulator's cost minimization problem is simultaneously constrained by the firms' participation and incentive compatibility conditions for both site types. This adds an additional layer of complexity to the analysis, but is considerably simplified by *proposition 1* (see appendix 3), which formalizes the single crossing property for the case of two observable outcomes and three effort levels. *Proposition 1* builds on the assumption that expected marginal productivity of effort is higher for *type h* than for *type l* sites for all e_i. It shows that the initial assumptions $\rho^l_{zl} < \rho^h_{zh}$ and $\rho^l_{zh} - \rho^l_{zl} < \rho^h_{zh} - \rho^h_{zl}$ are sufficient to define a *type l* site as less conservation efficient than a *type h* site.

With hidden effort and hidden type, the regulator solves the optimization problem:

$$\min_{t_z, t_0} E[C(T^{he/ht})] = \upsilon^l \left\{\rho^l_{zl}\, t_z + (1-\rho^l_{zl}) t_0 \right\} + \upsilon^h \left\{\rho^h_{zh}\, t_z + (1-\rho^h_{zh})\, t_0 \right\} \qquad \textit{Eq. 31}$$

s.t. *PC-l*

$$\left(1-\rho^l_{zl}\right)[\pi_l + t_0] + \rho^l_{zl}[\pi_l + t_z] = \pi_0 \qquad \textit{Eq. 32}$$

ICC-h

$$\left(1-\rho^h_{zh}\right)[\pi_h + t_0] + \rho^h_{zh}[\pi_h + t_z] = \left(1-\rho^h_{zl}\right)[\pi_l + t_0] + \rho^h_{zl}[\pi_l + t_z] \qquad \textit{Eq. 33}$$

After solving the first-order conditions, the optimal incentive schedule $T^{he\text{-}ht} = [t_z\,;\, t_0]$ results in the following specification, where the details are provided in the appendix 4:

$$t_0^* = d_l - (d_h - d_l)\frac{\rho^l_{zl}}{\rho^h_{zh} - \rho^h_{zl}} \quad \text{and} \quad t_z^* = d_l + (d_h - d_l)\frac{\left(1-\rho^l_{zl}\right)}{\rho^h_{zh} - \rho^h_{zl}} \qquad \textit{Eq. 34}$$

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23 See appendix 2 for an illustration of type differences and the resulting incentive problem.

24 Risk-neutrality of firms eliminates the inefficiency associated with the imperfect signal when firms are risk-averse. The set-up places the analytical focus on analyzing the information rent embedded in the incentive schedule, where firms have a linear utility function, $U[\pi_i + t_j] = [\pi_i + t_j]$.

Several observations about the incentive schedule can be drawn from t_0 and t_z:

(1) If $d_h = d_l$, then $t^*_0 = t^*_z$. This is not surprising, as for $d_h = d_l$, it must hold that $e_l = e_h$, which implies that the efficient effort levels on both site types are equal. This, however, would be true only if there are no differences in the site types in terms of their conservation efficiency, i.e. all sites provide the same expected conservation outcome conditional on effort. Without type differences and given the firms' risk neutrality, the regulator offers a flat payment, independent of outcomes.

(2) If $d_h \neq d_l$, the incentive schedule depends on the observed signal P_j. Each transfer, t_j, consists of two parts:

(i) A base transfer, which covers the cost of taking e_l, i.e. d_l, thus satisfying the firm's participation constraint;

(ii) A portion, which adjusts the base transfer. Since $\rho^l_{zl} / \rho^h_{zh} - \rho^h_{zl}$ is always > 0, it reduces the base transfer when signal P_0 is observed. Likewise, the base payment is enlarged if P_z is observed. It follows immediately that $t^*_0 < t^*_z$.

(3) Moreover, we can establish that $t^*_0 < 0$, if $d_l < (d_h - d_l)(\rho^l_{zl} / (\rho^h_{zh} - \rho^h_{zl}))$ or, equivalently, $\rho^l_{zl} / \mathrm{d}_l > (\rho^h_{zh} - \rho^h_{zl}) / (\mathrm{d}_h - \mathrm{d}_l)$. This implies that t_0 is negative, if the *type l* site's marginal probability of producing signal P_z when taking e_l is greater than *type h* site's marginal probability of producing signal P_z when taking e_h. In other words: The marginal expected increment for conservation performance is larger for *type l*, when choosing e_l over e_o, than it is for *type h* when choosing e_h over e_l.

(4) The components of t_o and t_z , which will be either subtracted from or added to the base payment, are interpreted as follows:

(i) The first part, $(d_h - d_l)$, is the marginal cost of choosing e_h over e_l.

(ii) The second part is a ratio of (a) the conditional probability of producing signal P_j when being *type l*, over (b) the differences in conditional probabilities of producing signal P_z when being *type h* and choosing e_h over e_l. The term resembles the likelihood ratio, but relates type differences.
For t_0, this ratio is the conditional probability of producing signal P_z when being *type l* and taking e_l over the marginal conditional probability of producing P_z, when being *type h* and taking e_h over e_l.
For t_z, this ratio is the conditional probability of producing signal P_0 when being *type l* and taking e_l over the marginal conditional probability of producing P_z, when being *type h* and taking e_h over e_l.

This incentive schedule satisfies type-specific participation and incentive compatibility conditions. The firms will choose e_l and e_h on sites *type l* and *h*, respectively, while each firm receives a type-dependent expected transfer (see appendix 4) of:

type l $$E^l[T] = \rho^l_{zl} t^*_z + \left(1 - \rho^l_{zl}\right) t^*_0 = d_l$$ *Eq. 35*

type h $$E^h[T] = d_l + \left(d_h - d_l\right)\frac{\left(\rho^h_{zh} - \rho^l_{zl}\right)}{\left(\rho^h_{zh} - \rho^h_{zl}\right)}$$ *Eq. 36*

A firm with a t*ype l* site receives an expected transfer, which exactly covers its conservation costs, d_l. If a firm with site *type h* chose e_l the expected payment reduces to (see appendix 4)

$$E^h[T(e_l)] \qquad = \quad d_l + \left(d_h - d_l\right)\frac{\left(\rho^h_{zl} - \rho^l_{zl}\right)}{\left(\rho^h_{zh} - \rho^h_{zl}\right)}$$ *Eq. 37*

Given the assumptions on $\rho^k{}_{zi}$, the specification of the incentive scheme does not provide an incentives for *type h* to take effort e_l, since by assumption $\rho^h{}_{zh} > \rho^h{}_{zl}$.

The results imply that the regulator can induce the efficient effort levels by specifying the performance based incentive schedule. However, to induce type revelation *a priori* at the time of signing the contract, the regulator would specify a contract menu in terms of the total expected transfer and expected provision of signal P_z. From the literature on self-selecting contracts it is known that the expected transfer to the more efficient firm (here: a firm with a site of *type h*) covers total costs of effort plus an information rent to prevent type misrepresentation. Noting d_h as total costs, the expected information rent *is* $E^h[I] = E^h[T] – d_h$. Simplifying yields:

$$E^h[I] = \left(d_h - d_l\right)\frac{\left(\rho^h_{zl} - \rho^l_{zl}\right)}{\left(\rho^h_{zh} - \rho^h_{zl}\right)}$$ *Eq. 38*

The information rent consists of two terms. The first term is the marginal cost of choosing e_h over e_l. The second term is the ratio of (i) marginal type difference in the conditional probability of producing signal P_z when taking effort e_l; and (ii) marginal conditional probability *type h* of producing signal P_z when taking effort e_h over e_l. With the assumptions of the model about the conditional probabilities of effort, the second term of the information rent is positive. Moreover, the second term will be greater than 1 (i.e. the information rent will be greater than the marginal cost of e_h), if site *type h's* marginal conditional probability of producing signal P_z from taking e_l , (i), is larger than *type h's* marginal conditional probability of producing signal P_z from taking e_l over e_h, (ii). However, the information rent is smaller than the marginal cost of e_h, if the converse is the case. Total program costs at the optimum are given by

$$E[C(GP^{he/ht})] \equiv \upsilon^l(d_l) + \upsilon^h(d_h + E[I]^h) + C(M^{he/ht})$$ *Eq. 39*

COMPARATIVE STATICS ACROSS INFORMATION SCENARIOS

The objective of this section is to identify the implications of parameters changes for the contracting costs. The analytical results will be supported by numerical illustrations. This is the basis for analysing policies of contracting under asymmetric information.

Conservation Costs

<u>Proposition 2</u>: *With hidden effort only, total expected contracting costs are increasing in conservation costs for both types, i.e.:*

$$\left.\frac{\partial L^{l*}}{\partial d_l}\right|_{t_0^{l*},\, t_z^{l*}} > 0 \qquad \textit{and} \qquad \left.\frac{\partial L^{h*}}{\partial d_h}\right|_{t_0^{l*},\, t_z^{l*}} > 0 \qquad \textit{Eq. 40}$$

The proof of *proposition 2* is provided in the appendix 5. As conservation costs are part of the contracting costs of the firm's pay-off, the pay-off must increase, as the conservation costs increase to satisfy the reservation constraint. However, the numerical examples will also demonstrate that the increase in total contracting costs is not only due to larger conservation cost, but also to the increase in the respective risk premia.

In the *hidden effort - hidden type* model, contractual inefficiencies are captured in the information rents granted to *type h* sites. The following analysis focuses on responses of the information rent of *type h* sites to changes in the underlying conservation costs.

<u>Proposition 3</u>: *With hidden effort and hidden type, the information rent to* types h *sites is increasing in conservation costs of* type h *sites, d_h, but decreasing in conservation costs of* type l *sites, d_l:*

$$\left.\frac{\partial E[I]^h}{\partial d_h}\right|_{t_0^*,\, t_z^*} > 0 \qquad \textit{and} \qquad \left.\frac{\partial E[I]^h}{\partial d_l}\right|_{t_0^*,\, t_z^*} < 0 \qquad \textit{Eq. 41}$$

The proof of *proposition 3* is provided in the appendix 6. The proposition implies that if the opportunity costs of conservation on site *type* increase, the information rent must increase as well to prevent type misrepresentation. However, if the opportunity costs of site *type l* increase, then the necessary information rent to site *type h* decreases. In a later section, I will complement the analytical results with numerical examples, and analyse simultaneous changes of d_l and d_h.

Ease of Type Misrepresentation

Proposition 4: *With hidden effort and hidden type, the information rent to* type h *sites is increasing in type h' s conditional probability of producing signal P_z, when taking effort level e_l, but decreasing in type l' s conditional probability of producing signal P_z, when taking effort level e_l:*

$$\left.\frac{\partial E[I]^h}{\partial \rho_{zl}^h}\right|_{t_0^*, t_z^*} > 0 \qquad \text{and} \qquad \left.\frac{\partial E[I]^h}{\partial \rho_{zl}^l}\right|_{t_0^*, t_z^*} > 0 \qquad \textit{Eq. 42}$$

Proposition can be interpreted as a measure for the ease of type misrepresentation. The larger site difference in terms of the conditional probability of producing a more favourable signal, P_z, when taking effort level e_l, the larger is the information rent granted to a firm managing a *type h* site (appendix 7).

NUMERICAL SIMULATIONS

The purpose of this section is to derive some generally interpretable insights for comparing the efficiency implications of incentive-compatible contract design under different information environments.[25] It investigates the implications of (i) the magnitude of both types' conservation costs, (ii) the differences thereof across types and (iii) the additivity question of contracting inefficiencies in contracts which address 'hidden effort' and 'hidden type' simultaneously. Efficiency of public-private conservation contracts is measured in terms of the contracting inefficiency (information rent and risk premia) associated with incentive compatible contract design.

Parameter Specifications: Conservation Costs, Site Types and Risk Preferences

The numerical simulations use the following assumptions: Forest sites are of one standard size (1 ha). Each firm's reservation profit is independent of type and amounts to \$1000 per site at effort e_0. Conservation efforts e_l and e_h are assumed to reduce the firm's reservation profit by 10% and 30%, respectively (opportunity cost of conservation), which corresponds to forgone profits of \$100 and \$300 per site. There exists an equal proportion of forest sites *type l* and *h*. All firms have homogeneous risk preferences. They are described by a von-Neuman-Morgenstern utility function and represented by a functional form $U[NR] = [NR]^{\alpha}$. NR denotes the firm's net revenues from production plus conservation transfers, and α is a coefficient of risk aversion.[26]

[25] As mentioned before, risk-neutrality in the *hidden effort - hidden type* model effectively reduces the problem to *hidden type only* [25]. Introducing risk-aversion allows for modeling contract structures for four information scenarios. Risk-premia as well as information rents to sites *type h* are isolated.

[26] The utility function implies CRRA. For risk neutral firms $\alpha = 1$ and for risk averse firms $0 < \alpha < 1$, explicitly $\alpha = 0.7$.

Type specific conditional probabilities for the numerical examples are specified to satisfy the single crossing property. With three effort levels, two site types and two observable signals, conditional probabilities for each type are chosen as in table 1.

Table 1:Type-Specific Conditional Probabilities of Conservation Outcome, (ρ^{k}_{ji})

type proportion	***Type l*** 50%		***Type h*** 50%	
effort	*Po*	*Pz*	*Po*	*Pz*
$e_o = 0$	1.00	0.00	1.00	0.00
$e_l = 100$	0.80	0.20	0.70	0.30
$e_h = 300$	0.65	0.35	0.50	0.50

Results of Base Specifications

Contracting Inefficiencies across Information Scenarios

Solving the program cost minimization problem derives incentive-compatible conservation contracts for a sequence of information scenarios. Depending on the information scenario, the objective function as well as the number of constraints changes.

Table 2 provides the numerical results under the base parameter specification. The table shows the total expected transfers from regulator to firms, the conservation contract schedule (t_o and t_z), the actual conservation cost and the contracting inefficiencies as percent of conservation costs for each of the four different information scenarios. The model behaves as anticipated. [27]

In the 'hidden effort only' model, the participation and incentive compatibility constraints of both types are binding; the expected transfer to both types increases in comparison to the full information case; and t_o is zero for sites type *l*. Also, notice that the aggregate inefficiency of the total expected transfer (in percent) is skewed upwards, despite the fact that both types are represented equally in the population. This originates in the proportionally higher risk premium for *type h* sites. All firms satisfy their reservation utility (125.9) with equality. In the 'hidden type only'

[27] The set-up for *hidden effort* and the basic cost minimization program for all scenarios are given in appendix 8.

Table 2:Contract Structures across Information Scenarios

	Full Information			***Hidden Effort***			***Hidden Effort - Hidden Type (Risk-Neutral Firms)***			***Hidden Effort - Hidden Type (Risk-Averse Firms)***		
	Type l	***Type h***	***Total***	***Type l***	***Type h***	***Total***	***Type l***	***Type h***	***Total***	***Type l***	***Type h***	***Total***
type proportion	*50%*	*50%*	***(1)***	*50%*	*50%*	***(2)***	*50%*	*50%*	***(3)***	*50%*	*50%*	***(4)***
Exp. Transfer	100.00	300.00	**200.00**	105.96	343.38	**224.67**	100.00	400.00	**250.00**	121.42	437.67	**279.55**
t^k_o ($units)	100.00	300.00		0.00	-188.31		-100.00	-100.00		-89.41	-89.41	
t^k_z ($units)	100.00	300.00		529.82	875.07		900.00	900.00		964.76	964.76	
Conservation Costs	100.00	300.00	200.00	100.00	300.00	200.00	100.00	300.00	200.00	100.00	300.00	200.00
Inefficiency	0.00	0.00	**0.00**	5.96	43.38	**24.67**	0.00	100.00	**50.00**	21.42	137.67	**79.55**
(%)	0.00%	0.00%	0.00%	**5.96%**	**14.46%**		**0.00%**	**33.33%**		**21.42%**	**45.89%**	
Contracting Inefficiencies						**12.34%**			**25.00%**			**39.77%**

model (risk-neutral firms), *type h* sites extract an information rent, while *type l* sites satisfy their reservation utility. Notice that the difference in performance-based pay-offs (variability of the incentive schedule) increases for *type l* in comparison to the 'hidden effort only' scenario, while it decreases for *type h*. Risk neutrality, however, renders the increase of variability inconsequential. The contracting inefficiency entirely results from the information rent extracted by *type h* sites.

In the 'hidden effort – hidden type' model, the regulator offers a menu of contracts specified in terms of expected transfers and expected conservation outcomes to separate types. The optimization program renders contract structures such that firms self-select according to their privately known sit type characteristics. In addition to the risk-premia, the excess transfer captures the information rent paid to *type h* sites, indicated by the higher utility level of *type h* sites, as reported in table 2. Comparing 'hidden effort only' with 'hidden effort - hidden type', one notices that the variability of the incentive schedule changes type-specifically between the two information scenarios. For *type l* sites, the variability of the incentive schedule becomes more variable with *hidden effort - hidden type* compared to *hidden effort* only. In contrast, the variability of the incentive schedule decreases for *type h* sites. In contrast, the expected utility of *type l* remains unchanged despite the higher expected transfer in this scenario.

One policy question concerns the relative importance of 'hidden effort' and 'hidden type'. As table 2 shows, in the given example 'hidden type' introduces a larger inefficiency than hidden effort. According to the numerical results of the base specification as shown in table 2, the total contracting inefficiency in the 'hidden type only' model (25%) exceeds the total contracting inefficiency associated in the 'hidden effort only' model (12%). However, despite the apparently larger efficiency impacts of hidden type, the underlying numerical specification of the model matters and it is difficult to infer a general statement about the relative importance of hidden effort compared to hidden type.[28]

Additivity of the Information Inefficiencies

We refer to contracting inefficiencies as 'super-additive' if the sum of the inefficiencies from 'hidden effort' plus 'hidden type' is smaller than the inefficiency from the combined problem of 'hidden effort - hidden type'. In contrast, if efficiencies are sub-additive the converse is true. Stewart (1994) suggests that the inefficiencies resulting from 'hidden effort - hidden type' are sub-additive. Numerical results of this study, using a different modelling approach, suggest more differentiated results.

The previous table 2 compares the size of the contracting inefficiencies across information scenarios. It reports the total expected transfers, weighted by the respective type proportions, indicated in columns *(1)* through *(4)*, and the respective conservation

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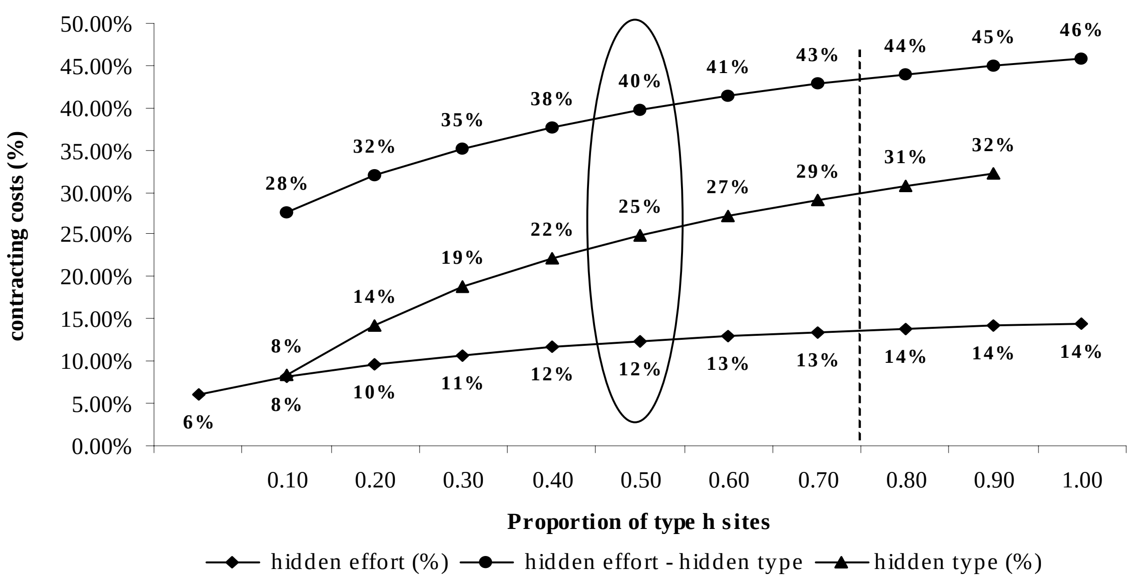
[28] Foremost, notice that the chosen utility function exhibits little curvature over the relevant income range underlying the simulations. I.e., over the relevant range, the specification of the utility function shows a low degree of risk aversion.

costs at each effort level. This allows calculating the excess transfer over and above costs to induce efficient effort levels under each scenario. The comparison for total expected transfers (i.e. transfers to the sum of both site types) reveals that the contracting inefficiency with 'hidden effort - hidden type' is larger (39.77%) than the sum of the inefficiencies associated with the individual problems (12.34% plus 25.00%, respectively). Thus, the contracting inefficiencies when considering the sum of all sites are super-additive.

However, when analysing both site types separately one notices that for *type l* sites (low opportunity costs of public good conservation) the information inefficiency is super-additive, while for *type h* sites (high opportunity costs of public good conservation) the information inefficiency is sub-additive. *Type h's* expected risk premium as well as the information rent is smaller under 'hidden effort - hidden type' than in the isolated information problems.[29] However, the increase of the necessary payment for *type l* sites when both problems occur simultaneously overrides this effect. This results in super-additive information inefficiencies when considering expected transfers to all sites.

The base model assumes an equal proportion of high and low site types. The following figure 1 shows total expected contracting inefficiencies for 'hidden effort only', 'hidden type only' and 'hidden effort-hidden type' on the vertical axis, and *type h* site proportions on the horizontal axis.

Figure 1: Contracting Inefficiencies and Proportions of *type h* sites



[29] Compare for *type h*: 'Hidden effort –hidden type' with 42.80 and 94.90 for risk premium and information rent, respectively, but 43.40 ('hidden effort only') and 100.00 ('hidden type only'). See appendix 9.

In all information scenarios, contracting inefficiencies are increasing in the proportion of *type h* sites, but at a decreasing rate. Unsurprisingly, altering the type proportions changes the total additivity of contracting inefficiencies. Given the discrete specifications of this example, the aggregated contracting inefficiencies of all sites are super-additive, for values of $\upsilon^h \leq 0.7$, but sub-additive for values of $\upsilon^h \geq 0.8$. Moreover, as υ^h increases the difference between the costs of inefficiency in the combined 'hidden effort - hidden type' problem and the sum of the isolated problems is decreasing. That is, if *type h* is represented at a high proportion, the sub-additivity of *type h* over-rides the super-additivity of *type l*.

Efficiency Implications of Changes in Conservation Costs

For 'hidden effort only' the analytical results had established previously that the expected transfers to the agent, irrespective of type, increase unambiguously in conservation costs. In contrast, for 'hidden effort – hidden type' the analytical results show an ambiguous behaviour of the information rent, as it increases in conservation costs of sites *type h*, but decreases in conservation costs of sites *type l*. The numerical analysis helps to better understand the relationship between conservation costs in terms of (i) their magnitude, and (ii) their differences across site types and the inefficiencies associated with incentive compatible contracts. This is important because it provides policy guidance for conservation contracts and possible alternatives.

Changes in conservation costs are simulated by a percentage increase, up to 50% of each type's base conservation costs (d_i). The simultaneous and equal increase in conservation costs to both types implies that the ratio of conservation costs between *type l* and *type h* sites remains unchanged. Table 3 shows the response of the contracting inefficiencies to an increase of both types' conservation costs across information scenarios, and complements the analytical results.

Table 3:Conservation Costs and Efficiency Implications across Information Scenarios

Increase in Conservation Cost		***Full Information***			***Hidden Effort Only***			***Hidden Type Only***			***Hidden Effort - Hidden Type***		
		Type l	***Type h***	***Total***	***Type l***	***Type h***	***Total***	***Type l***	***Type h***	***Total***	***Type l***	***Type h***	***Total***
		0,5	*0,5*	***(1)***	*0,5*	*0,5*	***(2)***	*0,5*	*0,5*	***(3)***	*0,5*	*0,5*	***(4)***
Base	Expected Transfer	100,00	300,00	200,00	105,96	343,38	224,67	100,00	400,00	250,00	121,42	437,67	279,55
	Conservation Cost	100,00	300,00	200,00	100,00	300,00	200,00	100,00	300,00	200,00	100,00	300,00	200,00
Contracting Inefficiency		*0,00%*	*0,00%*	*0,00%*	*5,96%*	*14,46%*	***12%***	*0,00%*	*33,33%*	***25%***	*21,42%*	*45,89%*	***40%***
10%	Expected Transfer	110,00	330,00	220,00	117,22	389,85	253,53	110,00	440,00	275,00	135,84	486,46	311,15
	Conservation Cost	110,00	330,00	220,00	110,00	330,00	220,00	110,00	330,00	220,00	110,00	330,00	220,00
Contracting Inefficiency		*0,00%*	*0,00%*	*0,00%*	*6,56%*	*18,14%*	***15%***	*0,00%*	*33,33%*	***25%***	*23,49%*	*47,41%*	***41%***
20%	Expected Transfer	120,00	360,00	240,00	128,59	440,55	284,57	120,00	480,00	300,00	150,69	536,44	343,56
	Conservation Cost	120,00	360,00	240,00	120,00	360,00	240,00	120,00	360,00	240,00	120,00	360,00	240,00
Contracting Inefficiency		*0,00%*	*0,00%*	*0,00%*	*7,16%*	*22,37%*	***19%***	*0,00%*	*33,33%*	***25%***	*25,58%*	*49,01%*	***43%***
30%	Expected Transfer	130,00	390,00	260,00	140,08	497,01	318,55	130,00	520,00	325,00	166,01	587,72	376,87
	Conservation Cost	130,00	390,00	260,00	130,00	390,00	260,00	130,00	390,00	260,00	130,00	390,00	260,00
Contracting Inefficiency		*0,00%*	*0,00%*	*0,00%*	*7,75%*	*27,44%*	***23%***	*0,00%*	*33,33%*	***25%***	*27,70%*	*50,70%*	***45%***
40%	Expected Transfer	140	420,00	280,00	151,69	562,40	357,04	140,00	560,00	350,00	181,82	640,45	411,14
	Conservation Cost	140,00	420,00	280,00	140,00	420,00	280,00	140,00	420,00	280,00	140,00	420,00	280,00
Contracting Inefficiency		*0,00%*	*0,00%*	*0,00%*	*8,35%*	*33,90%*	***28%***	*0,00%*	*33,33%*	***25%***	*29,87%*	*52,49%*	***47%***
50%	Expected Transfer	150,00	450,00	300,00	163,42	646,07	404,75	150,00	600,00	375,00	198,15	694,82	446,48
	Conservation Cost	150,00	450,00	300,00	150,00	450,00	300,00	150,00	450,00	300,00	150,00	450,00	300,00
Contracting Inefficiency		*0,00%*	*0,00%*	*0,00%*	*8,95%*	*43,57%*	***35%***	*0,00%*	*33,33%*	***25%***	*32,10%*	*54,40%*	***49%***

For ‘hidden effort only’ the results show that type specific expected transfers are increasing in conservation costs at a decreasing rate. The numerical examples allow isolating the risk premia to both types as an inefficiency measure. It clarifies that the response of the expected transfers to an increase in conservation costs is composed of (i) the cost increase in itself (direct effect), and (ii) an increase in the risk premium (indirect effect). Relatively higher conservation costs imply a comparatively larger spread in the agent's pay-off schedule. Assuming a given degree of risk-aversion the larger spread in pay-offs necessitates a larger risk premium to compensate the agents to accept a risky gamble. Consequently, relatively high conservation costs exacerbate the contracting inefficiency associated with incentive compatible contracts.[30]

In the 'hidden type only' model, the total expected transfer (column 3) increases linearly as both site types' conservation costs increase[31], and the expected information rent to *type h* changes proportionately to the underlying conservation costs. As the relationship between conservation costs on *type l* and *type h* sites remains unchanged, so does *type h*'s information rent relative to its conservation cost. Thus, in contrast to the 'hidden effort only' model, the proportion between total expected inefficiency (25%) and underlying total conservation costs remains unchanged. However, *proposition 4* stated that the information rent of *type h* responds differently to changes in d_l and d_h (it decreases as d_l increases, and increases as d_h increases). Therefore it may be possible that the first effect overrides the second. The numerical analysis show that magnitude of *type h*'s information rent is subject to the sites' type difference expressed as differences in opportunity costs of conservation (i.e. as d_l and d_h drift apart).[32] Thus, conservation cost differences matter for the magnitude of the associated contracting inefficiencies.

When contracts are designed to address 'hidden effort' and 'hidden type' simultaneously and firms are risk averse, the numerical results show an increase in total contracting inefficiencies from 40% to 49% in response to a 50% increase in both type's conservation costs. However, whether or not contracting inefficiencies are in general larger at higher levels of conservation costs is determined by the interaction between (i) the net effect on *type h*'s information rent induced by d_l and d_h; and (ii) the net effect of changes in risk premia to both types. If the information rent of *type h* shows a net increase and risk premia to both types are increasing in d_l and d_h, then contracting inefficiencies are increasing in conservation costs. In the given analysis, the spread in payoffs to the agents

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[30] The numerical results also show that the magnitude of conservation cost matters: While the risk premium for *type l* sites increases by approximately one-third from 6% to 9%, the risk premium for *type h* sites almost triples.

[31] A simultaneous 50% increase of d_l and d_h leads to an increase in *type h*’s information rent of 50% and an increase in total expected transfers by 25% from 250.00 to 375.00.

[32] Appendix 10 illustrates the behaviour of the information rent to *type h* in response to individual changes of d_i: An increase in *type h*'s conservation cost by 50% leads to an information rent of approximately 39%, while an increase in *type l*’s conservation costs leads to an information rent of 25% (both compared to 33% in the base scenario).

increases at higher levels of conservation costs, thus necessitating higher risk premia to both agents (this is the case in the 'hidden effort only' model). However, the overall effect of changes in conservation cost on contracting inefficiencies depends on the relative magnitude of each of these individual dynamics. Only if the information rent of *type h* sites shows a net increase, and risk premia to both types are simultaneously increasing in d_h and d_l are the contracting inefficiencies increasing in conservation costs.

Conservation Cost and Additivity of Contracting Inefficiencies

Type differences are (indirectly) characterized by the distinctness of sites conservation costs. Table 3 shows that the additivity of the inefficiencies in the 'hidden effort - hidden type' model decreases, as conservation becomes more costly. The reason is that an increase in conservation costs in the 'hidden effort only' model (as modeled from 10% to 50%) increases the risk premium particularly for *type h* sites. Contracts, however, when designed to address address 'hidden effort - hidden type' simultaneously, off-set this increase. The results imply that while addressing 'hidden effort - hidden type' simultaneously is increasingly more inefficient, the inefficiencies are actually becoming sub-additive when conservation costs increase.

CONCLUSIONS AND POLICY IMPLICATIONS FOR CONTRACT DESIGN

Agency Costs and Information Environments

The comparison of contracting inefficiencies associated with different information scenarios shows that increasingly asymmetric information environments between a regulator and private decision makers lead to larger contracting inefficiencies necessary to induce desired conservation behaviour. As these inefficiencies partly off-set efficiency gains from private management, retaining information on effort and/ or type may be welfare improving. This implies that the regulator must choose the efficient extend of information asymmetry between regulator and firms when delegating management tasks with public good characteristics.

Agency Costs and Opportunity Costs of Conservation

The paper elicits the impact of the magnitude and the distinctness of conservation costs across sites. The magnitude of site-specific conservation costs influences agency costs in all models. However, the *relative* magnitude of contracting inefficiencies in response to conservation costs increases only in the 'hidden effort only' and 'hidden effort - hidden type' models. With 'hidden effort only’ the risk premia increase as opportunity costs of conservation rise. Thus, if opportunity costs are high the regulator needs to consider adjusting the incentive compatible contract design. For example, target levels of effort could be lowered, thus reducing the associated costs of conservation and the necessary risk premium. Alternatively, the regulator can invest in more informative signals and/ or increase monitoring frequency in order to improve the information about the firms' conservation behaviour, thus reducing the asymmetry of information.

The 'hidden effort - hidden type' model shows the same pattern of increasing agency costs as opportunity costs of conservation increase. This increase is due to (i) an increase in both types' risk premia, induced by a larger spread in the pay-off schedule to the agent (variability in the incentive schedule), and (ii) an ambiguous *net* increase in information rent to high conservation quality sites. While (i) is motivated similarly as in the 'hidden effort only' model, two general conclusions can be drawn with respect to the relationship between information rent and magnitude of conservation costs. Firstly, the difference in opportunity costs across type matters, as it influences the magnitude of the information rent. The more similar opportunity costs between types are, the lower the information rent to high conservation quality sites. Secondly, the information rent is unambiguously increasing in conservation costs only if increasing conservation costs on high conservation quality sites (d_h) outweigh the rent decreasing effects of higher conservation costs on low conservation quality sites (d_l). This implies that if site types are distinct enough in terms of their conservation costs and conservation costs are large, then the associated contracting inefficiencies must be expected to be high, and it might indeed be welfare improving to address the 'hidden effort - hidden type' problem through other means than incentive compatible contract design.

Additivity of Inefficiencies: External Effects between Hidden Effort and Hidden Type

Regarding the additivity of contracting inefficiencies when comparing the sum of the individual problems to the combined 'hidden effort - hidden type' problem, the analysis concludes that (i) the additivity of *individual* contracting inefficiencies is type dependent, (ii) the aggregate contracting inefficiencies depend on the proportion of type h sites, and (iii) the additivity of *aggregate* contracting inefficiencies in the 'hidden effort - hidden type' model depends on the magnitude of opportunity costs of conservation and their relative difference across types.

The examples show that inefficiencies with ‘hidden effort - hidden type’ are super-additive for *type l* sites, while they are sub-additive for *type h* sites. Additivity results from the interaction between the risk premia (determined by the spread of the pay-offs to the agents) and the information rent of *type h* sites.[33] Aggregate inefficiencies depend on the proportion of *type h* sites. In the base model, total expected transfers to both types are super-additive. However, the super - additivity of total expected transfers is decreasing in the proportion of *type h* sites. While the contracting inefficiencies are super-additive in the base scenario, they can become sub-additive at larger levels of opportunity costs.

If types are observable by the regulator, type proportions have relatively little impact on contract inefficiencies, which is contrasted by the observation that large proportions of *type h* drive up total expected contracting inefficiencies when types are unobservable. This is due to the rent extracted by these types and the larger associated risk

[33] 'Hidden effort only' and 'hidden effort - hidden type' differ fundamentally in the number of signals, with two and four observable signals, respectively. Simultaneous problems of 'hidden effort - hidden type' have an off-setting effect (are sub-additive) only if (i) the risk premium is lower than in the isolated ‘hidden effort model’ and the information rent is lower than in the isolated ‘hidden type model’, or (ii) a reduction in one offsets an increase in the other.

premium. Therefore, if the proportion of *type h* sites is large, it might be more efficient to treat all sites as *type h* sites and request a uniform conservation effort e_h on all sites. This effectively reduces the regulatory task to a hidden effort only problem. Requiring firms with low conservation value sites (*type l* sites) to expend effort levels the same effort level as high conservation value sites (e_h) imposes additional inefficiencies, but depending on the trade-off between the different effects, the policy alternative may still be welfare improving. Moreover, the smaller the proportion of site *types h* is, the more pronounced is the total super-additivity of informational inefficiencies. Consequently, if the proportion of high quality conservation sites is relatively small, then type separation via incentive compatible contracts is expensive and increasingly inefficient. In these cases, the regulator might want to revert to type screening in order to identify types before offering the contracts. Alternatively, he could re-adjust effort levels on *type l* sites downwards or to minimal levels such that $e_l = e_o$.

Monitoring Targets: Hidden Effort versus Hidden Type

The discussion clarifies that contracts, which deal with simultaneous problems of hidden effort and hidden type create inefficiencies, even though they induce the desired effort levels. The decision as to which problem to prioritize, and where to invest monitoring efforts (either *a priori* type identification or close supervision of conservation activities), depends on the specific circumstances. For the base specification of parameters 'hidden type only' creates larger inefficiencies than 'hidden effort only' regardless of the proportion of *type l* to *type h*. This suggests that type identification can play a crucial role in incentive compatible contract design, and that the regulator should pay close attention to the informational implications of the institutional arrangements when public good benefits are at stake. However, at higher levels of conservation costs, the analysis reveals that as conservation costs increase the 'hidden effort only' problem requires larger total expected transfers than the 'hidden type only' problem (see table 3). Under these circumstances the regulator should consider closer monitoring of conservation effort and to capture, as a windfall effect, additional information on site types. Alternatively, the regulator can require the firms to self-report on their conservation performance in combination with additional monitoring of conservation effort.

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Appendices

Appendix 1: 'Hidden Effort Only' Model: Optimality Conditions

The regulator solves the minimization problem separately for each type. Note that the parameters *n*, υ*(k)* and λ are suppressed.

Type l

$$\min_{t_0^l, t_z^l} \quad E[C^l(T^{he})] = \left\{\rho_{zl}^l t_z^l + (1-\rho_{zl}^l) t_0^l \right\} \qquad \text{Eq. A1-1}$$

s.t. PC-l

$$(1-\rho_{zl}^l)U[\pi_l + t_0^l] + \rho_{zl}^l U[\pi_l + t_z^l] = U[\pi_0]$$

ICC-l

$$(1-\rho_{zl}^l)U[\pi_l + t_0^l] + \rho_{zl}^l U[\pi_l + t_z^l] = (1-\rho_{z0}^l)U[\pi_0 + t_0^l] + \rho_{z0}^l U[\pi_0 + t_z^l]$$

with $\rho_{z0}^l = 0$ for simplification. Both constraints bind with equality for cost minimization.

The Lagrangian function is written as

$$L^l = \left\{\rho_{zl}^l t_z^l + \left(1-\rho_{zl}^l\right)t_0^l \right\} + \mu_1^l \left\{U[\pi_0] - \left(1-\rho_{z1}^l\right)U[\pi_l + t_0^l] - \rho_{zl}^l U[\pi_l + t_z^l]\right\} + \mu_2^l \left\{U[\pi_0 + t_0^l] - \left(1-\rho_{zl}^l\right)U[\pi_l + t_0^l] - \rho_{zl}^l U[\pi_l + t_z^l]\right\} \qquad \text{Eq. A1-2}$$

With U_{t_j} denoting marginal utilities, the first order conditions are:

$$\frac{\partial L^l}{\partial t_z^l} \Rightarrow \rho_{zl}^l - \mu_1^l \left\{\rho_l^l U_{t_z}[\pi_l + t_z^l]\right\} - \mu_2^l \left\{\rho_l^l U_{t_z}[\pi_l + t_z^l]\right\} = 0 \qquad \text{Eq. A1-3}$$

$$\frac{\partial L^l}{\partial t_0^l} \Rightarrow (1-\rho_{zl}^l) - \mu_1^l \left\{(1-\rho_{zl}^l)U_{t_0}[\pi_l + t_0^l]\right\} - \mu_2^l \left\{(1-\rho_{zl}^l)U_{t_o}[\pi_l + t_0^l] - U_{t_0}[\pi_0 + t_0^l]\right\} = 0 \qquad \text{Eq. A1-4}$$

$$\frac{\partial L}{\mu_1^l} \Rightarrow U[\pi_0] - (1-\rho_{zl}^l)U[\pi_l + t_0^l] - \rho_{zl}^l U[\pi_l + t_z^l] = 0 \qquad \text{Eq. A1-5}$$

$$\frac{\partial L}{\mu_2^l} \Rightarrow U[\pi_0 + t_0^l] - (1-\rho_{zl}^l)U[\pi_l + t_0^l] - \rho_{zl}^l U[\pi_l + t_z^l] = 0 \qquad \text{Eq. A1-6}$$

Combining equations 5 and 6 yields

$$U[\pi_0] = U[\pi_0 + t_0^l] \qquad \text{Eq. A1-7}$$

which implies $t_0^{l*} = 0$, thus yielding the optimality conditions for t_z^{l*} as

$$\rho_{zl}^l \left\{U[\pi_l + t_z^l] - U[\pi_l]\right\} = U[\pi_0] - U[\pi_l] \qquad \text{Eq. A1-8}$$

Type h

$$\min_{t_o^h, t_z^h} E[C^h(T^{he})] = \rho_{zh}^h t_z^h + \left(1-\rho_{zh}^h\right) t_0^h \qquad \text{Eq. A1-9}$$

s.t. PC-h $\rho_{zh}^h U[\pi_h + t_z^h] + \left(1-\rho_{zh}^h\right) U[\pi_h + t_0^h] = U[\pi_0]$

ICC-h $\rho_{zh}^h U[\pi_h + t_z^h] + \left(1-\rho_{zh}^h\right) U[\pi_h + t_0^h] = \rho_{zl}^h U[\pi_l + t_z^h] + \left(1-\rho_{zl}^h\right) U[\pi_l + t_0^h]$

The Lagrangian function is written as

$$L^h = \left\{\rho_{zh}^h t_z^h + (1-\rho_{zh}^h) t_0^h\right\} + \mu_1^h \left\{U[\pi_0] - (1-\rho_{zh}^h) U[\pi_h + t_0^h] - \rho_{zh}^h U[\pi_h + t_z^h]\right\} \qquad \text{Eq. A1-10}$$

$$+\mu_2^h \left\{ \begin{array}{l} (1-\rho_{zl}^h) U[\pi_l + t_0^h] + \rho_{zl}^h U[\pi_l + t_z^h] \\ \qquad -(1-\rho_{zh}^h) U[\pi_h + t_0^h] - \rho_{zh}^h U[\pi_h + t_z^h] \end{array} \right\}$$

The first order conditions are:

$$\frac{\partial L^h}{\partial t_z^h} \Rightarrow \rho_{zh}^h - \mu_1^h \left\{\rho_{zh}^h U_{t_z}[\pi_h + t_z^h]\right\} + \mu_2^h \left\{\rho_{zl}^h U_{t_z}[\pi_l + t_z^h] - \rho_{zh}^h U_{t_z}[\pi_h + t_z^h]\right\} = 0 \qquad \text{Eq. A1-11}$$

$$\frac{\partial L^h}{\partial t_0^h} \Rightarrow (1-\rho_{zh}^h) - \mu_1^h \left\{(1-\rho_{zh}^h) U_{t_o}[\pi_h + t_0^h]\right\}$$

$$+\mu_2^h \left\{(1-\rho_{zl}^h) U_{t_o}[\pi_l + t_0^h] - (1-\rho_{zh}^h) U_{t_o}[\pi_h + t_0^h]\right\} = 0 \qquad \text{Eq. A1-12}$$

$$\frac{\partial L^h}{\mu_1^h} \Rightarrow U[\pi_0] - (1-\rho_{zh}^h) U[\pi_h + t_0^h] - \rho_{zh}^h U[\pi_h + t_z^h] = 0 \qquad \text{Eq. A1-13}$$

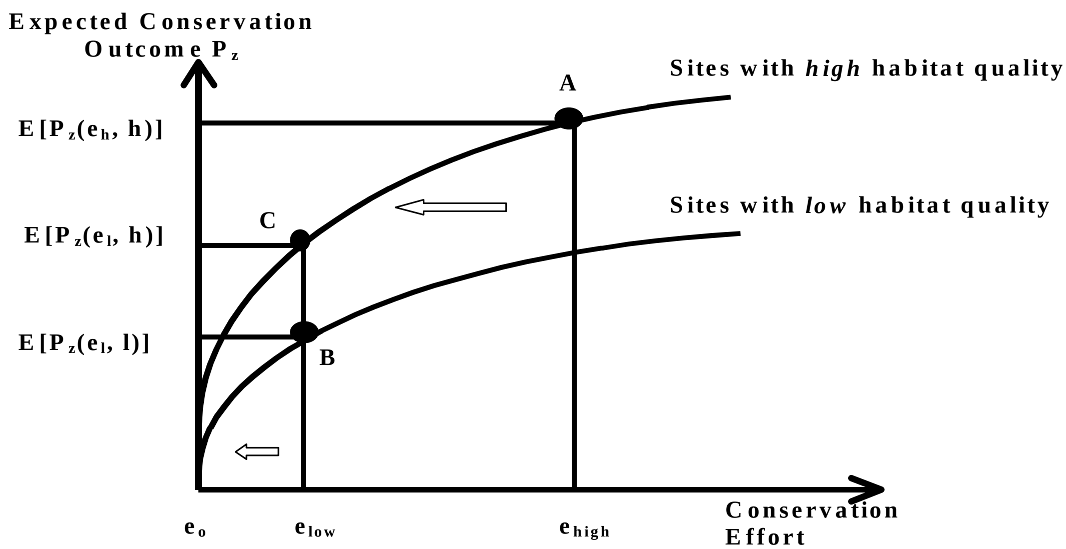
$$\frac{\partial L^h}{\mu_2^h} \Rightarrow (1-\rho_{zl}^h) U[\pi_l + t_0^h] + \rho_{zl}^h U[\pi_l + t_z^h] \qquad \text{Eq. A1-14}$$

$$-(1-\rho_{zh}^h) U[\pi_h + t_0^h] - \rho_{zh}^h U[\pi_h + t_z^h] = 0$$

Re-arranging, combining and simplifying equations 13 and 14 yields the following optimality conditions for the incentive schedule t_z^h; t_0^h for *type h*:

$$\rho_{zl}^h \left\{U[\pi_l + t_z^h] - U[\pi_l + t_0^h]\right\} = U[\pi_0] - U[\pi_l + t_0^h] \qquad \text{Eq. A1-15}$$

Appendix 2: ***The Incentive Problem with 'Hidden Effort -Hidden Type'***



The regulator wishes to induce efficeint effort levels taken by the respective types through contracts reflected in point A and B. *Type h*, however, has an incentive to move to point C, as this will yield systematically higher expected conservation performaces, thus granting an information rent.

Appendix 3: Proof of Proposition 1

Proposition 1: *If type differences of resource sties are specified under the assumptions that* $\rho^l{}_{zl} < \rho^h{}_{zl}$ *and* $(\rho^l_{zh} - \rho^l_{zl}) < (\rho^h_{zh} - \rho^h_{zl})$, *then*

(a) ICC-b of site type h is binding,

(b) ICC-a of both type l and h are slack,

(c) PC of site type l is binding and PC of site type h is slack.

Proof:

Assumptions

For substantial simplification of the analysis, assume risk neutral firms. Again, we assume $\rho^k{}_{z0} = 0$. The regulator wishes to induce effort levels e_l and e_h on site types *1* and *h*, respectively, at least social cost. With risk neutrality, which implies $U[\pi_i + t_j] = [\pi_i + t_j]$, the minimization is fully written as:

$$\min_{t_0,\, t_z} E[T^{he/ht}] = [\rho^l_{zl} t_z + (1-\rho^l_{zl}) t_0] + [\rho^h_{zh} t_z + (1-\rho^h_{zh}) t_0]$$

s. t. type l *PC-l* $(1-\rho^l_{zl})[\pi_l + t_0] + \rho^l_{zl}[\pi_l + t_z] \geq \pi_0$

ICC-l a $(1-\rho^l_{zl})[\pi_l + t_0] + \rho^l_{zl}[\pi_l + t_z] \geq [\pi_0 + t_0]$

ICC-l b $(1-\rho^l_{zl})[\pi_l + t_0] + \rho^l_{zl}[\pi_l + t_z] \geq$

$$(1-\rho^l_{zh})[\pi_h + t_0] + \rho^l_{zh}[\pi_h + t_z]$$

type h *PC-h* $(1-\rho^h_{zh})[\pi_h + t_0] + \rho^h_{zh}[\pi_h + t_z] \geq \pi_0$

ICC-h a $(1-\rho^h_{zh})[\pi_h + t_0] + \rho^h_{zh}[\pi_h + t_z] \geq [\pi_0 + t_0]$

ICC-h b $(1-\rho^h_{zh})[\pi_h + t_0] + \rho^h_{zh}[\pi_h + t_z] \geq$

$$(1-\rho^h_{zl})[\pi_l + t_0] + \rho^h_{zl}[\pi_l + t_z]$$

Re-writing yields some simplification:

$$\min_{t_0,\, t_z} E[T^{he/ht}] = [\rho^l_{zl}\, t_z + (1-\rho^l_{zl})\, t_0] + [\rho^h_{zh}\, t_z + (1-\rho^h_{zh})\, t_0] \qquad \text{Eq. A3-1}$$

s. t. *type l* *PC-l* $\pi_l + t_0 + \rho^l_{zl}(t_z - t_0) \geq \pi_0$ Eq. A3-2

ICC- la $\pi_l + t_0 + \rho^l_{zl}(t_z - t_0) \geq \pi_0 + t_0$ Eq. A3-3

ICC- lb $\pi_l + t_0 + \rho^l_{zl}(t_z - t_0) \geq \pi_h + t_0 + \rho^l_{zh}(t_z - t_0)$ Eq. A3-4

type h *PC-h* $\pi_h + t_0 + \rho^h_{zh}(t_z - t_0) \geq \pi_0$ Eq. A3-5

ICC-h a $\pi_h + t_0 + \rho^h_{zh}(t_z - t_0) \geq \pi_0 + t_0$ Eq. A3-6

ICC-h b $\pi_h + t_0 + \rho^h_{zh}(t_z - t_0) \geq \pi_l + t_0 + \rho^h_{zl}(t_z - t_0)$ Eq. A3-7

The following analysis will determine binding and non-binding constraints.

Incentive Compatibility Constraints

ICC-b

Assuming risk-neutral firms, and re-arranging both constraints yields

ICC-b l $\pi_l - \pi_h = d_h - d_l \geq (\rho^l_{zh} - \rho^l_{zl})[t_z - t_0]$ Eq. A3-8

ICC-b h $\pi_l - \pi_h = d_h - d_l \leq (\rho^h_{zh} - \rho^h_{zl})[t_z - t_0]$ Eq. A3-9

which implies

$$(\rho^l_{zh} - \rho^l_{zl})[t_z - t_0] \leq d_h - d_l \leq (\rho^h_{zh} - \rho^h_{zl})[t_z - t_0] \qquad \text{Eq. A3-10}$$

Given $(\rho^l_{zh} - \rho^l_{zl}) < (\rho^h_{zh} - \rho^h_{zl})$ there exist two possibilities for satisfying this condition:

(a) the incentive compatibility constraints are slack for both types;

(b) the incentive compatibility constraints are binding for *type h* sites, while they are slack for *type l* sites

Allowing both constraints to be slack implies that both site types receive an expected payment higher than necessary to induce efficient effort choices. As the regulator seeks to minimize program costs, however, one of the constraints will be binding as strict equality. Thus, the payment schedule is driven as low as possible, which suggests that *type h*'s incentive compatibility constraint binds with equality, leaving ICC-b for *type l* slack.

$$(\rho_{zh}^{l}-\rho_{zl}^{l})[t_z-t_0]<d_h-d_l=(\rho_{zh}^{h}-\rho_{zl}^{h})[t_z-t_0] \quad \text{Eq. A3-11}$$

It follows

ICC-l b
$$\frac{d_h-d_l}{(\rho_{zh}^{l}-\rho_{zl}^{1})}>\left(t_z-t_0\right) \quad \text{Eq. A3-12}$$

and *ICC-h b*
$$\frac{d_h-d_l}{(\rho_{zh}^{h}-\rho_{zl}^{h})}=\left(t_z-t_0\right) \quad \text{Eq. A3-13}$$

ICC-a

Type h:

Consider the constraint for t*ype h* first (Eq. A5-6). Re-arranging yields

$$(t_z-t_0)\geq\frac{\mathrm{d_h}}{\rho_{zh}^{h}-\rho_{z0}^{h}} \quad \text{Eq. A3-14}$$

Combining with Eq. A5-13 yields

$$\frac{\rho_{zh}^{h}-\rho_{z0}^{h}}{\rho_{zh}^{h}-\rho_{zl}^{h}}\geq\frac{\mathrm{d_h}}{\mathrm{d_h}-\mathrm{d_l}} \quad \text{Eq. A3-15}$$

and
$$\frac{(\rho_{zh}^{h}-\rho_{z0}^{h})}{(\rho_{zh}^{h}-\rho_{zl}^{h})}\frac{P_z}{P_z}\geq\frac{\mathrm{d_h}-\mathrm{d_0}}{\mathrm{d_h}-\mathrm{d_l}} \quad \text{Eq. A3-16}$$

This allows for a familiar interpretation of the inequality. The concavity assumption on the expected conservation performance implies that the weak inequality can hold as a strict inequality only. Thus, if *ICC-b h* is binding with strict equality then *ICC-a h* is slack.

Type l:

Consider (Eq. A3-3). Re-arranging yields

$$(t_z - t_0) \geq \frac{d_l}{\rho^l_{zl} - \rho^l_{z0}} \qquad \text{Eq. A3-17}$$

Combining with equation A3-13 yields

$$\frac{\rho^l_{zl} - \rho^l_{z0}}{\rho^h_{zh} - \rho^h_{zl}} \geq \frac{d_l}{d_h - d_l} \qquad \text{Eq. A3-18}$$

Again, given the concavity assumption of the expected conservation performance, this weak inequality holds as a strict inequality. This implies that the constraints *ICC-a* for both types *l* and *h* must be slack, given the assumptions $\rho^l_{zl} < \rho^h_{zh}$ and $(\rho^l_{zh} - \rho^l_{zl}) < (\rho^h_{zh} - \rho^h_{zl})$. This proves parts (a) and (b) of *proposition 1*.

Participation Constraints

***Type l*:**

Re-arranging *type l*'s participation constraint yields

$$(t_z - t_0) \geq \frac{(d_l - t_o)}{\rho^l_{zl}} \qquad \text{Eq. A3-19}$$

Combining with Eq. A3-13 yields $\frac{(d_h - d_l)}{(\rho^h_{zh} - \rho^h_{zl})} \geq \frac{d_l - t_0}{\rho^l_{zl}}$

and

$$t_0 \geq d_l - \frac{\rho^l_{zl}}{(\rho^h_{zh} - \rho^h_{zl})}(d_h - d_l) \qquad \text{Eq. A3-20}$$

***Type h*:**

Re-arranging type *h*'s participation constraint gives

$$(t_z - t_0) \geq \frac{(d_h - t_0)}{\rho^h_{zh}} \qquad \text{Eq. A3-21}$$

Combining with Eq. A3-13 yields

$$\frac{(d_h - d_l)}{(\rho_{zh}^h - \rho_{zl}^h)} \geq \frac{d_h - t_0}{\rho_{zh}^h} \qquad \text{and} \qquad t_0 \geq d_h - \frac{\rho_{zh}^h}{\left(\rho_{zh}^h - \rho_{zl}^h\right)}\left(d_h - d_l\right) \quad \text{Eq. A3-22}$$

Cost minimization implies that at least one of the participation constraints is binding. Consider three possible cases

(i) Eq. 20 is binding and A 5-3 Eq. 22 is slack. It follows:

$$d_l - \frac{\rho_{zl}^l}{(\rho_{zh}^h - \rho_{zl}^h)}(d_h - d_l) > d_h - \frac{\rho_{zh}^h}{\left(\rho_{zh}^h - \rho_{zl}^h\right)}\left(d_h - d_l\right)$$

which implies

$$-\frac{\left(d_h - d_l\right)}{\left(d_h - d_l\right)} > -\frac{\left(\rho_{zh}^h - \rho_{zl}^l\right)}{\left(\rho_{zh}^h - \rho_{zl}^h\right)} \quad \text{and} \quad \left(\rho_{zh}^h - \rho_{zl}^h\right) < \left(\rho_{zh}^h - \rho_{zl}^l\right) \qquad \text{Eq. A3-23}$$

such that $\rho_{zl}^l < \rho_{zl}^h$, as assumed at the outset.

(ii) Eq. 20 is slack and A 5-3 Eq. 22 is binding. It follows:

$$d_l - \left(d_h - d_l\right)\frac{\rho_{zl}^l}{\left(\rho_{zh}^h - \rho_{zh}^h\right)} > d_h - \left(d_h - d_l\right)\frac{\rho_{zh}^h}{\left(\rho_{zh}^h - \rho_{zl}^h\right)} \qquad \text{Eq. A3-24}$$

which implies $\rho_{zl}^l > \rho_{zl}^h$, which is inconsistent with the initial assumption.

(iii) Both, Eq. 20 and Eq. 22 are binding. This implies:

$$d_l - \frac{\rho_{zl}^l}{(\rho_{zh}^h - \rho_{zl}^h)}(d_h - d_l) = d_h - \frac{\rho_{zh}^h}{(\rho_{zh}^h - \rho_{zl}^h)}(d_h - d_l) \qquad \text{Eq. A3-25}$$

and $\rho_{zh}^h - \rho_{zl}^l = \rho_{zh}^h - \rho_{zl}^h$ which *inconsistent* with the initial assumption $\rho_{zl}^l < \rho_{zl}^h$.

This proves part (c) of *proposition 1*.

Appendix 4: Derivation of the Optimal Incentive Schedule for 'Hidden Effort - Hidden Type' with Risk-Neutral Firms

Based on *proposition 1*, the participation constraint of *type l* site (*PC-l*) and the second incentive compatibility constraint of *type h* (*ICCb-h*) site bind with equality, while *ICCa* are slack for both types. With risk-neutrality of the firms the utility function is written as $U[\pi_i + t_j] = [\pi_i + t_j]$. The regulator solves the following minimization problem, where the parameters *n*, υ*(k)* and λ are suppressed:

$$\min_{t_o, t_z} \upsilon^h \left(\rho^h_{zh} t_z + \left(1 - \rho^h_{zh}\right) t_0\right) + \upsilon^l \left(\left(1 - \rho^l_{z1}\right) t_0 + \rho^l_{zl} t_z\right)$$

s. t. PC *type l* $$(1 - \rho^l_{z1})[\pi_l + t_0] + \rho^l_{zl}[\pi_l + t_z] = \pi_0 \qquad \text{Eq. A4-1}$$

ICCb *type h*

$$(1 - \rho^h_{zh})[\pi_h + t_0] + \rho^h_{zh}[\pi_h + t_z] = (1 - \rho^h_{zl})[\pi_l + t_0] + \rho^h_{zl}[\pi_l + t_z]$$

The Lagrangian function is written as

$$\begin{aligned} L \;=\; & \upsilon^l \left\{\rho^l_{zl} t_z + \left(1 - \rho^l_{zl}\right) t_0\right\} + \upsilon^h \left\{\rho^h_{zh} t_z + \left(1 - \rho^h_{zh}\right) t_0\right\} \\ & + \mu_1 \left\{\pi_0 - \pi_l - t_0 - \rho^l_{zl}\left(t_z - t_0\right)\right\} + \mu_2 \left\{\left(\pi_l - \pi_h\right) - \left(t_z - t_0\right)\left(\rho^h_{zh} - \rho^h_{zl}\right)\right\} \end{aligned} \qquad \text{Eq. A4-2}$$

The first order conditions are:

$$\frac{\partial L}{\partial t_z} \Rightarrow \left(\upsilon^l \rho^l_{zl} + \upsilon^h \rho^h_{zh}\right) - \mu_1 \left\{\rho^l_{zl}\right\} - \mu_2 \left\{\rho^h_{zh} - \rho^h_{zl}\right\} = 0 \qquad \text{Eq. A4-3}$$

$$\frac{\partial L}{\partial t_0} \Rightarrow \upsilon^l \left(1 - \rho^l_{zl}\right) + \upsilon^h \left(1 - \rho^h_{zh}\right) - \mu_1 \left\{1 - \rho^l_{zl}\right\} + \mu_2 \left\{\rho^h_{zh} - \rho^h_{zl}\right\} = 0 \qquad \text{Eq. A4-4}$$

$$\frac{\partial L}{\partial \mu_1} \Rightarrow \pi_0 - \pi_l - t_0 - \rho^l_{zl}\left(t_z - t_0\right) = 0 \qquad \text{Eq. A4-5}$$

$$\frac{\partial L}{\partial \mu_2} \Rightarrow \left(\pi_l - \pi_h\right) - \left(\rho^h_{zh} - \rho^h_{zl}\right)\left(t_z - t_0\right) = 0 \qquad \text{Eq. A4-6}$$

with $\pi_0 - \pi_1 = d_1$ and $\pi_0 - \pi_2 = d_2$.

Combining (5) and (6) and substituting back yields:

$$t_0^* = d_l - (d_h - d_l)\frac{\rho_{zl}^l}{(\rho_{zh}^h - \rho_{zl}^h)}$$ Eq. A4-7

$$t_z^* = d_l + (d_h - d_l)\frac{(1-\rho_{zl}^l)}{(\rho_{zh}^h - \rho_{zl}^h)}$$ Eq. A4-8

Total Expected Compensation

Type l:

$$E^l[T] = \rho_{zl}^l \, t_z^* + (1 - \rho_{zl}^l)\, t_0^*$$

$$E^l[T] = \rho_{zl}^l \left\{ d_l + (1-\rho_{zl}^l)\frac{(d_h - d_l)}{(\rho_{zh}^h - \rho_{zl}^h)} \right\} + (1-\rho_{zl}^l)\left\{ d_l - \rho_{zl}^l \frac{(d_h - d_l)}{(\rho_{zh}^h - \rho_{zl}^h)} \right\}$$

which simplifies to $E^l[T] = d_l$ Eq. A4-9

Type h:

$$E^h[T] = \rho_{zh}^h t_z^* + (1-\rho_{zh}^h) t_0^*$$

$$E^h[T] = \rho_{zh}^h \left\{ d_l + (1-\rho_{zl}^l)\frac{(d_h - d_l)}{(\rho_{zh}^h - \rho_{zl}^h)} \right\} + (1-\rho_{zh}^h)\left\{ d_l - \rho_{zl}^l \frac{(d_h - d_l)}{(\rho_{zh}^h - \rho_{zl}^h)} \right\}$$

which simplifies to

$$E^h[T] = d_l + (d_h - d_l)\frac{(\rho_{zh}^h - \rho_{zl}^l)}{(\rho_{zh}^h - \rho_{zl}^h)}$$ Eq. A4-10

We can isolate the expected information rent by

$$E^h[I] = d_l + (d_h - d_l)\frac{(\rho_{zh}^h - \rho_{zl}^l)}{(\rho_{zh}^h - \rho_{zl}^h)} - d_h$$

which gives $$E^h[I] = (d_h - d_l)\frac{(\rho_{zl}^h - \rho_{zl}^l)}{(\rho_{zh}^h - \rho_{zl}^h)}$$ Eq. A4-11

Notice that if firms with site *type h* chose to take effort level e_l, the expected payment would be

$$E^h[T(e_l)] = \rho_{zl}^h\left\{d_l + \left(1-\rho_{zl}^l\right)\frac{(d_h - d_l)}{\left(\rho_{zh}^h - \rho_{zl}^h\right)}\right\} + (1-\rho_{zl}^h)\left\{d_l - \rho_{zl}^l\frac{(d_h - d_l)}{\left(\rho_{zh}^h - \rho_{zl}^h\right)}\right\}$$

$$E^h[T(e_l)] = d_l + (d_h - d_l)\frac{\left(\rho_{zl}^h - \rho_{zl}^l\right)}{\left(\rho_{zh}^h - \rho_{zl}^h\right)} \qquad \text{Eq. A4-12}$$

Comparing equations 10 and 12, it follows that the specification of the incentive scheme does not provide incentives for type to take effort e_l, since by assumption $\rho^h{}_{zh} > \rho^h{}_{zl}$.

Appendix 5: Proof of Proposition 2

<u>Proposition 2:</u>

In the hidden effort model, the program costs of type specific incentive compatible conservation contracts are increasing in their respective conservation costs, d_l and d_h. That is

$$\left.\frac{\partial L^{l*}}{\partial d_l}\right|_{t_z^{l*}(d_l)} > 0 \qquad \text{and} \qquad \left.\frac{\partial L^{h*}}{\partial d_h}\right|_{t_0^{l*},\, t_z^{l*}} > 0$$

This implies that total expected program costs are increasing in individual conservation costs.

<u>Proof</u>:

Type l

The Lagrangean function for *type l* at the optimal solution for t^{l*}_z, t^{l*}_o is written as:

$$\begin{aligned} L^{l*}\Big|_{t_z^*} = {} & \left\{\rho_{zl}^l\, t_z^{l*}\right\} \\ & + \mu_1^l \left\{U[\pi_0] - \left(1-\rho_{z1}^l\right)U[\pi_l + t_o] - \rho_{zl}^l\, U[\pi_l + t_z^{l*}]\right\} \\ & + \mu_2^l \left\{U[\pi_0] - \left(1-\rho_{zl}^l\right)U[\pi_l + t_o] - \rho_{zl}^l\, U[\pi_l + t_z^{l*}]\right\} \end{aligned} \qquad \text{Eq. A5-26}$$

Applying th envelop theorem and differentiating w.r.t d_l yields:

$$\left.\frac{\partial L^{l*}}{\partial d_l}\right|_{t_z^{l*}(d_l)} = \left(\mu_1^l + \mu_2^l\right)\left\{-\left(1-\rho_{z1}^l\right)U'[\pi_l](-1) - \rho_{zl}^l\, U'[\pi_l + t_z^*](-1)\right\}$$

$$\left.\frac{\partial L^{l*}}{\partial d_l}\right|_{t_z^{l*}(d_l)} = \left(\mu_1^l + \mu_2^l\right)\left\{\left(1-\rho_{z1}^l\right)U'[\pi_l] + \rho_{zl}^l\, U'[\pi_l + t_z]\right\} \qquad \text{Eq. A5-27}$$

where we notice that $\pi_l = \pi_o - d_l$

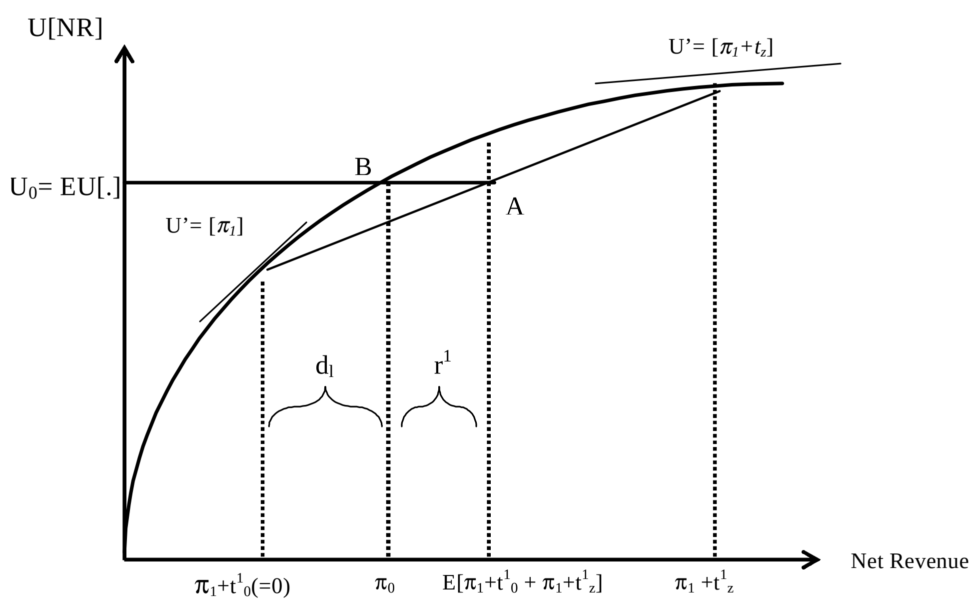
for $\left.\frac{\partial L^{l*}}{\partial d_l}\right|_{t_z^{l*}(d_l)} > 0$, it must hold

$$\left\{(1-\rho_{z1}^{l})U'[\pi_l] + \rho_{zl}^{l} U'[\pi_l + t_z^{l*}]\right\} > 0$$

and $$U'[\pi_l] > \rho_{z1}^{l}\left(U'[\pi_l] - U'[\pi_l + t_z]\right) \quad \text{Eq. A5-28}$$

which is true, since $\rho_{z1}^{l} < 1$ and $U'[\pi_l] > U'[\pi_l + t_z]$ for any concave expected utility function (see figure).

Figure A5-1: Payoff Schedule and Marginal Utilities



Type h

The Lagrangean function for *type h* at the optimal solution for $[t_z^h, t_0^h]$ is written as:

$$L^{h*} = (1-\rho_{zh}^{h})t_o^{h*} + \rho_{zh}^{h} t_z^{h*}$$

$$+\mu_1^h \{U[\pi_o] - (1-\rho_{zh}^{h})U[\pi_h + t_o^{h*}] - \rho_{zh}^{h} U[\pi_h + t_z^{h*}]\} \quad \text{Eq. A5-29}$$

$$+\mu_2^h \left\{ \begin{matrix} (1-\rho_{zl}^{h})U[\pi_l + t_o^{l*}] + \rho_{zl}^{h} U[\pi_l + t_z^{l*}] \\ -(1-\rho_{zh}^{h})U[\pi_h + t_o^{h*}] - \rho_{zh}^{h} U[\pi_h + t_z^{h*}] \end{matrix} \right\}$$

where $\pi_h = \pi_o - d_h$,

Differentiating w.r.t d_h yields:

$$\left.\frac{\partial L^{h*}}{\partial d_h}\right|_{t_z^{h*}(d_h)} = \mu_1^h \{-(1-\rho_{zh}^{h})U'[\pi_h + t_o^{h*}](-1) - \rho_{zh}^{h} U'[\pi_h + t_z^{h*}](-1)\}$$

$$+\mu_2^h \{-(1-\rho_{zh}^{h})U'[\pi_h + t_o^{h*}](-1) - \rho_{zh}^{h} U'[\pi_h + t_z^{h*}](-1)\} \quad \text{Eq. A5-30}$$

$$\left.\frac{\partial L^{h*}}{\partial d_h}\right|_{t_z^{h*}(d_h)} = (\mu_1^h + \mu_2^h)\{(1-\rho_{zh}^{h})U'[\pi_h + t_o^{h*}] + \rho_{zh}^{h} U'[\pi_h + t_z^{h*}]\} \quad \text{Eq. A5-31}$$

since $\left.\frac{\partial \pi_l}{\partial d_h}\right|_{t_z^{d*}(d_h)} = 0$

for $\left.\frac{\partial L^{h*}}{\partial d_h}\right|_{t_z^{d*}(d_h)} > 0$ it must hold

$$(1-\rho_{zh}^{h})U'[\pi_h + t_o^{h*}] + \rho_{zh}^{h} U'[\pi_h + t_z^{h*}] > 0$$ Eq. A5-32

and

$$U'[\pi_h + t_o^{h*}] > \left(\rho_{zh}^{h}\left(U'[\pi_h + t_o^{h*}] - U'[\pi_h + t_z^{h*}]\right)\right)$$ Eq. A5-33

which is true since $\rho_{zh}^{h} < 1$ and $U'[\pi_h + t_o^{h*}] > U'[\pi_h + t_z^{h*}]$ for any concave expected utility function.

Appendix 6: Proof of Proposition 3

<u>Proposition 3:</u>

With hidden effort and hidden type, the information rent to types h *sites is increasing in conservation costs of* type h *sites, d_h, but decreasing in conservation costs of* type l *sites, d_l.*

$$\left.\frac{\partial E^h[I]}{\partial d_h}\right|_{t_0^*,t_0^*} > 0 \qquad \text{and} \qquad \left.\frac{\partial E^h[I]}{\partial d_l}\right|_{t_0^*,t_0^*} < 0$$

<u>Proof:</u>

At the optimal compensation schedule, $[t_0^*, t_z^*]$, the expected information rent granted to *type h* sites is represented by

$$E^h[I] = (d_h - d_l)\frac{(\rho_{zl}^h - \rho_{zl}^l)}{(\rho_{zh}^h - \rho_{zl}^h)} \qquad \text{Eq. A6-34}$$

Differentiating with respect to d_h yields

$$\left.\frac{\partial E^h[I]}{\partial d_h}\right|_{t_0^*,t_z^*} = \frac{(\rho_{zl}^h - \rho_{zl}^l)}{(\rho_{zh}^h - \rho_{zl}^h)} > 0 \qquad \text{Eq. A6-35}$$

Likewise, differentiating Eq. A7-3 with respect to d_l yields

$$\left.\frac{\partial E^h[I]}{\partial d_l}\right|_{t_0^*,t_z^*} = -\frac{(\rho_{zl}^h - \rho_{zl}^l)}{(\rho_{zh}^h - \rho_{zl}^h)} < 0 \qquad \text{Eq. A6-36}$$

Appendix 7: Proof of Proposition 4

<u>Proposition 4:</u>

With hidden effort and hidden type, the information rent to types h *sites is increasing in type h's conditional probability of producing signal P_z, when taking effort level e_l, i.e:*

$$\left.\frac{\partial E^h[I]}{\partial \rho_{zl}^h}\right|_{t_0^*,t_0^*} > 0 \qquad \text{Eq. A7-37}$$

<u>Proof:</u>

At the optimal compensation schedule, $[t_0^*, t_z^*]$, the expected information rent granted to *type h* sites is represented by

$$E^h[I] = (d_h - d_l)\frac{(\rho_{zl}^h - \rho_{zl}^l)}{(\rho_{zh}^h - \rho_{zl}^h)} \qquad \text{Eq. A7-38}$$

Differentiating this identity with respect to $\rho^h{}_{zl}$ yields

$$\left.\frac{\partial E^h[I]}{\partial \rho_{zl}^h}\right|_{t_0^*,t_z^*} = (d_h - d_l)\left\{\frac{(1)}{(\rho_{zh}^h - \rho_{zl}^h)} + \frac{(\rho_{zl}^h - \rho_{zl}^l)}{(\rho_{zh}^h - \rho_{zl}^h)^2}\right\} \qquad \text{Eq. A7-39}$$

which simplifies to

$$\left.\frac{\partial E^h[I]}{\partial \rho_{zl}^h}\right|_{t_0^*,t_z^*} = (d_h - d_l)\frac{(\rho_{zh}^h - \rho_{zl}^l)}{(\rho_{zh}^h - \rho_{zl}^h)^2} > 0 \qquad \text{Eq. A7-40}$$

Differentiating Eq. A9-2 with respect to $\rho^l{}_{zl}$ yields

$$\left.\frac{\partial E^h[I]}{\partial \rho_{zl}^l}\right|_{t_0^*,t_z^*} = (d_h - d_l)\frac{-1}{(\rho_{zh}^h - \rho_{zl}^h)} < 0 \qquad \text{Eq. A7-41}$$

Differentiating Eq. A9-2 with respect to $\rho^h{}_{zh}$ yields

$$\left.\frac{\partial E^h[I]}{\partial \rho_{zh}^h}\right|_{t_0^*,t_z^*} = (d_h - d_l)\frac{(\rho_{zl}^h - \rho_{zl}^l)}{(\rho_{zh}^h - \rho_{zl}^h)^2}(-1) < 0 \qquad \text{Eq. A7-42}$$

Appendix 8: Numerical Specification of the Program Cost Minimization Problem

Hidden Effort Only

type l

$$\min_{t_o^l, t_z^l} \; 0.80 * t_o^l + 0.20 * t_z^l$$

s.t.

$$0.80 * [900 + t_o^l]^{0.7} + 0.20 * [900 + t_z^l]^{0.7} \geq [1000]^{0.7}$$

$$0.80 * [900 + t_o^l]^{0.7} + 0.20 * [900 + t_z^l]^{0.7} \geq 1.00 * [1000 + t_o^l]^{0.7} + 0.00 * [1000 + t_z^l]^{0.7}$$

$$0.80 * [900 + t_o^l]^{0.7} + 0.20 * [900 + t_z^l]^{0.7} \geq 0.65 * [700 + t_o^l]^{0.7} + 0.35 * [700 + t_z^l]^{0.7}$$

$$t_o^l \geq -700 \quad \text{and} \quad t_z^l \geq -700$$

type h

$$\min_{t_o^h, t_z^h} \; 0.50 * t_o^h + 0.50 * t_z^h$$

s.t.

$$0.50 * [700 + t_o^h]^{0.7} + 0.50 * [700 + t_z^h]^{0.7} \geq [1000]^{0.7}$$

$$0.50 * [700 + t_o^h]^{0.7} + 0.50 * [700 + t_z^h]^{0.7} \geq 1.00 * [1000 + t_o^h]^{0.7} + 0.00 * [1000 + t_z^h]^{0.7}$$

$$0.50 * [700 + t_o^h]^{0.7} + 0.50 * [700 + t_z^h]^{0.7} \geq 0.70 * [900 + t_o^h]^{0.7} + 0.30 * [900 + t_z^h]^{0.7}$$

$$t_o^h \geq -700 \quad \text{and} \quad t_z^h \geq -700$$

Cost Minimization Program for all Information Scenarios

				Hidden Effort		**Hidden Type**		**Hidden Effort-Hidden Type**	
				type l	*type h*	*type l*	*type h*	*type l*	*type h*
	min								
	Expected Transfers			**105.96**	**343.38**	**250.00**		**279.55**	
	incentive		t0	0.00	-188.31	-100.00		-89.41	
	schedule		tz	529.82	875.07	900.00		964.76	
s.t.	**constraints**								
PC1	EU(e1)	>,=	U(eo)	0.00		0.00		0.00	
ICC1a	EU(e1)	>,=	EU(eo)	0.00		100.00		7.99	
ICC1b	EU(e1)	>,=	EU(e2)	11.21		50.00		5.01	
PC2	EU(e2)	>,=	U(eo)		0.00		100.00		8.60
ICC2a	EU(e2)	>,=	EU(eo)		17.11		200.00		16.59
ICC2b	EU(e2)	>,=	EU(e1)		0.00		0.00		0.00
to >,=				-700.00	-700.00	-700.00		-700.00	
tz >.=				-700.00	-700.00	-700.00		-700.00	
Exp. Utility				125.89	125.89	1000.00	1100.00	125.89	134.50
Expected transfer						100.00	400.00	121.42	437.67

Software: Excel - Solver

Appendix 9: Decomposition of Expected Transfer to Type h Sites

The expected transfer convolutes the risk premium with *type h*'s information rent. Isolating *type h*'s risk premium and information rent from the expected transfer requires comparison of the two information scenarios in terms of their certainty equivalent (CE) at the reservation utility level (U_o = 125.90). In the case of the *hidden effort* - *hidden type* problem, the certainty equivalent of *type h* is the expected value necessary to satisfy the reservation constraint (certainty), *given* the optimal incentive schedule [-89.41; 964.76]. Therefore, calculating the certainty equivalent requires calculating the weights of the respective outcomes, ρ, as an auxiliary variable. Thus,

$$U_o = 125.90 = \rho\ [700 - 89.41]^{0.7} + (1-\rho)\ [700 + 964.76]^{0.7} = \rho\ [89\ 10] + (1-\rho)[179.90]^{0.7}\ .$$

Solving for ρ yields $\rho = 0.59$, which in turn yields: $CE[89.41; 964.76] = 1042.80$

The following table summarizes the results. Comparing *hidden effort* - *hidden type* and *hidden effort* only, CE is actually slightly smaller for the first than the latter ($units 1042.80 compared to $units 1043.40). The risk premium for *type h* is calculated as the difference between the reservation profits ($units 1000) and the calculated certainty equivalents and results in $units 42.80 for *HE/ HT* compared to $units 43.40 for *hidden effort* only. The information rent extracted by *type h* is equivalent to an expected payment over and above costs of expected transfer minus risk premium = $units 94.90.

Table A9-1: Comparison between Hidden Effort and Hidden Effort/ Hidden Type

	type-h	
	HE	**HE/HT**
Expected Compensation	343.40	437.70
t0	-188.30	-89.40
tz	875.10	964.80
net revenue [profit (e2)+t0]	511.70	610.60
net revenue [profit (e2)+tz]	1575.10	1664.80
Expected Utility	125.90	134.50
Certainty Equivalent at Uo=125.90	**1043.40**	**1042.80**
Decomposition total Exp. Transfer	**0.00**	**0.00**
Conserv. Cost taking e2 (dh)	300.00	300.00
Risk Premium	**43.40**	**42.80**
Info Rent	0.00	**94.90**

Appendix 10: Response of Information Rent to Changes in Conservation Costs

	Change in conservation costs of type l (d_l)									
	Base	+10%	+15%	+20%	+25%	+30%	+35%	+40%	+45%	+50%
CC type l	100	**110.00**	**115.00**	**120.00**	**125.00**	**130.00**	**135.00**	**140.00**	**145.00**	**150.00**
CC type h	300	300	300	300	300	300	300	300	300	300
Total Exp. Transfers	**250.00**	**252.50**	**253.75**	**255.00**	**256.25**	**257.50**	**258.75**	**260.00**	**261.25**	**262.50**
to	-100.00	-80.00	-70.00	-60.00	-50.00	-40.00	-30.00	-20.00	-10.00	0.00
tz	900.00	870.00	855.00	840.00	825.00	810.00	795.00	780.00	765.00	750.00
Exp.Transfer l	100.00	110.00	115.00	120.00	125.00	130.00	135.00	140.00	145.00	150.00
Exp.Transfer h	400.00	395.00	392.50	390.00	387.50	385.00	382.50	380.00	377.50	375.00
Exp. Rent type h	**100.00**	**95.00**	**92.50**	**90.00**	**87.50**	**85.00**	**82.50**	**80.00**	**77.50**	**75.00**
%	**33%**	**32%**	**31%**	**30%**	**29%**	**28%**	**28%**	**27%**	**26%**	**25%**

	Change in conservation costs of type h (d_h)									
	Base	+10%	+15%	+20%	+25%	+30%	+35%	+40%	+45%	+50%
CC type l	100	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00
CC type h	300	**330.00**	**345.00**	**360.00**	**375.00**	**390.00**	**405.00**	**420.00**	**435.00**	**450.00**
Total Exp. Transfers	**250.00**	**272.50**	**283.75**	**295.00**	**306.25**	**317.50**	**328.75**	**340.00**	**351.25**	**362.50**
to	-100.00	-130.00	-145.00	-160.00	-175.00	-190.00	-205.00	-220.00	-235.00	-250.00
tz	900.00	1020.00	1080.00	1140.00	1200.00	1260.00	1320.00	1380.00	1440.00	1500.00
Variability	1000.00	1150.00	1225.00	1300.00	1375.00	1450.00	1525.00	1600.00	1675.00	1750.00
Exp.Trans l	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00
Exp.Trans h	400.00	445.00	467.50	490.00	512.50	535.00	557.50	580.00	602.50	625.00
Exp. Rent type h	**100.00**	**115.00**	**122.50**	**130.00**	**137.50**	**145.00**	**152.50**	**160.00**	**167.50**	**175.00**
%	**33%**	**35%**	**36%**	**36%**	**37%**	**37%**	**38%**	**38%**	**39%**	**39%**