Time Inconsistent Resource Conservation Contracts

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July 21, 2005
Working Paper Number: 2005-02

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Abstract. Are commonly observed resource conservation contracts efficient? In this paper we construct a model that embodies common characteristics of resource contracts. Using this model, we analyze a large class of real-world resource contracts and find them to be economically inefficient. This inefficiency stems from a time inconsistency inherent in these contracts. There are two possible ways to overcome this time inconsistency. The first is to employ a sufficiently large penalty for early termination of the contract. The second and possibly easier method is to offer an upward sloping conservation payment schedule so far overlooked by resource contracts. Under this payment schedule, the agent's ex-ante and ex-post contract choices coincide, social externalities are fully internalized, and the contractual outcome is economically efficient even in the absence of a penalty for early termination.

Keywords: Resource Conservation Contracts, Conservation Payments, Time Inconsistency

JEL Classification: Q200, Q580

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1. Introduction

Resource conservation contracts are used across the world to partially or fully induce resource users to internalize externalities associated with resource utilization. Consider a brief list of examples.[1] According to the OECD (1997), between 1993 and 1997, fourteen countries in Europe paid the equivalent of $11 billion to divert 20 million hectares of agricultural land into land reserve and forestry. The U.S. Conservation Reserve Program (CRP) spends approximately $1.5 billion annually to contract 12-15 million hectares (Ferraro and Simpson 2002). The Forest Conservation Easement Contract, which is a part of the Payment for Environmental Services Program (PESP) in Costa Rica, pays farmers $42 per acre per year for five years to grow forest products on their land (Malavasi and Kellenberg, 2002). And finally, Conservation International (2000) is currently leasing a large area of forested land in Guyana to preserve biodiversity.

Are commonly observed resource conservation contracts efficient? In this paper we construct a simple model embodying commonly observed characteristics of resource contracts. We then use this model to analyze the economic efficiency of what appears to be a large class of real-world resource contracts.

Our model has the following four defining features. 1) The agent[2] is required to adopt a resource conserving technology. For example, this could entail setting land aside, or reducing tillage on existing fields. 2) The contract is for a pre-specified period of time. For example, the CRP requires farmers to put land aside for 10-15 years, and the lease on forested land in Guyana lasts 30 years. 3) Agents receive conservation payments while the conserving technology is

[1] Many other resource contracts were discussed at a symposium titled **"**Direct Payments as an Alternative Approach to Conservation Investment"**,** held at the 16th Annual Meetings of the Society for Conservation Biology, Canterbury, England, July 2002 (http://epp.gsu.edu/pferraro/special/special.htm). Also see Pagiola et. al. (2004) for other examples.

[2] For the rest of the paper we shall call the entity offering the contract a principal (this is usually either a governmental, or a non-governmental agency). The entity accepting the contract is called the agent (this is usually either a private land, or resource owner, or can even be another government).

employed, and are not penalized for exploitative behavior once the contract expires. This feature holds for programs such as the CRP, or PESP. Consequently, the resource contract can prevent the exploitation of a resource only temporarily. Once the contract expires, the agent has the incentive to revert to exploitative behavior in place before payments were made. And finally, 4) the payment schedule associated with the contract can be one of two types. Either the agent receives a constant payment per period for adopting a resource-conserving technology (we call this a *technology contract*). Or the agent receives a payment depending on the amount of resource conserved (we call this a *measured accumulation contract*).[3]

We find that resource contracts sharing these features are economically inefficient. The inefficiency stems from a time inconsistency[4] associated with a "payment-discount" inherent in these contracts. As the principal cannot penalize actions outside the contract, he discounts conservation payments below actual benefits associated with conservation.[5] This *payment-discount* accounts for the external costs of resource exploitation after the contract expires. Because the contract payment, and consequently, the payment discount are pre-determined before the contract is implemented, we find that the agent's incentives before, and during the contract differ. Before the contract is implemented, the agent prefers a contract with the efficient length of time. However, once in a contract with the efficient length of time, she has the incentive to exit the contract early (as the payment discount can no longer be adjusted for early

[3] The contracts listed in the first paragraph are examples of technology contracts. Examples of measured accumulation contracts include the Sustainable Forest Management Contract (a declining payment contract within PESP), and various forms of debt-for-nature-swaps, which are managed by *The Nature Conservancy* (see their website for details). Technology contracts and measured accumulation contracts are currently being developed to induce farmers to accumulate soil carbon in an attempt to offset greenhouse gas emissions (Feng et. al. 2002, Antle et. al. 2003).

[4] Kydland and Prescott (1977) introduced time inconsistency to economics. While, their original exposition involved monetary policy, time inconsistency naturally applies to several issues involving dynamic interactions.

[5] Please see Feng et al. (2002), and Chomitz and Lecocq (2003) for a discussion of how the price of sink-based carbon in a tradeable permit system should be discounted relative to the price of carbon associated with permanent greenhouse gas reductions.

abandonment) and make an even higher profit than the ex-ante efficient contract promises. The principal recognizes this incentive, and if the agent cannot credibly commit to stay in the contract for the efficient length of time, the contract that emerges from their interactions is shorter than the efficient contract. This inefficiency persists irrespective of whether a technology or measured accumulation contract is employed.

We also analyze the relative efficiency of the technology and measured accumulation contract. Contrary to results in recent literature (e.g., Antle et al. 2003, Ferarro and Kiss 2002, Ferraro and Simpson 2002), we find that a technology contract is more efficient than a measured accumulation contract. Technology payments are often criticized because marginal payments do not coincide with marginal resource accumulation. However, in the presence of time inconsistency, technology payments offset some of the agent's incentive to abandon the contract early. In a measured accumulation contract, payments decline along the length of the contract. This is because most renewable resources (such as soil carbon) accumulate at a decreasing rate as they approach their steady state. In a technology contract, payments are equally distributed across the entire contract. This difference implies that the marginal benefit of being in a technology contract declines slower than in a measured accumulation contract, and the agent stays in the contract for longer.

As mentioned earlier, the time inconsistency derives from the agent's inability to commit to the efficient contract. A potential commitment device is a cost incurred by the agent for early abandonment of the contract (for example, a penalty imposed by the principal). We investigate the effects of costly abandonment in the context of the two types of contracts discussed above. We find that the minimum cost of abandonment required to restore efficiency in the technology contract is smaller than the measured accumulation contract. This is consistent with fact that greater inefficiency is associated with a measured accumulation contract.

Finally, we present a conservation payment scheme that overcomes time inconsistency even in the absence of costly abandonment. The payments in this scheme are not related to technology adopted, or resource conserved. Payments are equal to the social marginal benefit of an additional unit of time in the contract. In direct contrast to technology, or measured accumulation contracts, these payments increase over time. Further, on receiving these payments the agent's ex-ante and ex-post contract term choices coincide.

The intuition behind the increasing marginal payment scheme is simple. In the case of a temporary resource contract where the required technology is imposed and exogenous, the agent's real choice variable is time spent in the contract (or equivalently the time she abstains from exploitative behavior). This implies that payments in the proposed scheme equal the social marginal benefit of the agent's choice variable. Consequently, these payments help the agent to internalize the payment-discount consequences of early abandonment, and overcome the problem of time inconsistency. This is not possible if payments are linked to exogenous variables like technology, or the amount of resource accumulated.[6]

The main contribution of this paper is in recognizing a previously ignored commitment aspect of resource conservation contracts. Most conservation contracts have discounted and pre-determined payment schedules extending over several periods of time. This implies that issues of commitment are central to their implementation. On recognizing these issues, the time inconsistency inherent in commonly observed temporary resource conservation contracts becomes apparent. Another contribution is that this paper presents an intuitive payment schedule

[6] Note that the lesson learnt from this result is quite intuitive: in order to design efficient resource contracts the principal should link payments to the agent's choice variable and not to other exogenous variables in the contract.

that overcomes this problem of time inconsistency even in the absence of penalties.[7]

The rest of the paper is structured as following. In Section 2 we present the basic contracting model. In Section 3 we discuss the optimal time in a first-best contract, and compare this with the time spent in a technology, or a measured accumulation contract. We also discuss the role of cost of abandonment as a commitment device. In Section 4 we present a modified conservation payment that overcomes time inconsistency, and we conclude in Section 5.

2. Model

The agent can choose one of two technologies. Technology *A* is resource conserving (e.g., grassland, or forest land). Technology *B* is relatively resource depleting (e.g., cultivated cropland). In the absence of a payment for resource conservation, technology *B* is more profitable, and is chosen by the agent.

The principal (i.e., contracting agency) offers the agent a one-time resource conservation contract. If the agent accepts, she agrees to use technology *A* until date *T*. During this phase the resource is accumulated. Once the contract expires, the agent switches back to the more profitable technology *B*. From this point onwards, the resource accumulated during the contracting phase is de-accumulated.

Resource State Equations: Assume that there exists a long-run steady state resource stock associated with either technological choice. The steady state associated with resource conserving technology *A* is R_a, and the steady state stock associated with technology *B* is R_b ($R_a > R_b$). Without loss in generality, we normalize these stocks so that $R_a - R_b = 1$. As the default technology of choice for the agent is *B*, we assume that that at the start of the relevant

[7] A potential practical issue is that the proposed non-linear, efficient payment schedule might be difficult to implement. However, a linear payment schedule approximating the efficient schedule is also likely to significantly improve the efficiency of resource contracts.

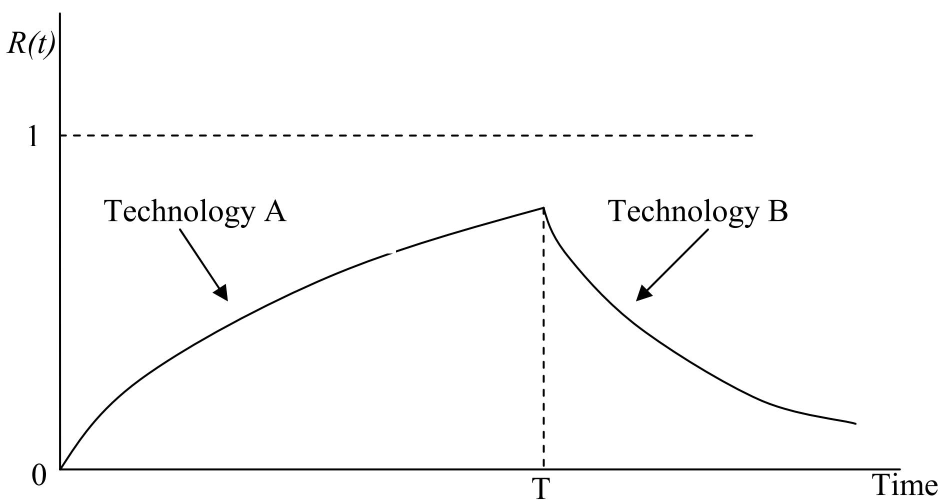
time horizon (date 0 – when the contract is offered), the resource stock is at the steady state: R_b.

Let *R(t)* denote resource in excess of R_b at date *t*. If the agent adopts technology *A*, the stock of resource rises albeit at a declining rate. This reflects the fact that growth slows as the resource approaches its steady state. Once the agent reverts back to technology *B*, the resource stock in excess of R_b declines continuously toward zero at rate *b*. Formally, these two assumptions imply that

$$R(t) = \begin{cases} 1 - e^{-at} & for\, t \le T \\ \left(1 - e^{-aT}\right) e^{-b(t-T)} & for\, t > T \end{cases}. \tag{1}$$

We assume that $b > a > \rho$ (ρ is the common discount rate). The growth and decline of the resource is illustrated in Figure 1.

Figure 1: Excess Resource Accumulation and De-Accumulation



Technology Choice in the Absence of a Contract: While using technology *A*, the agent earns a fixed amount π_a at each instant of time.[8] This approximates situations such as land retirement programs. While using technology *B*, the agent earns an instantaneous return of $\pi_b + kR(t)$

[8] This is a simplifying assumption. One might think of a more general specification where instantaneous returns during the contracting phase are related to the stock of the resource. However, making this assumption does not alter the qualitative results presented here.

(where $k > 0$ is a fixed parameter). This captures the fact that the agent's returns from exploitative behavior are typically related to the stock of the resource, for example, crop yields are relatively high when land is rich in organic matter. We assume that $\pi_b > \pi_a$ to ensure that profits from using technology *B* are higher than profits from technology *A* for all $R(t) \geq 0$.

Consider the agent's decision regarding use of technology *A* in the absence of a contract. As indicated earlier, *T* denotes time the agent spent in technology *A* prior to permanently switching to technology *B*. The agent's objective is to choose *T* to maximize the present value of profits subject to the resource growth equation:

$$\max_T \left\{ V(T) = \int_0^T \pi_a e^{-\rho t} dt + \int_T^\infty \left(\pi_b + kR(t)\right) e^{-\rho t} dt \qquad \text{s.t. equation (1)} \right\}. \tag{2}$$

Integrating and using equation (1) to substitute for *R(t)* we get

$$\max_T \left\{ V(T) = \frac{\pi_a}{\rho}\left(1 - e^{-\rho T}\right) + \frac{k\left(1 - e^{-aT}\right)}{b + \rho} e^{-\rho T} + \frac{\pi_b}{\rho} e^{-\rho T} \right\}. \tag{3}$$

and

$$\frac{dV(T)}{dT} = e^{-\rho T}\left[\pi_a - \left[\pi_b + \frac{k}{b+\rho}\left[\rho - (a+\rho)e^{-aT}\right]\right]\right]. \tag{4}$$

Equation (4) can be rearranged to illustrate the instantaneous marginal benefit and cost from remaining in technology *A* at time *T*.

The instantaneous marginal benefit is,

$$MB = \pi_a + \frac{ae^{-aT}}{b+\rho} k. \tag{5}$$

Remaining in technology *A* marginally longer at date *T* provides the agent with instantaneous profit π_a, and raises the excess resource by ae^{-aT}. This increases the discounted stream of profits from operating with technology B by $\frac{ae^{-aT}}{b+\rho}k$. Note that the marginal benefit declines as T increases (i.e., as $T \to \infty$, $MB \to \pi_a$). This is because as the resource approaches its carrying capacity, its rate of increase declines.

The instantaneous marginal cost of maintaining technology A for an extra unit of time is the profit foregone by not choosing technology B:

$$MC = \pi_b + \frac{\rho\left[1-e^{-aT}\right]}{b+\rho}k. \qquad (6)$$

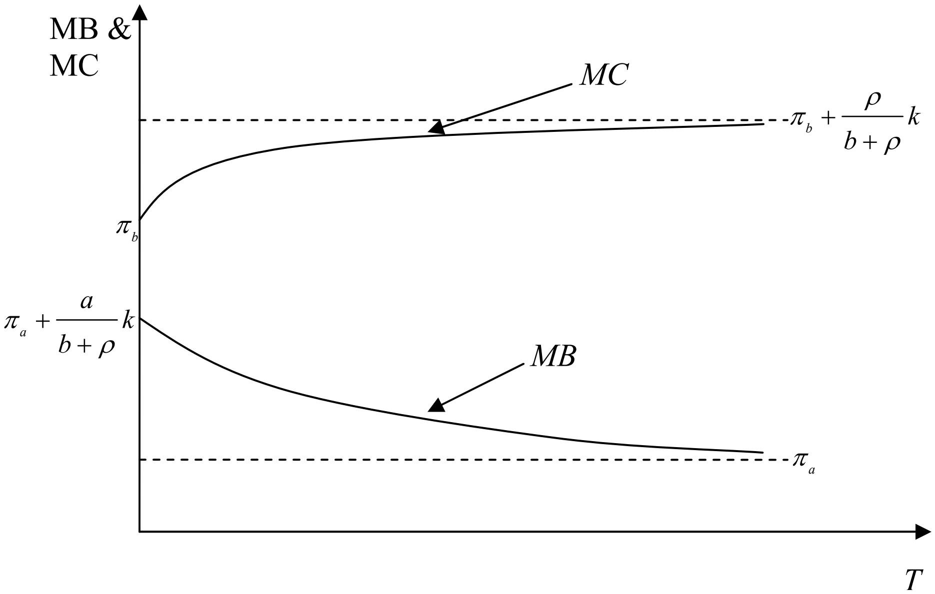
In addition to foregoing constant profit π_b, the agent also forgoes the discounted stream of profits associated with exploiting the excess resource. This discounted stream of profits increases over time as the resource stock increases.

To ensure that technology A is never chosen in the absence of a contract (this ensures that $R(0) = R_b$), the marginal benefit and cost schedules must not intersect. The formal condition to ensure that $T = 0$ is optimal in the absence of a contract is

$$k < \frac{b+\rho}{a}\left[\pi_b - \pi_a\right]. \qquad (7)$$

This restriction is illustrated in Figure 2. If the inequality in equation (7) does not hold, it becomes optimal for the agent to build up the resource by employing technology *A,* and earn relatively low short-run profits. The agent later employs the relatively profitable technology B and reaps the benefits from exploiting the accumulated resource.

Figure 2: Technology A is not used in the absence of a Contract



The Resource Conservation Contract: Every unit of resource conserved has an instantaneous social value of p (conversely, resource exploited has a social value of –*p*). The date 0 value of a unit of resource conserved at time t is therefore $pe^{-\rho t}$.

The agent receives continuous payments for the time in the contract. Further, the principal cannot link these payments to any actions taken by the agent after the contractual period. The contractual payment at date t is denoted *w(t)*:

$$w(t) = \theta(T, \alpha) + \alpha p e^{-\alpha t} \text{ with } \alpha \in \{0, a\}. \tag{8}$$

When $\alpha = 0$, the contract specifies a "technology payment" because the agent receives a constant payment over time for employing technology A. When $\alpha = a$, the contract specifies a "measured accumulation payment" because the instantaneous payment is equal to the actual value of resource accumulated less a constant discount factor. As we shall see below, this constant discount factor captures the social loss from resource de-accumulation on expiration of the contract.

The principal correctly anticipates that once the contract expires, the agent switches from technology *A* to *B* and exploits the excess resource conserved. Using equation (1), we can calculate the social value of the resource accumulated and de-accumulated. Initially the agent starts at the steady state resource stock R_b. In the contracting phase, the agent employs technology *A* until date *T*. On exiting the contract the agent reverts back to technology *B* for all remaining time, and the resource returns to the steady state prevalent before the contract was offered. Let $\Phi(T)$ denote the social value of such a contract. The appropriate expression is:

$$\Phi(T) = ap\int_0^T e^{-(a+\rho)t}dt - bp\left(e^{bT} - e^{(b-a)T}\right)\int_T^\infty e^{-(b+\rho)t}dt\,, \tag{9}$$

which can be reduced to,

$$\Phi(T) = p\left[\frac{b}{b+\rho}\left(1-e^{-\rho T}\right) - \left(\frac{b}{b+\rho} - \frac{a}{a+\rho}\right)\left(1-e^{-(a+\rho)T}\right)\right]. \tag{10}$$

Throughout this paper, we assume that the principal pays the agent the discounted social value of resource accumulated and de-accumulated. Formally, this implies $\int_0^T w(t)e^{-\rho t}dt = \Phi(T)$. Using equations (8) and (10), and integrating, we obtain the relevant expression for the intercept term of the payment schedule – $\theta\left(T,\alpha\right)$:

$$\theta(T,\alpha) = \rho p\left[\frac{b}{b+\rho} - \left(\frac{b}{b+\rho} - \frac{a}{a+\rho}\right)\frac{\left(1-e^{-(a+\rho)T}\right)}{\left(1-e^{-\rho T}\right)} - \frac{\alpha}{\alpha+\rho}\frac{\left(1-e^{-(\alpha+\rho)T}\right)}{\left(1-e^{-\rho T}\right)}\right]. \tag{11}$$

If the agent agrees to a contract of length *T*, the principal pays according to equations (8) and (11), with either $\alpha = 0$ for a technology payment, or $\alpha = a$ for the measured accumulation payment. Note that $\theta(T,\alpha)$ is positive under a technology contract ($\theta(T,0) > 0$), and negative under a measured accumulation contract ($\theta(T,a) < 0$). Also note that $\theta(T,a) < 0$ is a measure of the instantaneous average social loss from the resource exploited on expiration of the contract.

3. The Optimal Time in a Contract

We now examine the equilibrium length of the resource contract. We present both the first best outcome and the actual outcome of the technology and measured accumulation contracts.

The Efficient (First-Best) Outcome: The efficient outcome is achieved when the agent fully internalizes the social value of her actions. One way to induce internalization is to pay the agent the social value of resource accumulated with technology A, and charge for the social value of the resource de-accumulated with technology B. This first-best (or complete) contract maximizes the sum of profits, and the social value of resource accumulation and de-accumulation. Further, as the principal pays the entire social value to the agent, this contract also maximizes the agent's post-contract private returns.

Under the first-best contract, the agent's maximization problem is

$$\max_T \left\{ V^F(T) = \int_0^T \left(\pi_a + ape^{-at}\right) e^{-\rho t} dt + \int_T^\infty \left(\pi_b + \left(k - bp\right) R\left(t\right)\right) e^{-\rho t} dt \right\}, \qquad (12)$$

where the superscript F denotes first-best. Let T^* denote the first best-length of the contract. As the right hand side of equation (12) equals the sum of equations (3) and (10) it can be shown that

$$\frac{dV^F}{dT} = -\rho\left(\frac{k-bp}{b+\rho} + \frac{\pi_b - \pi_a}{\rho}\right) e^{-\rho T} + (a+\rho)\left(\frac{k-bp}{b+\rho} + \frac{ap}{a+\rho}\right) e^{-(a+\rho)T}. \qquad (13)$$

We can solve for T by setting equation (13) to zero to get:[9]

$$T^* = -\frac{1}{a}\left\{ \ln\left(\frac{\rho}{a+\rho}\right) + \ln\left(\frac{k-bp}{b+\rho} + \frac{\pi_b - \pi_a}{\rho}\right) - \ln\left(\frac{k-bp}{b+\rho} + \frac{ap}{a+\rho}\right) \right\}. \qquad (14)$$

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[9] To ensure that T^* is positive, $k > \frac{b+\rho}{a}\left[\pi_b - \pi_a\right] - \rho p$ is necessary. This restriction is consistent with equation (7), which ensures that technology A is not chosen in the absence of a contract.

As we did earlier, we can also rearrange equation (13) to illustrate the marginal benefit and cost from maintaining technology *A* at time *T*. Under the first-best contract, the marginal benefit of extending the contract is

$$MB^F = \pi_a + \left[p + \frac{1}{b+\rho}\left[k - bp\right] \right] ae^{-aT} . \tag{15}$$

By maintaining technology *A*, the agent earns instantaneous profit, π_a, a contract payment pae^{-aT}, and the capitalized value of increased profitability of technology *B* due to additional resource accumulated: $\left[p + \frac{1}{b+\rho}\left[k - bp\right] \right] ae^{-aT}$.[10] The marginal benefit from equation (15) can also be re-expressed as:

$$MB^F = \pi_a + \left[k + \rho p\right] \frac{a}{b+\rho} e^{-aT} . \tag{16}$$

A comparison of equations (5) and (16) reveals an expected result, the first-best contract shifts the agent's marginal benefit schedule upward.

Now consider the marginal cost of staying in the first-best contract:

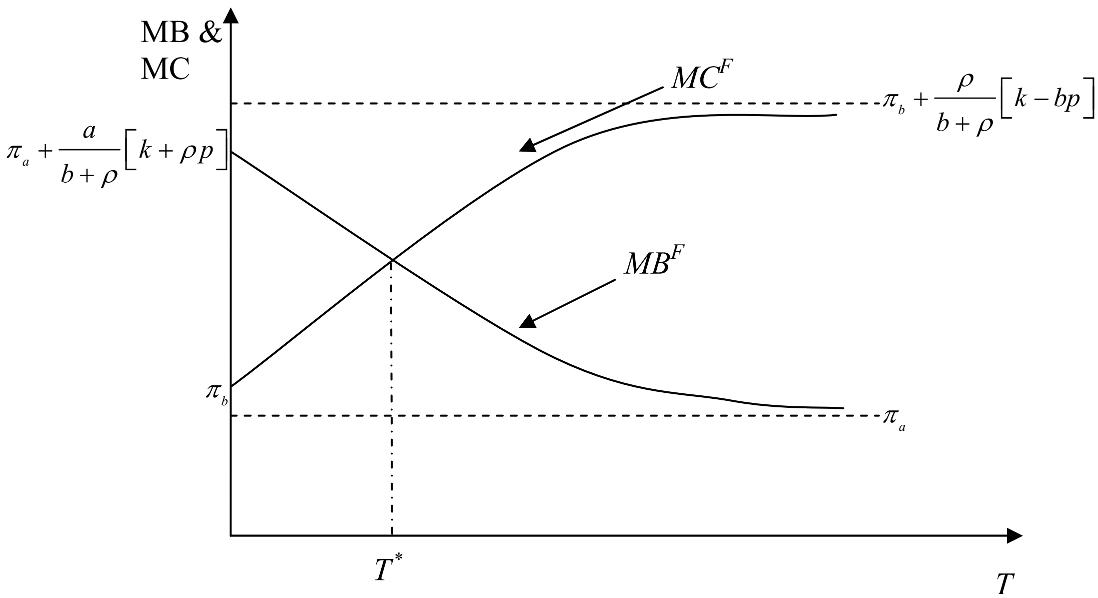
$$MC^F = \pi_b + \frac{\rho\left(1 - e^{-aT}\right)}{b+\rho}\left(k - bp\right) . \tag{17}$$

In terms of marginal cost, equations (6) and (17) show that because the agent is penalized for resource exploited, profit earned by using technology *B* at date *T* is relatively lower under the first-best contract. Assuming that $k > bp$, equation (17) also implies that the marginal opportunity cost of maintaining technology *A* increases as *T* increases. The combination of an upward shift in marginal benefit and a downward shift in marginal cost induces the agent to

[10] Note that this capitalized value is lower than that in equation (5). This is because under the first-best contract, returns from technology *B* are lower than in the absence of a contract.

spend time under the contract. We illustrate this in Figure 3.

Figure 3: Agent Choice in a First Best Contract



Time Inconsistency: In this section we evaluate the efficiency of the technology, and the measured accumulation contract relative to the first-best. We assume that the agent is free to abandon the contract prior to the scheduled termination date at no cost. Later in the paper, we show that the results of this section also hold if early abandonment is costly, as long as it is not excessively costly.

The principal offers a contract which requires the agent to adopt technology *A* until date *T*, in exchange for a pre-specified payment. Once the contract is signed, the agent takes the pre-specified payments as given, and thus from the agent's perspective, the payment schedule is: $w^C(t) = \theta^C(\alpha) + \alpha p e^{-\alpha t}$ with $\alpha \in \{0, a\}$. The difference between this payment schedule and the original payment schedule given by equation (8) is that $\theta^C(\alpha)$ is written as a fixed parameter rather than a function of *T*. This is because once the contract is signed, time in the contract *T* cannot alter the payment discount anymore.

The agent takes this payment schedule as given, and then optimizes her time in the contract. In a rational equilibrium, the principal recognizes the agent's ex-post optimization. As a consequence, the principal offers a contract for the optimal ex-post period of time for the agent. This implies that the value of $\theta^C(\alpha)$ is given by equation (11) with the agent's ex-post optimal choice of *T* substituted in.

The agent's objective function under the contract is

$$V^C(T) = \int_0^T \left(\pi_a + w^C(t)\right)e^{-\rho t}dt + \int_T^\infty \left(\pi_b + kR(t)\right)e^{-\rho t}dt \, , \tag{18}$$

Using equations (1) and (8) to substitute for *R(t)* and *w(t)* (with $\theta(T,\alpha) = \theta^C(\alpha)$) we get

$$V^C(T) = \frac{\pi_b e^{-\rho T} + \left(1-e^{-\rho T}\right)\left(\pi_a + \theta^C(\alpha)\right)}{\rho} + \frac{\alpha p\left(1-e^{-(a+\rho)T}\right)}{\alpha+\rho} + \frac{ke^{-\rho T}\left(1-e^{-aT}\right)}{b+\rho} \, . \tag{19}$$

The first-order condition for the maximization of equation (19) can be written as

$$\begin{aligned} \frac{dV^C(T)}{dT} &= -\rho\left(\frac{\pi_b-\pi_a}{\rho} + \frac{k-bp}{b+\rho}\right)e^{-\rho T} - \frac{\alpha p\rho}{\alpha+\rho}\frac{e^{-\rho T}\left(1-e^{-(\alpha+\rho)T}\right)}{1-e^{-\rho T}} \\ &\quad -\rho\left(\frac{bp}{b+\rho} - \frac{ap}{a+\rho}\right)\frac{e^{-\rho T}\left(1-e^{-(a+\rho)T}\right)}{1-e^{-\rho T}} + \left(a+\rho\right)\left(\frac{\alpha p}{\alpha+\rho} + \frac{k}{b+\rho}\right)e^{-(a+\rho)T} = 0 \end{aligned} \tag{20}$$

Unlike the first-best case, a closed form for the optimal time in the contract does not exist. Nevertheless, by expressing equation (20) in terms of the marginal benefit and cost of staying in the contract we can illustrate the effects of time inconsistency on the contractual outcome.

Consider first the measured accumulation contract (where $\alpha = a$). The marginal benefit of staying in the measured accumulation contract is

$$MB^{MA} = \pi_a + \left[p + \frac{1}{b+\rho}\left[k-bp\right]\right]ae^{-aT} + \frac{bp}{b+\rho}\left[ae^{-aT} - \rho\frac{e^{-\rho T}}{1-e^{-\rho T}}\left[1-e^{-aT}\right]\right]. \tag{21}$$

Given the earlier assumption that $a > \rho$, the third term of the *MB* schedule is negative for all $T > 0$.[11] On comparing equations (15) and (21), this implies that for all positive and finite *T*, the marginal benefit of being in the measured accumulation contract is lower than the marginal benefit of being in the first-best contract. Correspondingly the marginal cost of staying in either the measured accumulation, or technology contract is the same as that under no contract (given by equation (6)). This is because the agent cannot be charged for actions taken once the contract expires. As discussed earlier while comparing equations (6) and (17), this implies that the marginal cost of staying in either contract is higher than under the first-best contract.

Now consider the technology contract (where $\alpha = 0$). The marginal benefit of staying in the technology contract is

$$MB^{TC} = \pi_a + \left[p + \frac{1}{b+\rho}\left[k - bp\right] \right] ae^{-aT} + p\left[\frac{b}{b+\rho} - \frac{a}{a+\rho} \right]\left[ae^{-aT} - \rho \frac{e^{-\rho T}}{1-e^{-\rho T}}\left[1-e^{-aT}\right] \right] \quad (22)$$

As explained earlier, the last bracketed term of the *MB* schedule is negative for all $T > 0$. Further, given that *b*>*a*, we know that $p\left[\frac{b}{b+\rho} - \frac{a}{a+\rho} \right] > 0$. In other words, like the measured accumulation contract, the marginal benefit of staying in the technology contract is lower than the marginal benefit of being in the first-best contract.

Compared to the first-best contract, the downward shift in the marginal benefit schedule and the upward shift in the marginal cost schedule for both contracts implies that the equilibrium length of either resource contract is sub-optimally low. We illustrate this in Figure 4.

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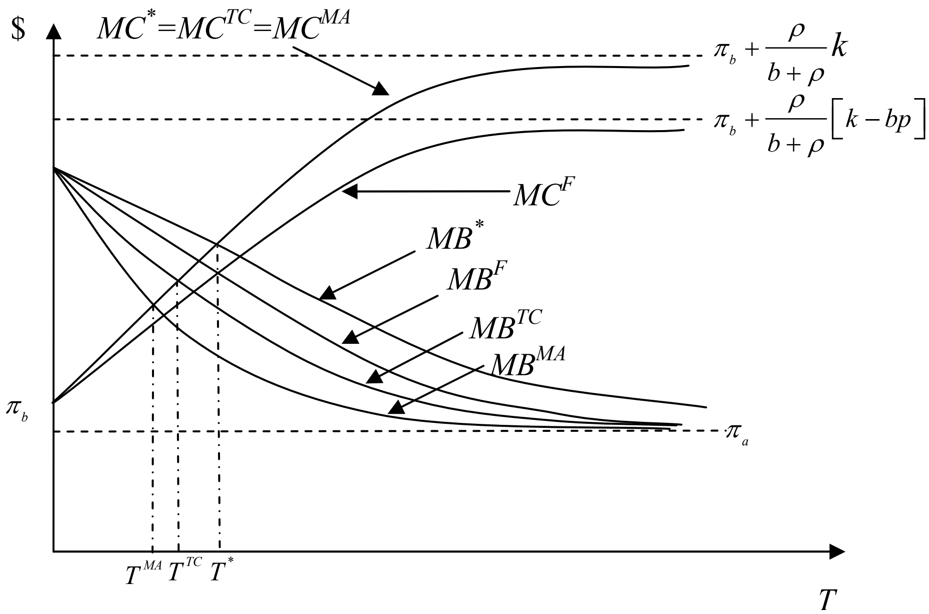
[11] This expression can be signed negative if $\rho e^{-\rho T}\left(1-e^{-aT}\right) > ae^{-aT}\left(1-e^{-\rho T}\right)$. Given that $a > \rho$ this condition holds because both sides vanish when *T = 0* and the left-hand side rises more quickly than the right-hand side as *T* is increased.

Figure 4: The Equilibrium Length of Contracts



On comparing equations (15) with (21) and (22) we can see that all *MB* curves coincide as $T \to \infty$, and that for any given positive and finite *T*, the following relation holds true: $MB^F > MB^{TC} > MB^{MA}$. Further, as negative payments in contracts are not possible, all *MB* curves also coincide when $T = 0$. We also know that for all positive *T,* $MC^F < MC^{TC} = MC^{MA}$, and that the *MC* curves coincide when $T = 0$. This implies that $T^* > T^{TC} > T^{MA}$. This result is illustrated in Figure 4, and is also stated below.

Proposition 1. Assume that the agent can costlessly abandon the contract prior to the specified termination date. The equilibrium length of time spent by the agent in either the technology or the measured accumulation contract is shorter than the ex-ante efficient length of time.

Proof: Follows from Figure 4 and the corresponding discussion. ■

Ex-ante (i.e., before the payments are predetermined) the agent would prefer a contract for the efficient amount of time (T^*). However, once in the contract, payments are pre-determined, and T^* is no longer optimal. Note that as T^* maximizes the agent's profits, and *V(T)* is strictly concave, Proposition 1 also implies that agent welfare under either contract is sub-optimal. This inefficiency is the result of time inconsistency. As the agent cannot credibly commit to stay in the contract for the ex-ante efficient length of time, the equilibrium amount of time spent in either contract is less than optimal.

If the principal naively offers the agent payments based on the ex-ante efficient time, the agent has the incentive to quit early and earn even higher profits than the first-best contract promises. This occurs as contract payments include a discount for resource exploited in the post-contract phase and, this discount is a decreasing function of time in the contract *T*. The agent realizes that once payments have been pre-determined, there is no mechanism to raise the price discount retroactively for time not spent in the contract. This provides the agent an incentive to cheat on the ex-ante agreed terms by quitting early. This gives the agent the benefit of a lower discount, and higher ex-post profits. However, in equilibrium, the principal recognizes the agent's incentives. The principal thus offers payments based on the ex-post marginal benefit and cost of staying in the contract which results in an inefficient outcome.

Now consider the relative performance of the technology and measured accumulation contract.

Proposition 2. Assume that the agent can costlessly abandon the contract prior to the specified termination date. The equilibrium length of time the agent stays in the technology contract is longer than the length of time in the measured accumulation contract.

Proof: Follows from Figure 4 and the corresponding discussion.■

Because the agent's objective function is concave in T, an immediate implication of Proposition 2 is that the agent's profits are lower with a measured accumulation contract than with a technology payment contract. In other words, the technology payment contract is more efficient than the measured accumulation contract.

Unlike the measured accumulation contract, the technology contract pays an average benefit for resource accumulation and de-accumulation which does not decline over time. It follows, therefore, that the payment with a technology contract is less than the social value of the resource accumulated in the early part of the contracting period and is greater than the social value in the latter part of the contracting period. Given that the marginal opportunity cost is the same for both types of contracts, the averaging feature of the technology contract serves to extend the equilibrium length of the contract beyond the length of the measured accumulation contract. Recall however that the technology contract suffers from the time inconsistency pointed out in Proposition 1. Thus despite the additional contract length, the technology contract is still inefficiently short.

An interesting aspect of the previous analysis is that if $b = 0$ then all contractual inefficiency in the measured accumulation contract disappears. With $b = 0$ the marginal benefit and cost schedules are identical for the measured accumulation contract and the first-best contract. This occurs because with $b = 0$, the resource is not exploited once the agent exits the contract. Consequently, the payment schedule is not discounted to account for the post contract resource exploitation. Interestingly if b=0, the equilibrium outcome under the technology contract is inefficiently long. [12]

Costly Abandonment and Credible Commitment: Time inconsistency arises in the previous section as the agent is free to abandon a contract prior to the specified termination date. Costless

[12] From equation (22) one can see that if $b < a$, the length of time the agent stays in the technology contract exceeds the efficient outcome.

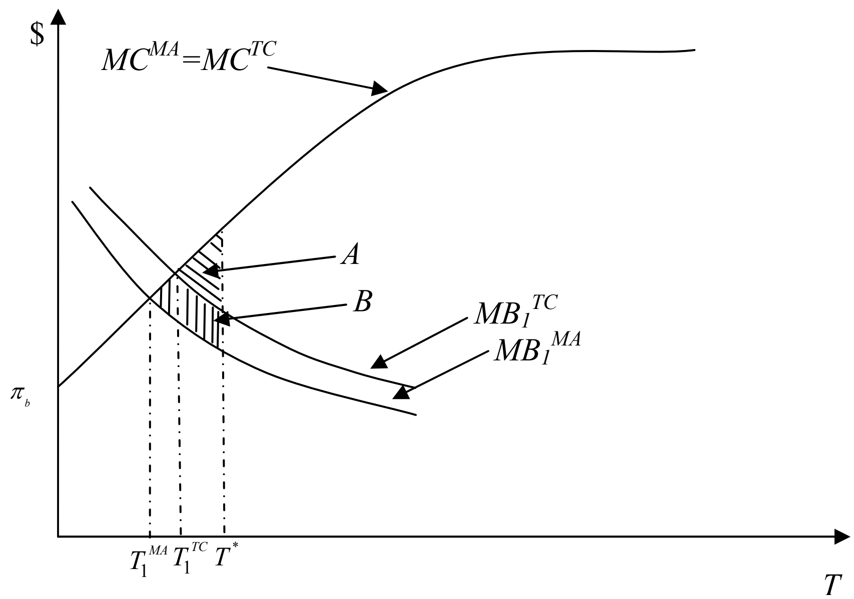
early abandonment implies that the agent cannot credibly commit to stay in the contract for the efficient length of time. In this section we show that the time inconsistent outcomes implied by Propositions 1, and 2, can emerge even if early abandonment is costly, but not excessively costly.[13] We graphically illustrate the threshold cost of abandonment for either type of contract. If the actual cost is less than or equal to this threshold, the results stated in Propositions 1, and 2 are valid. If the cost is higher than these thresholds, the agent can credibly commit to stay in the contract for the ex-ante efficient length and efficiency is restored.

Assume that the principal offers the agent payments based on the efficient time of exit (T^*).[14] Let MB_1^{TC} denote the marginal benefit of staying in this contract when technology payments are offered. Further, let T_1^{TC} denote the optimal time to exit the contract when this marginal benefit function is offered and abandonment is costless. Let MB_1^{MA} and T_1^{MA} be the corresponding function and time associated with measured accumulation payments. From equations (21) and (22) we know that $MB_1^{TC} > MB_1^{MA}$ for all positive and finite T.

Now let C denote the agent's cost of abandoning the contract. We define a threshold value C^{TC} associated with the technology contract. If $C \geq C^{TC}$, the agent stays in the technology contract for the efficient time. However, if $C < C^{TC}$ the agent abandon's early at T_1^{TC}. Similarly, C^{MA} is the threshold associated with the measured accumulation contract. We illustrate these thresholds with the aid of Figure 5.

[13] This cost of abandonment could be a sum of penalties, legal fees, and loss in reputation.
[14] In other words, the discount is calculated under the assumption that the agent will exit at the efficient time: $\theta\left(T^*, \alpha\right)$

Figure 5: Costs of Abandonment or Penalties Necessary



A measure of C^{TC} is given by the cross-hatched area A in Figure 5, and a measure for C^{MA} is given by summing areas A and B in Figure 5. These cross-hatched areas signify the gain in profits for the agent who abandons early (before T^*) and benefits from the fact that the principal applied a payment discount lower than it should have been. However, if the cost to exit early is higher than the profitability of abandonment, it is no longer optimal to abandon early. A comparison of the size of cost of abandonment results in the following corollary.

Corollary to Proposition 2. For all positive and finite T^*, the minimum cost required to restore efficiency in the technology contract is smaller than that required under the measured accumulation contract.

Proof: From Figure 5 we can see that $C^{TC} < C^{MA}$ ■

This corollary also implies that for all $C \in \left(C^{TC}, C^{MA}\right)$ the first best outcome T^* emerges with the technology contract, and an inefficient outcome (T_1^{MA}) emerges with the measured accumulation contract. In other words, this corollary is an alternative way of presenting

Proposition 2. It restates the earlier result, that given the time inconsistency problem inherent in these contracts, a technology contract is more efficient than a measured accumulation contract.

4. An Efficient Non-Linear Contract Payment Schedule

Irrespective of the cost of abandonment, there exists a non-linear payment schedule that always results in the first-best outcome. Consider the following proposition.

Proposition 3. Suppose the agent is offered the following payment schedule,

$$w^*(t) = \frac{d\Phi(T)}{dT}e^{\rho T} = p\left(\frac{\rho b}{b+\rho} - (a+\rho)\left(\frac{b}{b+\rho} - \frac{a}{a+\rho}\right)e^{-at}\right). \tag{23}$$

With this schedule, the first best outcome is achieved even if the cost of abandoning the contract is zero.

Proof: Substitute the expression for $w^*(t)$ into equation (18). The objective function is now identical to the objective function in equation (12) that gives rise to the first best outcome (T^*).■

The intuition behind Proposition 3 is simple. In the case of a resource contract where the required technology is imposed and exogenous, the agent's real choice variable is time in the contract. If we pay the agent the social marginal benefit of an additional unit of time in the contract, the efficient outcome results.

Note that $w^*(t)$ is increasing in t, starting from the limit of $t \to 0$, $w^*(t) \to \frac{a}{b+\rho}\rho p$, and as $t \to \infty$, $w^*(t) \to \frac{b}{b+\rho}\rho p$. The instantaneous payment under this schedule increases over time. This is in direct contrast to measured accumulation contract, where the payment declines over time, and to the technology contract, where the payment is constant over time. With the efficient contract, future payments rise fast enough at the margin to allow the producer to fully internalize the payment discount consequences of early abandonment. This internalization is not possible if the payment is linked to exogenous variables such as technology, or the amount of resource accumulated. In a sense, the proposed payment schedule contains an implicit dynamic Pigouvian tax to address the abandonment externality.

The marginal benefit of staying in the efficient non-linear contract is

$$MB^* = \pi_a + \left[p + \frac{1}{b+\rho}\left[k - bp\right] \right] ae^{-aT} + \frac{b}{b+\rho}\rho p\left[1 - e^{-aT}\right] \tag{24}$$

On comparing equations (15) and (24) we can see that the marginal benefit of staying in this contract is higher than the marginal benefit of staying in the efficient or complete contract. As explained earlier, the marginal cost of staying in this contract is the same as that under no contract. In other words, the marginal cost of staying in the efficient non-linear contract is higher than under the efficient contract. The efficient non-linear payment schedule is illustrated in Figure 4. The marginal benefit of staying in this contract is denoted MB^*, and it intersects the marginal cost of staying in the contract MC^* (which is the same as the marginal cost under the technology, or measured accumulation contract) at the optimal time T^*.

4. Conclusions

Through this paper we illustrate a time inconsistency inherent in most resource contracts. We also discuss two potential ways to overcome time inconsistency. The first is to create credible commitment through a cost of abandonment. The second is to present the agent with an efficient upward sloping payment schedule that encourages her to internalize externalities associated with early abandonment.

While a comparison of the relative efficiency of these two methods to overcome time inconsistency is out of the scope of the paper, an informal discussion at this point might be useful. Resource contracts can include an explicit penalty for abandonment. However, for political or other reasons these penalties may be problematic to implement and costly to enforce. More importantly, if the size of penalty is not as high as the threshold discussed earlier, the contract remains inefficient. On the other hand, adjusting payments to reflect the efficient payment schedule is likely to be an easier and less costly means to overcome time inconsistency. The potential practical issue might be implementing the complicated non-linear upward sloping schedule required for efficiency. However, a linear upward sloping payment schedule that approximates the efficient payment schedule is likely to be a significant improvement. This will encourage the agent stay in the contract for a longer and more efficient length of time under constant or declining payments.

The upward sloping efficient schedule highlights the fact that temporary resource contracts are inherently different from permanent resource contracts. If the resource is permanently conserved, a payment scheme that links payments to the amount of resource conserved is efficient. However, this is not true if the resource is conserved only for brief period of time. In such a case, payments should be linked to the length of time the owner abstains from exploitation. Linking the payments to the technology adopted, or the amount of resource conserved can lead to an inefficient amount of time allocated to resource conservation. This clarification is increasingly important given that conservation contracts are being proposed as a means to preserve resources worldwide.

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