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Optimal hardwood tree planting and forest reclamation policy on reclaimed surface mine lands in the Appalachian coal region

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ABSTRACT

We study the optimal hardwood tree planting decision on reclaimed surface coal mines in the Appalachian region using a mine operator-focused, expected cost model that recognizes costs of preparing the site for tree planting, unit costs of planting seedlings, and opportunity costs of reforestation treatments and the performance bond. We also consider the possibility of failed initial attempts by incorporating the probability of reforestation success, based on empirical seedling ,survival rates and regulated tree survival standards, as well as fixed and unit costs of returning for additional planting. Optimal planting levels from 319 to 780 trees per acre and expected costs from $1049 to $2338 were found using simulations over a range of unit planting costs, fixed costs of replanting, tree survival standards, and interest rates. Further simulations compared optimal planting across unweathered gray sandstone and weathered brown sandstone substrate materials, finding gray sandstone to be associated with lower expected costs. We conclude that optimal planting density and expected reforestation cost are sensitive to economic parameters, regulations, and planting substrate materials; and those policies influencing these factors may have substantial impact on reforestation outcomes and the choice of post-mining land use by mine operators. Our study provides a framework for understanding forest reclamation decisions that incorporates incentives faced by the mine operators who develop and implement the plans for mine reclamation, including forestry.

Introduction

Although most surface coal mine lands in the Appalachian region were hardwood forests prior to mining (Burger and Zipper, 2011), the predominant reclamation approach since the enactment of the Surface Mining Control and Reclamation Act of 1977 (SMCRA) has entailed the establishment of grasses ostensibly for hay production and grazing (Ford, 2004, Isabell, 2004). The hayland/pasture post-mining land use preference was likely due to the ease of grassland establishment and bond release, while being justified as "higher or better use" than native forests (Baker, 2008). However, as many of these established grasslands have gone unused, interest has grown in restoring forests for a variety of benefits such as marketable products and so-called ecosystem services that forests can provide (Burger and Zipper, 2011).

Perhaps most notable among the efforts to restore native forests to the region are those of the Appalachian Regional Reforestation Initiative, and their Forestry Reclamation Approach (FRA) (Burger et al., 2005; Zipper et al., 2011). Though forest reclamation practices such as the FRA are becoming well developed and accepted, little recognition has been given to economic tradeoffs inherent in reforestation decisions. Recognizing these tradeoffs is important for making efficient use of often limited funding for reclamation efforts, as well as in designing policy tools for encouraging adoption of reclamation on existing and abandoned mine lands.

Economic tradeoffs can be considered where specific reforestation treatment levels are not prescribed in state-specific regulations established under SMCRA, such as tree planting level which we consider here. Despite that tree survival standards are mandated in individual state regulations, the number of seedlings planted is not specified, and in making that decision mine operators must weigh immediate costs of planting against the risk of having to return to the site to mitigate an unsuccessful reforestation outcome. That is, a greater number of trees planted will increase upfront costs, but may improve the likelihood of meeting the regulated survival standard and thereby reducing expected mitigation costs. Of course, upfront cost could be reduced by planting fewer trees initially, but the probability of realizing a failed outcome and having to pay additional replanting costs also will be increased. Complicating this decision are multiple factors that include site conditions and expected seedling survival over the liability period, economic parameters such as

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planting costs and prevailing interest rates, and regulated survival standards that vary by state. Mine operators attempting to implement forest reclamation and the regulators who oversee and approve reclamation plans have had little guidance[1] in making such economic decisions.

Of recent interest in the forest reclamation literature is the role of soil substrate material in the success of forest establishment (e.g., Emerson et al., 2009; Showalter et al., 2010; Skousen et al., 2011; Zipper et al., 2011). In the Appalachian coal region characterized by its steep slopes, brown weathered and gray un-weathered sandstones are used commonly as soil substitute materials in mine reclamation when original soils are unavailable in sufficient quantity (Zipper et al., 2011). A particular preference is expressed in this literature for the use of brown weathered sandstone-based material over gray, un-weathered sandstone as a top soil substitute in reclamation where native soils are not available due to improved growth characteristics. However, these parent materials have shown differing characteristics regarding tree seedling survival, with higher seedling survival noted in the gray sandstone (Emerson et al., 2009), which raises a question of the economic cost of utilizing the best growth medium with the brown sandstone.

In this paper, we seek to outline an economic framework for analyzing tree planting for surface mine reforestation, and apply the framework to identify optimal mixed hardwood tree planting levels across scenarios regarding economic parameters and state-specific policies regarding survival requirements for performance bond release. Our analysis utilizes recent empirical findings on tree seedling survival, and further allows us to consider the implications of differences in soil substitute materials (i.e., gray versus brown sandstone) on planting sites.

The remainder of the paper is structured as follows. First, we develop a decision framework that recognizes the economic perspective relevant to a mine operator facing the tree planting decision as a part of forest reclamation of surface mine land. Second, we construct and implement an empirical analysis based on our decision framework to determine optimal mixed hardwood tree planting levels under a range of assumptions regarding tree planting costs and prevailing interest rates. We also consider differences in optimal planting and expected costs across soil substitute materials. Finally, we offer conclusions and policy implications.

Decision framework

The tree planting decision in the mine reclamation context is fundamentally different than in earlier studies of optimal tree planting in traditional reforestation situations (e.g., Caulfield et al., 1992; Gong, 1998; Huang et al., 2005; Solberg and Haight, 1991; Taylor and Fortson, 1991), where the objective typically is maximization of (discounted) net future commercial forest value, based on the traditional Faustmann model of bare land value (see Amacher et al., 2009 for discussion). In mine reclamation, mine operators are tasked with meeting performance standards used to judge successful reforestation, which when met satisfactorily ends operator liability for reclamation of the site and allows remaining portions of the reclamation performance bond to be released. When performance standards are deemed to be unmet, operators must return to the site to repair deficiencies, with the liability period being extended and final bond release delayed until standards are satisfied. Hence, following Sullivan and Amacher (2009, 2010), the optimal tree planting decision for the mine operator involves minimizing expected (discounted) costs, which recognizes initial planting expenses, expected mitigation costs in the event of a failed initial reforestation attempt, and the opportunity cost of the reclamation performance bond, which can be expressed in this case as follows:

$$EC(D,\bar{S}) = C_G\delta^{t_M} + c_D D\delta^{t_M} + \int_0^{t_M+t_F} rB\delta^t\,dt + [1-\rho_1(D,\bar{S})]EC_2\delta^{(t_M+t_F)} \quad (1)$$

where EC is the expected (discounted) cost of forest reclamation at the time the mine permit is issued, D is the tree planting level (trees per acre), $\bar{S}$ is the tree survival standard (trees per acre) required for a successful reclamation project and subsequent final bond release, C_G is the total cost of preparing the site for tree planting (i.e., grading the site and establishing herbaceous ground cover)[2], c_D is the unit cost of planting seedlings (i.e., seedlings and labor), the performance bond is denoted as B, and lost annual bond interest is rB. A critical factor in the operator's decision is the probability of reforestation success, $\rho_1(D,\bar{S})$, which is based on planting level and tree survival standard, where $\partial\rho/\partial D > 0$ and $\partial\rho/\partial\bar{S} < 0$. Mining and reforestation time periods are represented by t_M and t_F, respectively, r is the interest rate, and δ is a discount factor (i.e., $\delta = e^{-r}$).

Eq. (1) calculates expected costs at the point in time at which the reclamation plan is agreed upon and the mining permit granted, hence all costs are discounted to that time. At the reclamation stage of an overall mining operation, previous costs of mining are unrecoverable, often referred to as "sunk" costs, and thus they do not factor into current reclamation decisions. In addition, growth and value of future timber stands are not incorporated into our model, as they are in the Faustmann-based models mentioned above, due to differences in objectives between forest landowners and mine operators, for whom the obligation and decision-making end when reclamation performance standards are met.

In the event of unsuccessful bond release in the initial attempt, the process is repeated, and EC_2 represents the expected cost at the time of the second next forest establishment attempt:

$$EC_2(D,\bar{S}) = C_R + c_D D + \int_0^{t_F} rB\delta^t\,dt + [1-\rho_2(D,\bar{S})]EC_3\delta^{t_F}$$

where: C_R represents a fixed cost for returning (labor and equipment) to the site[3] , which the operator might incur along with the variable costs of planting trees $c_D D$. Likewise, EC_3 represents the expected cost of the third attempt in the event that the second attempt fails. The process could continue to repeat until final bond release is achieved:

$$EC_i(D,\bar{S}) = C_R + c_D D + \int_0^{t_F} rB\delta^t\,dt + [1-\rho_i(D,\bar{S})]EC_{i+1}\delta^{t_F} \quad \forall i = 3 \text{ to } \infty$$

Minimization of expected costs in (1) will yield optimal planting level, D^*, for a given tree survival requirement, $\bar{S}$, which varies according to state mining regulations established under SMCRA. We anticipate that D^* will increase with $\bar{S}$, i.e., $\partial D^*/\partial\bar{S} \geq 0$. In addition, our framework allows us to consider the effect of

[1] Burger and Zipper (2011) suggest that 550 crop trees per acre, plus 60–100 wildlife-promoting trees might be an appropriate planting level in Virginia, where a tree survival standard of 440 trees per acre is required for final performance bond release for commercial forests. Their suggestion is based on an assumption of a 70% seedling survival rate, where 650 trees planted would be expected to yield 455 surviving trees per acre.

[2] Our cost of preparing the site (C_G) includes the first three steps of the FRA process: (1) creating a suitable growth medium, (2) loosely grading the topsoil or topsoil substitute, and (3) establishing herbaceous ground cover.

[3] These fixed costs are not included in (1), because it is assumed that labor and equipment are already on site, and do not have to be returned to the site, as we would expect in subsequent reforestation attempts.