COMBINING SHARECROPPING AND COMMAND AND CONTROL INCENTIVES IN PRINCIPAL AGENT ANALYSIS: A FORESTRY EXAMPLE

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ABSTRACT

Command and control provisions may be implemented in situations where firms receive some return from their regulated actions. A case in point involves forest regeneration requirements on private or public land. A model is developed that is used to show how optimal command and control penalties may be set when firms have some equity in future crops. Results show that as stumpage collected increases, equity to the firm decreases, causing the optimum penalty to increase. Likewise, if a divergence in social and private time preferences and/or non-timber benefits cause social values to be external to the firm, the optimum penalty may be adjusted to internalize these values.

Keywords: *command and control, government regulation, principal agent analysis, reforestation incentives, sharecropping.*

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INTRODUCTION

The literature on principal agent analysis has traditionally approached regulatory incentive problems from two general angles. One approach has been to provide the agent with an equity share in the fruits of its labor, typically studied in farm cropping situations (e.g. Cheung, 1969). Another approach has been to command an action, frequently related to pollution control, and put in place penalties to ensure that the action is enforced (e.g. Cohen, 1987). In practice, however, principal agent problems may contain sharecropping and command and control elements.

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For example, governments, as principals, frequently regulate the behavior of private firms managing forest resources. These regulatory practices may be justified by noting that private and social values associated with forest resource values and time preferences may diverge.[1] In response to these market failures, many governments have constructed tenure arrangements which specify conditions under which private forestry firms may operate on private or public lands.[2] These arrangements frequently contain a wide variety of commands and controls regarding where, how, and how much timber may be harvested and reforested.[3] At the same time, however, these tenures may allow firms some equity in the returns from their reforestation investment. If future equity from forestry investments is not completely eroded by insecurity of tenure, the collection of future rents in the form of stumpage fees, and/or other types of property right attenuations, firms may face some expectation of future returns.[4]

The purpose of this paper is to present a principal agent model which considers, simultaneously, incentives created by command and control provisions and equity shares in future proceeds. The paper will proceed by first presenting a model based on the forest tenure example. The optimal penalty, which aligns the objectives of the principal and the agent, will be shown to be dependent on the level of equity which is granted to the forestry firm. A corollary of this result will also be explored, where it will be shown that in the absence of market failures, the full value of the reforested timber is a component of the optimum penalty only in cases where agents hold no equity in future pro-

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[1] For a review of externalities common in forestry situations, see Boyd & Hyde (1989). For a review of divergences in private and social discount rates, see Markandya & Pearce (1991).

[2] Situations where the forest management of private firms is regulated by governments are found in many parts of the world including the United States, Canada and Indonesia. In the United States, private firms may manage private lands, while in Canada and Indonesia, governments regulate private firms operating on public lands.

[3] Principal agent models assume that there is a regulator with the authority and will to regulate private firms. Therefore, the model may be difficult to apply in some developing country contexts.

[4] The level of future equity (i.e. rights to benefits from harvesting future crops) may vary between jurisdictions and tenure types. We treat future equity as a variable, but assume that it is positive.

ceeds. In cases where equity is shared, it will be shown that the amount of rent, and the manner in which the principal collects from the agent, is central in influencing the optimum penalty. Finally, the analysis will be extended to solve for the optimum penalty in the presence of non-timber externalities and divergences in social and private time preferences.

THE MODEL

Assume that the principal is the government, representing society, with regulatory authority over operations of forest company agents that are required to meet regeneration standards. Assume further that, to begin with, timber is the only resource produced by the forest, and that private and social discount rates coincide. Hidden action exists in the forest renewal arrangement in that the firm must undertake some costly effort to reforest to standards, but the government is unsure of the actual level of effort put forth by the companies. There is also hidden information, because firms might know more than the regulators about the effectiveness of a specific reforestation activity on a particular site within their tenured area.

The following model, to be used as a basis for assessing the forest regeneration situation, is an adaptation of a model used by Cohen (1987) for assessing oil spill regulations.[5] Similar to Cohen's approach, this model will employ several simplifying assumptions. First, tenure arrangements are negotiated as individual agreements with each forest company, and the actions of one agent do not impact the actions of the other agents. Also, the time period over which trees grow and are harvested is sufficiently long to ignore the potential for repeated games.[6] Furthermore, firms are risk neutral so that a strict liability approach from moni-

[5] Cohen (1987) adapted his model from work originally developed by Epple & Visscher (1984).

[6] Forest regeneration regulations may be viewed as policy prescriptions that set up rules for one round of the game. Given that a policy's life is probably less than the rotation of a tree, and that new information and interactions will likely be in place before the principal-agent game is completed, we do not consider these principal-agent interactions as a repeated game. However, one could consider principal agent interactions where one agent holds various parcels of land within a single principal's jurisdiction as repeated games.

toring outcomes and penalising sub-standard behaviour may be followed (Shavell, 1979).[7] Finally, it will be assumed that the principal is seeking to maximize the net benefits derived by all parties in its pursuit of a Potential Pareto Improvement.

A key variable in this problem is the degree to which reforestation is accomplished using "command and control" regulations, as compared to the situation where companies voluntarily make efforts toward regeneration because there is some portion of future benefits from the forest, as in sharecropping, which will accrue to the company. Whether reforestation is stimulated by a command and control situation or a promise of future equity is a matter of degree — a continuous variable rather than a discrete choice. The following model takes this relationship into account, and allows for structuring reforestation incentives according to the degree of future equity held by the forest industry.

Principal agent models may be characterised as having four components: (*i*) individual rationality; (*ii*) informational feasibility and efficiency; (*iii*) incentive compatibility; and (*iv*) a welfare indicator. Our model may be characterised by these components as follows. First, the principal and the agent are assumed to be rational in pursuing their respective objectives over long time horizons. The government, we assume, seeks to maximise the expected welfare to society, independent of distribution. The agent, we assume, is a profit maximising firm considering only its own welfare. Second, regarding informational feasibility and efficiency, the agent has information on the regeneration activities and success that is unknown to the principal. However, the principal is interested in the benefits from these activities and in designing an efficient means of maximising social welfare. Accordingly, and third, the principal attempts to put a penalty in place that will cause the objective function of the agent, in the presence of the penalty, to coincide with the objective function of the principal. Fourth,

[7] Although much of the current principal agent literature does not assume risk neutrality, we use this assumption for two primary reasons. First, many forestry firms, in jurisdictions such as Canada, are sufficiently large and diversified that regeneration expenditures can be assumed to be made under risk neutrality. Second, the complication of employing more generalized risk preferences is not necessary to address the purposes of this paper.

because our paper is conceptual, we use a broad definition of social welfare, specified below, as our welfare indicator.

Let z indicate the fraction of total harvested land area that has been successfully replanted, where the total harvested land area is normalized to 1. The value of z will be less than 1 due to replanting or natural regeneration failure, or perhaps due to no replacement of the trees whatsoever. These failures could result in forgone revenue due to barren land, or a delay of the next timber crop. Let $B(z)$ represent benefits to the firm of replanting the proportion of total land area to z over multiple forest rotations. The government principal requires that a portion of the harvested area be reforested to reforestation standards. The portion is chosen recognising that not all harvested lands will warrant regeneration efforts due to the potential for natural regeneration, or perhaps because of the lack of benefits associated with second growth crops. In the absence of market failures, the portion z, chosen by the principal, is synonymous with what the agent would choose as a rational profit maximising firm, if the agent held full equity in future timber crops. However, the agent does not hold full equity, as the principal holds a portion, collected as stumpage fees and/or through other types of attenuations in property rights. Let $S(z)$ denote that portion of future equity held by the principal.[8] Thus, the total social value from reforestation is equal to $B(z) + S(z)$.

While the forest company agent is not able to entirely control the success of reforestation, it can make some level of effort, e, to increase the likelihood of successful regeneration. If reforestation does not succeed, the probability that the principal will discover the situation is $P_D(z,m)$, where m is the level of government resources assigned to the detection of infractions. If the agent's reforestation treatments are found to be failing, the principal could impose a penalty of $T_D(z)$.

[8] Implicit in the definition of $S(z)$ is that rents are collected such that the amount available to collect is dependent on the reforested area z. This assumption coincides with most government practices, as rents are usually collected as stumpage fees which depend on the quantity harvested. If stumpage was collected as a land rent, irrespective of production, then $S(z) = 0$.

The agent experiences private benefits, $B(z)$, equal to the value of gained resources due to reforestation. This variable is distinguished from the cost of reforestation effort, e, in that $B(z)$ is the future benefit from regenerated stands the tenure holder captures. That is, $B(z)$ is only positive if the agent's property rights allow a share in the future equity from reforestation investments.

Using the above notation, and assuming risk neutrality, the company's expected profit (loss) from reforestation can be written as:

$$EU(e) = \int_z \left\{B(z) - P_D(z,m)\,T_D(z)\right\} f(z,e)\,dz - e \tag{1}$$

where

e = effort expended by the forest company; also understood as the dollar value of the company's initial reforestation effort;

$EU(e)$ = expected profit;

z = fraction of harvested area which has been successfully reforested;

$B(z)$ = value of the agent's benefit from future timber yields ($B'(z) > 0$);

m = amount of government resources devoted to detection of infractions;

$P_D(z,m)$ = probability that reforestation failure will be detected ($P'(z) < 0$; $P'(m) > 0$);[9]

$T_D(z)$ = penalty for failure to reforest;

$f(z,e)$ = a probability distribution function describing the probability that some fraction of a harvested area has been successfully reforested (z) conditional on effort (e) applied.[10]

[9] The probability of detection in this model is shown to depend on the size of the area z and the amount of government monitoring, m. However, other potential factors to consider would be the size of the forest operation, proximity to civilisation, proximity to roads, government resources, or other variables. Also, it may be possible for forest companies to spend time and money to circumvent government regulators and to lower the probability that they are detected. Indeed, the incentive to do this will increase as the penalty gets higher. P_D may therefore be complex and may make an optimum penalty difficult to ascertain in practice.

[10] Note that lands that regenerate in the absence of effort (i.e. left for natural regeneration) are included in z so long as the regeneration standard is met.

The principal's expected utility, taken as a measure of social welfare, can be written as:

$$EW(e,m) = \int_z \{B(z) + S(z)\} f(z,e)\, dz - e - m \qquad (2)$$

where

$EW(e,m)$ = expected social welfare;

$S(z)$ = "stumpage fees" or government portion of future wealth created, collected as a function of reforestation (S'(z)>0);

The principal could maximize social welfare by maximizing the sum of timber benefits and stumpage fees collected, less expenditures on effort e and monitoring expenses m. The portion z is chosen by the principal to maximize this welfare function. That is, the optimal size of z would result from equating the marginal benefits from reforestation with the marginal costs of reforestation.

From equation (2), it can be seen that the fine, $T_D(z)$, is not included in the social welfare function. The fine is a transfer of wealth, and society's marginal benefit from reforestation does not depend on the amount of the penalty imposed. However, the amount of the fine does affect the agent's incentive to meet standards, and may therefore impact the outcome. In contrast to $T_D(z)$, $S(z)$ is included in the welfare function as it represents that portion of the future benefits from growing trees that belongs to the principal.

Optimal Penalties with Sharecropping and Rent Collection

In seeking to maximize social welfare, the government would try to design a penalty system which results in a desired level of effort, detection expenses, and re-treatment area to maximize (2). To determine the optimal level of e, we take the derivative of (2) with respect to effort, to derive the marginal social benefit:

$$\int_z \{B(z) + S(z)\} f_e(z,e)\, dz = 1 \qquad (3)$$

In this way, the marginal social benefit of an increased level of reforestation effort is equated to its marginal cost (here normalised to 1). Let the solution to this maximization problem be z^*. However, since the government has limited control over the reforestation efforts and expenditures a company makes, an arrangement must be devised so that the company achieves its maximum profits and private benefits (modelled by equation (1)) by making the socially optimal level of effort. This may be done with the following penalty function:

$$T_D(z) = \frac{S(z^*) + m}{P_D(z^*, m)} \tag{4}$$

If (4) is substituted into (1), the result is (2). Given this penalty, the agent would expend the level of effort *e,* which maximises social welfare.

In equation (4), and in the analysis which follows, it will be assumed that *m* is exogenously determined. That is, for some given level of *m*, an optimal penalty will be derived.[11,12] If all failures to reforest are detected, (that is if P_D $(z,m) = 1$), then (4) would imply that the expected penalty should be set equal to the expected "benefits" from reforestation, plus the costs of monitoring. Consequently, the penalty would ensure that the company takes into account the social benefits of reforestation in addition to its private benefits, which are contained in its profit maximisation equation (1). However, if P_D $(z, m) < 1$, then the penalty increases. Although the companies that are discovered pay more than the social cost of reforestation failure for their area and the undiscovered companies pay nothing, the possibility of paying this penalty gives all companies the incentive to make optimal effort toward reforestation success.[13]

Continue to assume, for the moment, that non-timber benefits equal zero and that private and social time preferences coincide. Following the above notation, total social

[11] We focus on the choice of *z* to derive the optimal penalty, assuming that *m* follows whatever decision is made with respect to *z*. However, consideration could be given to the choice of both *z* and *m*. This would significantly complicate the analysis but may provide little insight into the key factors.

[12] Note that if information regarding compliance is costly, not all agents will be in compliance (Greenburg 1984).

[13] Equation 4 implies that the penalty may always be made severe enough to induce compliance with the regulations. Shavell (1987) notes that this is difficult to justify when there are detection errors.

benefits from reforesting timber ($V(z)$) are made up of future benefits from regenerated stands, captured by the principal and the agent:

$$V(z) = B(z) + S(z). \tag{5}$$

In cases where private agents are operating on public lands governed by a principal, the principal is frequently concerned with collecting rent from the agents. The choice of *S(z)* by the principal has implications on the agents' compliance with reforestation regulations in that more rent collected leads to less agent equity and less incentive to reforest.

Because the principal and the agent may share in forgone rents due to failed reforestation, incentives to avoid reforestation failure are also shared. Equation (5) can be written as $B(z) = \alpha V(z)$ where a is the share of timber value captured by the firm. In equation (4), *S(z)* is included as part of the penalty, while *B(z)* is absent because this term is already internalised in the behaviour of firms in equation (1). In general, the more economic rent captured by the government, the less equity agents will hold in future proceeds and the higher will be the penalty needed to ensure that reforestation is accomplished on public lands. Therefore, if the principal wishes to increase its share of rent by raising stumpage fees, the remaining equity held by agents decreases, and the principal must increase penalties imposed on forest companies. These observations illustrate that it is generally not necessary to know the full value of foregone timber, due to regeneration failure to determine the optimal penalty. Instead, the command and control penalty may be based on the price of stumpage which dictates the principal's equity share.

If the government is collecting the full economic rent from future stands of timber, then the stumpage fees, *S(z)*, would be equal to total timber value, *V(z)*, and private equity, *B(z)*, would be zero.[14] The tenure holder would have no equity in future stands of timber, and thus no incentive

[14] We assume in our model that any level of rent may be collected in an incentive-neutral fashion. In fact, practical difficulties associated with collecting full economic rent would likely prevent an extreme solution where $B(z) = 0$ and agents face no incentives for reforestation other than the avoidance of penalties.

to regenerate. The social benefits from timber would be fully represented by stumpage fees, and the optimal penalty would reflect these revenues. There would be no equity incentives to reforest on the part of the forest companies, so command and control penalties would have to be high, to cover the full value of stumpage. On the other hand, if stumpage fees are zero, then $B(z)$ would be equal to $V(z)$. Under this scenario, the value of reforestation could be internalised by charging zero stumpage fees, and allowing the companies to manage their timber stands with complete future equity. This would be a case where the agent is essentially in a private land situation with no property right attenuations. Alternatively, the principal could employ land rents instead of stumpage fees for collecting resource royalties, thereby disentangling the rent collection from the penalty function. However, accounting for non-timber values and the potential for divergences in private and social discount rates could cause the need for a penalty, even in the absence of stumpage fees.

OPTIMAL PENALTIES INCLUDING MARKET FAILURES

Assume now that in addition to timber "benefits" from reforestation, there are also non-timber "benefits" from reforestation, $X(z)$.[15] These benefits are captured by the principal on behalf of society because they are, by assumption, external to the property rights of the agents. The $X(z)$ term must therefore be added to equation (2).

$$EW(e,m)=\int_z \{B(z)+S(z)+X(z)\}\,f(z,e)\,dz-e-m \qquad (2')$$

Equation (2′) illustrates that the principal must concern itself, not only with benefits from forest harvesting, $(B(z) + S(z))$ but also with non-timber benefits $(X(z))$ and the tradeoffs between producing timber vs. non-timber outputs.

Furthermore, if social and private discount rates diverge, then $B(z)$ would not, from a social point of view, correctly register the agents share of benefits. In this case, the social benefits of timber from reforestation may be depicted as:

[15] These might include benefits from aesthetics, recreation, wildlife, biodiversity, existence value, or spiritual aspects of the forest.

$$B_s(z) = B(z) + \delta \tag{6}$$

where:

$B_S(z)$ = the social value of the timber "benefits" to the agent;

δ = the difference between forgone timber proceeds received by the agent computed with private and social discount rates.

If equation (6) is substituted for the $B(z)$ term in equation (2'), and once again z^* represents the solution to the principal's optimization problem, then the optimum penalty may again be derived:

$$T_D(z) = \frac{S(z^*) + X(z^*) + m + \delta}{P_D(z^*, m)} \tag{7}$$

Because $X(z)$ and δ are external to the agent in equation (1), but internal to the principal in equation (2), they appear in the penalty function.

Assume that private discount rates are higher than social discount rates causing δ to be positive.[16] Further assume that $X(z)$ is positive. Finally, assume that no stumpage fees are collected by the government so that the tenure holder has complete equity in the private proceeds of timber crops. Under these conditions, $S(z^*)$ would be completely internalised in equation (*1*) and would drop out of the numerator of equation (7). To the extent that some stumpage fees are collected by the principal, equity for the firm would be incomplete, and some level of $S(z^*)$ would also enter into the penalty calculation.

CONCLUSIONS

The split within the principal agent literature, between studies which have investigated sharecropping and command and control literature, is likely due to the different types of problem which each branch has been addressing.

[16] For a review of reasons why private rates are likely to be lower than social rates see Markandya & Pearce (1991).

While analyses of command and control efforts concentrated on negative externalities associated with pollution, sharecropping analyses were dealing with incentives associated with investments desirable to enhance the value of a resource. In essence, while command and control models have dealt with "active" externalities, which result from actions of firms, the sharecropping literature has dealt with "passive" externalities which result from the absence of firm's actions. If the absence of resource enhancement incentives is viewed as a positive externality, it may be included in a command and control principal agent framework and considered simultaneously with command and control type provisions.

The magnitude of the "passive" positive externality associated with the agent's actions depends on the amount of rent collected and the manner in which the principal collects rent. If no rent is collected, the private equity of the agent is complete and no penalty is required in the absence of market failures. Likewise, in the absence of market failures, if rent is collected so that it is not dependent on the output of the firm, no penalty is required. To the extent that rent is collected with production dependent mechanisms, the agent's equity decreases, and the optimum penalty must increase to internalize the positive externality. This phenomenon creates a result that is in marked contrast to solutions found in the principal agent literature dealing with command and control provisions and "active" negative externalities. While the command and control literature concentrates on total social costs of non-compliance, the solution in the "passive" sharecropping case involves subtracting those costs which are internal to the agent from the total social costs, in order to calculate that portion of costs which is external to the agents. Accordingly, in the absence of market failures, resource rents, collected by principals as a function of output, represent the portion of costs which are external to agents and are the relevant values to use in penalty calculations. In sum, in cases where agents have shares in future benefits, the optimum penalty does not depend on the total potential value of the resource being enhanced, but on that portion of the potential value which is collected by the principal and external to the incentives of the agent.

As equity shares held by the agent increase, penalties, and transactions costs associated with policing agents' actions may decrease. Future research may examine the potential for governments to reduce transactions costs by decreasing the amount of equity that they take from forestry firms in the form of stumpage fees. However, even if the firm is given complete equity, penalties are nonetheless required in the presence of market failures. To the extent that there are "active" externalities associated with the actions of firms, and to the extent that there are divergences between private and social discount rates, penalties may be used to align agents' and social objectives.

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