Why don’t environmental bonds fully cover reclamation costs?☆

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ABSTRACT

Governments often require that extractive industry firms post environmental bonds as financial assurance to cover eventual reclamation liabilities. Such bond requirements frequently do not fully cover the reclamation cost. We show that a revenue-maximizing government may reasonably require a bond amount smaller than the full reclamation cost. This is because large bonds may discourage the extractive activities, diminishing fiscal income from project rents that could more than offset the decreased reclamation liability falling on the government. The selected bonding rate largely depends on the regulator’s estimation of the elasticity of exit in response to bonding. Western Australia’s recent refund of mining reclamation bonds to strong balance sheet firms, the US Bureau of Land Management’s (BLM) historical concern over exit of oil and gas operators on onshore federal lands in response to bonding requirements and willingness to accept for its own account reclamation risks associated with incomplete bonding, and Texas’s requirement for full-cost onshore oil and gas reclamation bonding are shown to all be consistent with this calculus.

1. Introduction

In most countries mining and energy firms must post a bond to ensure that disturbed land is reclaimed after production ends. The bond may be forfeited if the firm does not reclaim as required. Some literature recommends the bond be set to cover the worst-case scenario (e.g., Costanza and Perrings, 1990; Boyd, 2002). In the United States, the Surface Mining Control and Reclamation Act of 1977 (SMCRA) requires that a bond must be adequate to cover the cost of reclamation as determined by the “worst case scenario” (US DOI, 2000). The US EPA’s draft proposal for CERCLA 108(b) also proposed bonding or other financial assurance amounts that covered the worst-case scenario (US EPA, 2017). However, governments often intentionally set bonding rates that fail to cover full reclamation costs, even on average, such that reclamation is in part funded by the taxpayer (Webber and Webber, 1985; Galloway and Fitzgerald, 1987; Dutzik et al., 2013). In Western Australia bonding only covered 25% of anticipated mine reclamation costs (Government of Western Australia, 2014). For coal mining in Pennsylvania, the average reclamation cost per acre has been about $6,700, while the average bond amount per acre has been about $730 (Shogren et al., 1995, p.120). A 2011 federal review of “Performance Bond Adequacy” in Kentucky showed that 49 coal mining bonds were forfeited between January 1, 2007 and May 1, 2010. Only 7 of the 39 forfeitures examined had a sufficient bond amount to complete reclamation (US DOI, 2011). Previous federal reviews had shown similar deficiencies in Kentucky and in other states (Means and Armstrong, 2013). Even when the federal government urged, and indeed required, Kentucky to overhaul its bonding to full-cost standards in order to comply with SMCRA, state officials were concerned that such standards would be “impractical and unaffordable” to many operators (Cheves, 2013). Ho et al. (2018) measure onshore oil and gas well bonding in 13 US States and find that 11 of them have insufficient bonding requirements to cover even the average plug & abandon cost of orphan wells. In the 9 states where the highest actual reclamation costs are listed, bonding at best only covers 25% of those costs, and on average covers only 7%. At the federal level, the US Bureau of Land Management has historically been directed “not to place an undue burden on industry” when setting oil and gas bond amounts (US GAO, 2011). In a 2008 survey only 73 of the 120 US-based oil and gas operators in the Gulf of Mexico were required to post full-cost reclamation bonds, and even then the posted bond requirements were well below the reclamation costs realized by these operators (Kaiser and Snyder, 2009).

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1 We calculate this number from the data provided in Table S5 of the Supporting Information of Ho et al. (2018).

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Is there any rational explanation for governments choosing such low bonding amounts? There is certainly the possibility that as reclamation costs escalate state bonding formulas cause bonding amounts to be insufficient (Kaiser and Pulispher, 2008), or that regulators do not have full information on the actual reclamation costs and consistently underestimate them. But in many cases it is clear that governments do not want or expect firms to post full-cost reclamation bonds. This paper formally models an explanation qualitatively proposed by Peck and Sinding (2009), where “revenue hungry host governments” will select a bond rate that covers less than full-cost liability because that maximizes their net tax revenue. We undertake no analysis of the efficiency of bonding or taxation as a remedy for stock pollution (see, for example, Farzin, 1996; White et al., 2012; Yang and Davis, 2018), and nor of the injustices that incomplete bonding and delayed government-led reclamation can impose on societies (Peck and Sinding, 2009), and simply analyze how revenue-maximizing governments that ignore these factors may come to decide upon incomplete bonding amounts. For such a revenue-maximizing government the tension is between the increased financial crisis that come with more extractive activities versus the increased reclamation burden that falls on the government due to insufficient bonding amounts.

Concerns about full-cost bonding pushing producers out of the market seem warranted. Mitchell and Casman (2011) suggest that large bonds have liquidity constraints and may pose significant barriers for firms entering the market. Western Australia’s six-year plan to gradually increase bonding rates to cover the full cost of mine rehabilitation and closure was halted when the global financial crisis hit and there were concerns that increased bonding fees would drive mining firms out of business (Greore et al., 2014). According to Kentucky state officials, some small independent coal mine operators are unable or unwilling to secure surety bonds because of the substantial collateral required (US GAO, 1988). And Boomhower (2019) finds that an increased bond requirement in Texas immediately pushed about 5% of the producers, mainly small operators, out of the market. Kaiser and Snyder (2009) worry that increasing bond amounts for small oil and gas operators in the Gulf of Mexico will put them out of business.

The rest of the paper is arranged as follows. In Section 2, a model of a revenue-maximizing government’s bonding rate selection in light of a firm’s investment responses to bonding is developed. In Section 3 we show that the bond rate set by such a government is a function of entry and environmental shirking elasticities. The results are demonstrated via a calibrated simulation. Conclusions are given in Section 4.

2. The model

To avoid the complexities with market-provided financial assurance, we presume that financial assurance is achieved by the firm annually depositing a percentage of a project’s reclamation cost into a trust fund. As suggested by Mitchell and Casman (2011) and Dutzik et al. (2013), the trust fund can be transferred along with the ownership of the project. Thus each property owner has to pay a share of the ultimate cleanup cost, and reclamation may be undertaken regardless of the solvency of the last operator (Mitchell and Casman, 2011). We also assume that reclamation can only happen at the end of operation and therefore there is no progressive reclamation during operation. Reclamation is binary; it is either undertaken to its full extent by the firm, or the site is abandoned and the responsibility for full reclamation falls on the government.

In its simplest form, suppose there are a number of identical extractive projects operating in a jurisdiction controlled by a government. All projects are initiated at time 0 and terminated at time T.

During that period the total net revenue of each project is \( pQ \), where \( p \) is the competitive net price and \( Q \) is the cumulative sum of the annual production, \( Q = \int_0^T q(t) dt \). Let \( C \) represent the full reclamation cost at time \( T \), known to both the firm and the government and unaffected by the bonding mechanism. A percent of (0 ≤ \( \alpha \) ≤ 1) of the project’s reclamation cost is deposited annually into an escrow account (a trust fund), making the cumulative trust amount \( aC \) at time \( T \). When \( \alpha = 1 \), the trust amount can fully cover the real reclamation cost \( C \) at time \( T \). For any \( \alpha < 1 \), reclamation is not fully funded and default on the part of the final operator transfers some of the burden of reclamation onto the government, and ultimately the taxpayer. We first analyze how a firm responds to this bonding requirement.

2.1. The firm’s decisions on reclamation and entry

Suppose there are \( N \) identical, socially beneficial, permitted projects operated by two or more non-identical firms. By socially beneficial we mean that the rent produced by each project, \( pQ \), exceeds the costs of reclamation, \( C \), by enough to fund the project’s initial investment. The firms operating the projects vary in two ways. First, they vary in their ability to finance the reclamation bond, indicative of market frictions, with the variance perhaps a result of size and strength of the balance sheet. For clarity we could refer to those with limited abilities to fund reclamation bonding as small firms and those with deep pockets as large firms. Second, we assume that since bonding has not in practice been complete and yet reclamation is often undertaken, each firm has its own, positive reputational costs from shirking that can cause it to choose to reclaim even under incomplete bonding. Such reputational costs reflect the influence of investors, local communities, NGOs, and other stakeholders (Peck and Sinding, 2009; Berg et al., 2018). Large firms with sustained operations in the region may suffer greater reputational costs from abandoning reclamation as compared with a firm with only that operation in the region. Each firm in operation during the planning period and subject to a bonding requirement maximizes the NPV of its project by optimizing its reclamation decision,

\[
NPV = (1 - \beta)pQ - r(aC \text{ min}(C, aC + Rep)),
\]

where \( \beta \) is a constant percentage of profits (0 < \( \beta \) < 1) taken by government via an income tax or net proceeds royalty, \( r(aC) \) is firm j’s total cost of financing the reclamation bond during operations and \( Rep \) is the reputational costs for firm \( j \) from shirking reclamation at the end of the project life. In the absence of reputational costs, for any \( \alpha < 1 \) all firms would shirk reclamation, as demonstrated in practice by declaring bankruptcy (United States Court of Appeals, 2016, p.10), walking away, or claiming temporarily suspended operations (Muehlenbachs, 2015).

Given the schedule of reputational damage across firms from shirking, from the last term in equation (1) as \( \alpha \) increases fewer firms will find \( aC + Rep < C \) and as a result more firms will choose to undertake reclamation at cost \( C \). Hence, the following market responses to bonding are considered:

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2. An alternative bonding system, a “bond pool,” that requires less initial expenses has been recommended to cover these small operators (US GAO, 1988).

3. Our paper abstracts from the reality that the bonding mechanism will distort, either intentionally or unintentionally, the production, abatement, and ongoing reclamation decisions of the firm (Farzin, 1996; White et al., 2012; Yang and Davis, 2018).

4. To avoid unnecessary complexity we assume an interest rate of zero. We limit bonding to a maximum of the full reclamation cost to prohibit revenue-seeking governments from turning environmental bonding into a source of fiscal revenue.

5. Frictions include the administrative costs of obtaining bonding and the opportunity cost to the firm of tying up those funds (Boyd, 2002; Davis, 2015). The US EPA estimated in 2016 that such costs could be on average as high as 3% of the bonded amount (United States Environmental Protection Agency US EPA, 2016).
Assumption 1. The probability that the operator of a project will shirk the duty of reclamation is \( f(\alpha) \), where \( 0 \leq f(\alpha) \leq 1 \) and \( \frac{\partial f}{\partial \alpha} \leq 0 \).

Each firm, given its value-maximizing reclamation decision modeled above, enters only if the NPV in equation (1) is positive. As the bond rate increases, firms with the highest financing costs and the highest reputational costs of shirking cleanup may find the project uneconomic on an after-tax basis and will not enter:

Assumption 2. With a trust fund accumulating \( \alpha \) percent of \( C \), the number of projects will reduce to \( N(\alpha) \), where \( 0 \leq N(\alpha) \leq N(0) = N \)
and \( \frac{\partial N}{\partial \alpha} \leq 0 \).

Assumption 2 provides that as the bond amount increases, some projects may be suboptimally curtailed due to the financial frictions associated with higher project bond financing costs. In addition, similar to the relocation of some extractive activities to jurisdictions with lower tax rates (Manillo and Manning, 2018), some projects may be suboptimally reallocated to other jurisdictions with smaller bonding requirements (Galloway and Fitzgerald, 1987). In the extreme, \( N(\alpha) \) may be zero with any positive \( \alpha \). In the other extreme, the bond rate may have no effect on the number of projects. Based on these market responses, we now examine government’s decision over bonding levels.

2.2. The government’s decision over bonding levels

The government’s problem is to incentivize firms to reclaim at the end of operations via reclamation bonding. Insights as to why governments may require less than full bonding can be gained from a relatively simple model of government choice over bonding levels such that its net revenue from extractive activity is maximized. We model a single government entity that receives taxes and royalties from the extractive projects and is also responsible for reclamation in the event of a firm’s default. In the case of default the government has access to the established trust fund for a firm’s project or projects. Thus \( f(\alpha) \) is also the probability of the trust fund for that firm’s projects being forfeited to the government.

In a single-period representation of the planning horizon over which firms operate, pay into the trust fund, and then either default or reclaim the disturbed lands, the government seeks to maximize its aggregate positive net revenue,

\[
\text{Maximize } R = \beta pQ N(\alpha) + f(\alpha)N(\alpha)\alpha C - f(\alpha)N(\alpha)C. \tag{2}
\]

In equation (2), \( \beta pQ N(\alpha) \) represents the government tax and royalty revenue over the production period, paid by all \( N(\alpha) \) projects that are active. To simplify the analysis we assume that the royalty rate \( \beta \) is fixed.\(^8\) The term \( f(\alpha)N(\alpha)\alpha C \) is the total income to the government from the forfeited funds as released by the delinquent firms at time \( T \). The final term \( f(\alpha)N(\alpha)C \) is the total cost that the government has to pay for the reclamation that is shirked by firms.\(^8\) When \( \alpha < 1 \), reflecting current practice by governments of not requiring fully covered bonding, the sum of the last two terms is negative. Yet in maximizing total net revenue, and given that any project that diminishes net revenue will not be permitted, a government that requires incomplete bonding will only permit projects with positive societal NPV.\(^10\)

From Assumptions 1 and 2, the bond rate \( \alpha \) will affect government net revenue in two ways. First, a higher \( \alpha \) has a negative effect on the number of operating projects in a jurisdiction. This decreases fiscal revenues. Second, the higher \( \alpha \) reduces the net reclamation burden on the government by reducing the number of defaulting firms both through a direct reduction in the number of firms in operation and a reduction in the number of those firms defaulting.

Taking the first order condition,

\[
\frac{\partial R}{\partial \alpha} = \beta pQ \frac{\partial N}{\partial \alpha} + f(\alpha)N(\alpha)C + \left( \frac{\partial f}{\partial \alpha} N(\alpha) + f(\alpha) \frac{\partial N}{\partial \alpha} \right) \alpha C = 0. \tag{3}
\]

When \( \alpha > 0 \), we can define the entry elasticity as \( \epsilon_N = \frac{\partial N}{\partial R} \) and the shirking elasticity as \( \epsilon_f = \frac{\partial f}{\partial \alpha} \). From \( \frac{\partial f}{\partial \alpha} \leq 0 \) in Assumption 1 and \( \frac{\partial N}{\partial \alpha} \leq 0 \) in Assumption 2, it follows that \( \epsilon_f \geq 0 \) and \( \epsilon_N \leq 0 \). Equation (3) can then be rewritten as,

\[
\frac{\partial R}{\partial \alpha} = \frac{\partial N}{\partial \alpha} \beta pQ N(\alpha) + f(\alpha)\alpha C + (\epsilon_f + \epsilon_N) (\alpha - 1) C = 0. \tag{4}
\]

Rearranging equation (4) yields the revenue-maximizing bond rate,

\[
a^* = f(\alpha)C (\epsilon_f + \epsilon_N) - \beta pQ N(\alpha) \frac{f(\alpha)}{f(\alpha)C (1 + \epsilon_f + \epsilon_N)} \tag{5}
\]

It should be noted that equation (5) is an implicit function with \( f(\alpha) \) a function of \( \alpha \).

Actual government choices over taxation of extractive activities are considerably more complex than what we have modeled here. For example, there may be information asymmetries over the actual cost of reclamation, and the government’s selection of the bonding level may be clouded by an inaccurate understanding of the bonding cost \( C \). If this is the case governments may approve and establish bond trusts on projects that have negative social value. It is our opinion that governments have a good basis for estimating total reclamation costs, and hence bonding levels, based on their experience as regulators and based on the fairly regular relationship between production and reclamation costs (see Andersen et al. (2009)), as well as the example of demonstrated empirical efforts by the EPA to understand reclamation costs under the 2018 CERCLA 108(b) proposed bonding rules (US EPA, 2017). The threat of audit and fines also provides incentives for companies to report accurately. In Western Australia, where there is an annual levy on reported mine waste stocks, an audit of 1881 mining tenements revealed 1596 as having waste stocks being accurately reported by the firm (Government of Western Australia, 2020). Moreover, reclamation costs become clearer as waste stocks build over time. Our modeling results would not change if the bonding cost \( C \) was updated annually as new information came to light. Governments may also be concerned with more than just maximizing net revenues (e.g., Manillo and Manning, 2018). Our model highlights only the salient tax components needed to explain incomplete bonding and includes complexities such as financial frictions and tax jurisdiction competition through the reduced-form

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\(^6\) We assume that the bond rate \( \alpha \) affects the total production of a jurisdiction mainly through reducing the number of projects \( N(\alpha) \) rather than \( Q \). See Boomhower (2019).

\(^7\) As net revenue from extractive activity decreases, perhaps due to increased bonding requirements, non-resource taxes may be increased to offset the loss. Given evidence that the offset is incomplete (Crivelli and Gupta, 2014; James, 2015), there is no loss in generality from ignoring these offsets.

\(^8\) Allowing \( \beta \) to decrease with \( \alpha \), as might be the case when governments try to offset the losses from decreased bonding income by increasing royalty rates, would not change Assumptions 1 and 2 below as long as the offset is incomplete and NPV continues to rise as bonding requirements fall.

\(^9\) It may be that reclamation is more expensive for government. Adding a multiplier to \( C \) in the last term \( f(\alpha)N(\alpha)C \) adds nothing to the insights of the model and so we abstract from this possibility.

\(^10\) In the case where the firm shirks reclamation, according to equation (1) the firm only proceeds with the project if \( (1 - \beta pQ - \tau C - aC - R_{Rep}) > 0 \), or \( pQ > \beta pQ + (1 + \tau) aC + R_{Rep} \). If governments only permit projects with \( R = \beta pQ + aC - C > 0 \), then \( pQ > R + C + (\tau aC + R_{Rep}) > C > 0 \). Thus, only projects with a positive societal NPV \( (pQ - C > 0) \) will be permitted. When financing frictions \( \tau \) cause the project’s NPV to be negative, \( pQ > \beta pQ + (1 + \tau) aC + R_{Rep} \), the firm will not proceed with the project. However, it is still possible that \( pQ > C \), and that the frictions associated with bonding result in the cancellation of a project with positive societal NPV, an inefficient outcome whereby too few projects are undertaken.
functions \( f(\alpha) \) and \( N(\alpha) \). Given these reduced-form functions the elasticities of firm responses to bonding, both in terms of entry and shirking, are the key concern when revenue-maximizing governments set bonding rates. The next section examines bonding decisions under a range of entry and shirking elasticities.

3. The bond rate under different cases

3.1. Perfect inelasticity of entry under varying bond rates

The actual reclamation cost may be a very small percent of a project’s net revenue and thus the corresponding bond amount, even under a fully covered obligation, may not curtail any operations. In the extreme, the number of projects entering with respect to the bond rate is perfectly inelastic, \( \varepsilon_N = 0 \). In this case, we have the following proposition:

**Proposition 1.** If the number of projects entering is perfectly inelastic with respect to the bond rate, the government will require a bond equal to the full reclamation cost.

**Proof:** At \( \varepsilon_N = 0, N(\alpha) = N \forall \alpha \) and \( \frac{dN(\alpha)}{d\alpha} = 0 \). From equation (2), we have \( \frac{d\alpha}{\alpha} = \frac{\partial N}{\partial C} f(\alpha) + \frac{\partial f(\alpha)}{\partial \alpha} (\alpha - 1) > 0 \). Government net revenue increases with \( \alpha \) until it is maximized at \( R(\alpha^*) = R(1) = bpQN(1) \) and there is no burden on the government from reclamation.

Proposition 1 shows that if bonding requirement does not deter any projects from entry, the government will charge a bond amount to cover the entire future reclamation cost, a corner solution.

3.2. Perfect elasticity of number of projects entry under varying bond rates

In the other extreme, the number of projects entering this market may be very sensitive to the bond rate. If a small amount of bond poses an entry barrier for all operators, \( \varepsilon_N = -\infty \). This may be the case when \( N \) is a very small number (for example, \( N = 1 \)), or when only small operators are in this market and their bond financing costs are high.

**Proposition 2.** If the number of projects entering is perfectly elastic with respect to the bond rate, the government will not charge a bond as long as the government revenue from taxation is high enough to cover the reclamation cost.

**Proof:** At \( \varepsilon_N = -\infty, N(\alpha) = 0 \) for any \( \alpha > 0 \). Government fiscal revenue will be zero, as the industry is shut down. If the government does not charge a bond \( (\alpha = 0) \), net revenue will be \( R = bpQ - f(0)/C \). As long as \( bpQ > f(0)/C \), the fiscal revenue can cover the reclamation cost and thus will be positive and maximized at this corner solution.

In this scenario income taxes are substituting for bonding. If income taxes do not fully cover reclamation, \( bpQ < f(0)/C \), and the government will charge a positive bond such that entry is prohibited.

3.3. Moderate elasticity cases

In the above two extremes the bond rate will be either at a level that completely covers the reclamation cost or at zero. Here we assume that the bond rate has a more moderate effect on the number of projects that operate in a jurisdiction, \( -\infty < \varepsilon_N < 0 \). From equation (2), when \( \alpha = 1, N(1) > 0 \), we have government net revenue \( R = bpQN(1) > 0 \). Because \( \frac{\partial N}{\partial \alpha} < 0, \) there may exist an \( \alpha < 1 \) that can increase government net revenue:

**Proposition 3.** When \( -\infty < \varepsilon_N < 0 \), the government may be able to achieve a higher net revenue by charging a bond smaller than the full reclamation cost.

**Proof.** When \( \alpha < 1 \), there would be more project entry in the jurisdiction and thus \( N(\alpha) > N(1) \). Government net revenue is \( R(\alpha) = bpQ N(\alpha) + f(\alpha) N(\alpha) (\alpha - 1)C \). Compared with \( R(1) = bpQ N(1) \), there could exist \( R(\alpha) > R(1) \) when the absolute value of \( f(\alpha) N(\alpha) (\alpha - 1)C \) is small.

When \( R(\alpha) > R(1) \), the following condition exists:

\[
\beta |N(\alpha) - N(1)| > - f(\alpha) N(\alpha) (\alpha - 1)C.
\]

The left-hand side is the increased government tax revenue from additional firms in the sector and the right-hand side is new government cost (the bond deficit) from sharing reclamation costs. As long as the increased income is great enough to offset insufficient bond amounts, the government can achieve a higher net revenue.

Confirming the noted government concerns about bonding forcing firms out of the market, the calculus of the revenue-maximizing bond rate in the case where incomplete bonding is indicated depends crucially on the entry and shirking elasticities. From Equation (5), a sufficient condition for a revenue-maximizing bond rate \( 0 < \alpha^* < 1 \) is:

\[
\varepsilon_N < -\frac{C}{bpQ} f(\alpha^*), \text{ if } \varepsilon_N + \varepsilon_f < -1;
\]

\[
\varepsilon_N > -\frac{C}{bpQ} f(\alpha^*), \text{ if } \varepsilon_N + \varepsilon_f > -1.
\]

That is, when either of the above conditions are satisfied, relaxing the bond rate from complete bonding will increase government revenue.

In the following section we examine revenue-maximizing bond rates under a range of entry and shirking elasticities.

3.4. Bonding under a range of entry and shirking elasticities

From equation (5), the derivative of \( \alpha^* \) with respect to \( \varepsilon_N \) is:

\[
\frac{\partial \alpha^*}{\partial \varepsilon_N} = \frac{fC - f(1 + \varepsilon_f)}{(1 + \varepsilon_N + \varepsilon_f) (f - \beta p Q N(\varepsilon_N \alpha^*) f(\alpha^*) + \beta p Q N(\varepsilon_N \alpha^*) f(\alpha^*))}
\]

When shirking is elastic to the bond rate, \( \varepsilon_f < -1 \), we have the following proposition:

**Proposition 4.** If the bond works well to reduce shirking \( (\varepsilon_f < -1) \), the revenue-maximizing bond rate will increase as \( \varepsilon_N \) becomes less elastic, until \( \alpha^* = 1 \).

**Proof.** If \( \varepsilon_f < -1, \) equation (7) is positive. The revenue-maximizing bond rate will increase as \( \varepsilon_N \) increases until \( \alpha^* \) is maximized at 1, where \( \varepsilon_N = -\frac{C}{bpQ} f(1) \).

This relationship between the revenue-maximizing bond rate \( \alpha^* \) and the elasticity of project entry \( \varepsilon_N \) is represented in Fig. 1 where the relationship for interior solutions is assumed to be convex.

![Fig. 1. Project Entry Elasticity and the Revenue-maximizing Bond Rate.](image-url)
3.5. Simulating revenue-maximizing bond rates

In this section calibrated simulations are performed to illustrate the revenue-maximizing bond rates under different parameterizations of the model. To inform our simulations we look to the literature for reasonable parameter levels. According to Lin et al. (1976), when coal reclamation requirements changed from bonding for 50% backfilling to 100% backfilling, total coal production decreased by about 3%. In our model, the bond amount over the reclamation cost αC corresponds to the percentage of backfilling. For example, when the bond rate α changes from 0.5 to 1, backfilling would increase from 50% to 100%. We take the reduction of total production as a decrease of the number of projects in a jurisdiction. Thus, the project entry elasticity in that case would be \( \varepsilon_N = \frac{\text{change of } N}{\text{change of } f} = -0.03 \). However, two recent studies of firm response to increased bonding in the US oil and gas industry find almost no change in aggregate production (Boomhower, 2019; Lange and Redlinger, 2019). This motivates an even lower estimate. We use \( \varepsilon_N = -0.005 \) for this lower elasticity and \( \varepsilon_K = -0.015 \) to represent a moderate case. Thus, we compare three different project entry elasticities \( \varepsilon_K: -0.005, -0.015 \text{ and } -0.03 \). To compare the different responses of small and big firms, we assign an elasticity of 0.03 to small firms and 0.005 to large firms.

The number of projects \( N(\alpha) \) is assumed to be in constant elasticity form \( N(\alpha) = 100\alpha^r \), reflecting 100 operating projects in a full bonding state and more projects as the bonding requirement is relaxed. Fig. 2 shows the number of projects entering in a jurisdiction when \( \alpha \) decreases under the three different elasticities.\(^{11}\) When the bond rate decreases from 100% to 0% of the reclamation cost, the number of projects increases by about 2%, 5% and 9% for entry elasticities of \( -0.005, -0.015 \text{ and } -0.03 \) respectively. Large firms (represented by \( \varepsilon_K = -0.005 \)) have lower responsiveness to the bond rate than small firms (represented by \( \varepsilon_N = -0.03 \)).

We use the cumulative logistic distribution function to define the reclamation shirking rate \( f(\alpha) \), where \( d \) and \( b \) are positive parameters such that \( f(\alpha) \) satisfies \( 0 < f(\alpha) < 1 \) and \( \frac{\partial f}{\partial \alpha} < 0 \). Note that the elasticity \( \varepsilon_f \) is dependent on \( \alpha \) using this formulation.

Boomhower (2019) shows that prior to a bond requirement in Texas, the rate of orphaned wells was 9.7% among small operators. Under a $2/ft bonding requirement, reclamation shirking went from 9.7% to 2.3%. While it is not clear whether Texas expected this bond amount to cover reclamation costs in full, Bay and Offshore operators were required to post an additional $60,000 for bay wells and $100,000 for offshore wells, equal to their “presumed plugging cost” (Railroad Commission of Texas, 2005). If we consider the kind of reduction in shirking measured by Boomhower (2019) as a response to the implementation of complete bonding, we can let \( f(0) = 100\% \), where the reputational costs mentioned in our model cause 90% of firms to conduct full reclamation even under a zero bond requirement, and \( f(1) = 2\% \).\(^{12}\) This calibrates the parameters \( d = 2.2 \) and \( b = 1.6 \), providing an elasticity of shirking of \( 1.6 < \varepsilon_f \leq 0 \) for the entire range of \( \alpha \) from high to low.\(^{13}\) If we consider a larger initial probability of shirking, \( f(0) = 20\% \), we will have the parameter \( d = 1.4 \) in \( f(\alpha) \), providing \( -1.5 < \varepsilon_f \leq 0 \). The tax rate \( \beta \) is set at 35% of the project’s revenue.\(^{14}\) For simplicity we set the project’s net revenue \( pQ = 1 \) with a reclamation cost \( C = 0.05 \) and \( C = 0.2 \) to represent the cases of low reclamation cost and high reclamation cost, respectively, for two societally positive NPV projects. In Table 1 we summarize the parameters for the basic and alternative models.

For the base model \( (f(0) = 10\%) \) Fig. 3a shows that when the reclamation cost is relatively small \( (C = 0.05) \), the best strategy is no bond requirement since the government’s revenue is maximized at \( \alpha = 0 \). Fig. 3b shows that when the reclamation cost is relatively large \( (C = 0.2) \), the government requires bonds covering 90% and 100% of reclamation costs when \( \varepsilon_K = -0.015 \) and \( \varepsilon_K = -0.005 \) respectively. These results are consistent with the real-world cases where bonds are often required only for the cases of high reclamation cost. In the mining industry, for example, there are some exceptions to bonding requirements when activities cause “little or no disturbance” (US GAO, 2016), and one of the first tasks under CERCLA 108(b) in the United States was to identify which industries to regulate via federal bonding. Priority was determined based on “degree of injury and risk” associated with the “production, transportation, treatment, storage, or disposal of hazardous substances.”

For the case of a relatively high responsiveness of firm entry to bonding, \( \varepsilon_K = -0.03 \), which we feel represents small firms, Fig. 3a and 3b shows that the government would elect not to require firms to bond over reclamation, even when reclamation cost is high.

Fig. 4 plots a series of revenue-maximizing bonding rates as entry elasticity varies, both for strong and weak balance sheet firms, firms with low \((f(0) = 10\%)\) and high \((f(0) = 20\%)\) probability of reclamation default, respectively. The plot confirms the negative relationship between the revenue-maximizing bond rate and the elasticity of entry proposed schematically in Fig. 1. There are 5 zones of interest. When entry elasticities are smaller than \(-0.012\) in the numerical simulation depicted in Fig. 4, bonding is set to 100% for all firms, even for firms that are unlikely to default. When the entry elasticity is slightly larger, between \(-0.018\) and \(-0.012\) in our simulation, weak balance sheet firms will face full bonding but strong balance sheet firms will face less than full bonding. For still larger entry elasticities, between \(-0.025\) and \(-0.018\) in our simulation, weak balance sheet firms will face full bonding but strong balance sheet firms will face no bonding requirement. For entry elasticities that are larger, between \(-0.037\) and \(-0.025\) in our simulation, weak balance sheet firms will face less than full bonding, while but strong balance sheet firms will still face no bonding requirement. When the entry elasticity is sufficiently negative, below \(-0.037\) in our simulation, there is no bonding requirement for all firms.

From this analysis governments that set different bonding rates across different types of firms could well have revenue maximization, rather than socially optimal reclamation incentives, as their objective. The two recent studies of firm response to increased bonding in the oil and gas industry in Texas and North Dakota find almost no change in aggregate production, with producing wells transferring from the few small operators who do exit to larger operators who remain (Boomhower, 2019; Lange and Redlinger, 2019). The full-cost bonding intent of the 2001 Texas oil and gas bonding initiative, set without concern for the default propensities of individual firms, is in keeping with the predictions of a revenue-maximizing agency that recognizes that exit is unlikely. This case is sketched onto the most inelastic firm entry zone in Fig. 4. The US Bureau of Land Management’s (BLM) historical concern over exit of oil and gas operators on onshore federal lands in response to bonding requirements, and its willingness to accept for its own account

\(^{11}\) When there is no bond requirement (\( \alpha = 0 \)), the number of projects \( N(0) \) is calculated using percentage increase from the previous number of projects \( N(0.1) \). For example, for \( \varepsilon_K = -0.015 \) at \( \alpha = 0.1 \), we have the number of projects \( N(0.1) = 100 \times 0.01 - 0.015 = 104 \). Then we calculate \( N(0) = N(0.1)/(1 + 0.015) = 105 \).

\(^{12}\) Here even complete bonding had a non-zero percentage of default, perhaps because of legitimate bankruptcies at the closure of the operation.

\(^{13}\) The function \( f(\alpha) \) assumes a higher bond rate works better to reduce shirking than a lower bond rate. For example, when \( \alpha = 1 \), \( \varepsilon_f = -1.56 \); when \( \alpha = 0 \), \( \varepsilon_f = 0 \).

\(^{14}\) Under our other parameterizations this results in a 44% government take of project rents in the high reclamation cost case, and 37% in the low reclamation cost case. These takes are on the low end of those observed empirically (Davis and Smith, 2019) so as to not bias the results too heavily in favor of low bonding rates.
reclamation risks associated with incomplete bonding, is consistent with this calculus (US GAO, 2011). So is its requirement for increased bonding amounts for firms with histories of non-compliance and who have weak balance sheets. 15 Similarly, the US Bureau of Ocean Energy Management (BOEM) has incomplete bonding requirements for offshore oil and gas, with an approximation to full bonding only for weak balance sheet firms, firms whose net worth is less than 400% of the potential end-of-lease reclamation liability (Kaiser and Pulsipher, 2008; Kaiser and Snyder, 2009). Western Australia’s decision to have incomplete bonding for weak balance sheet firms and no bonding for strong balance sheet firms is indicative of an estimation that the entry elasticity is relatively high compared with the Texas and federal oil and gas cases.

4. Conclusion

Cash reclamation bonds have been proposed as a low-risk alternative to current bonding mechanisms in the extractive industries (Boyd, 2002; Mitchell and Casman, 2011; Dutzik et al., 2013). What level of bonding will be called for by governments under this scheme? There is much to be learned from the simple recognition that governments may seek to maximize net revenue rather than economic efficiency or some other social objective. Our analysis shows that full bonding may well be implemented by revenue-maximizing governments if they expect there to be limited firm exit in response. Texas’s 2001 implementation of full-cost oil and gas reclamation bonding and the limited production decline in response is a case in point. However, if the bond is estimated to even modestly affect the number of projects and thus the total production in a jurisdiction, a revenue-maximizing government may relax the bond requirements and accept for its own account a certain share of reclamation costs. The current US Bureau of Land Management requirement of a fixed and incomplete bonding amount, with increased bonding only for previously delinquent operators and for operators with weak balance sheets, is consistent with revenue maximization under this presumption. The US Bureau of Ocean Energy Management requires full-cost bonding only for weak balance sheet firms, again consistent with a revenue-maximization algorithm when exit in response to full-cost bonding is anticipated. On the other hand, when firms are environmentally responsible due to strong balance sheets and demonstrated private incentives to reclaim, a zero bonding rate may be optimal under this revenue-maximizing objective. Western Australia’s recent removal of reclamation bonding on mining operators with strong balance sheets, while requiring it for firms with weak balance sheets, is reflective of these circumstances.

A key criterion for full-cost bonding over all firm types, which is typically the societal preference under the polluter pays principle, is the absence of exit in response to such bonding. Two recent empirical studies have shown little total variance in oil and gas production in Texas and North Dakota when increased bonding requirements were imposed (Boomhower, 2019; Lange and Redlinger, 2019). Additional studies of this nature for other extractive activities and in other jurisdictions would be most useful for revenue-maximizing governments seeking to determine the appropriate level of reclamation bonding.

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Table 1

<table>
<thead>
<tr>
<th></th>
<th>pQ</th>
<th>C</th>
<th>εk</th>
<th>f(α)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Base model</td>
<td>1</td>
<td>0.2</td>
<td>−0.015</td>
<td>f(0) = 10%, b = 1.6, d = 2.2, −1.6 &lt; e_f &lt; 0</td>
</tr>
<tr>
<td>Alternatives</td>
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<td>0.05</td>
<td>−0.03</td>
<td>f(0) = 20%, b = 1.6, d = 1.4, −1.5 &lt; e_f &lt; 0</td>
</tr>
</tbody>
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15 Instruction Memorandums sent in 2006, 2008, and 2010 to BLM field offices administering an oil and gas program state that “BLM staff are to be mindful of the need to maintain an acceptable risk level, yet not to place an undue burden on industry.” The latest Memorandum, issued in November 2018, replaces field office discretion with a bond amount of $5/ft. of idle well depth, augmented in a formulaic way when there is a history of operator non-compliance (https://www.blm.gov/policy/im-2019-014). That memorandum states that the BLM must also seek bond increases for firms with weak balance sheets, though with guidance that “the BLM will work with operators under financial duress on a case-by-case basis to ensure that lease operations can continue consistent with the applicable statutes and regulations.”


CRediT authorship contribution statement

Peifang Yang: Conceptualization, Methodology, Formal analysis, Writing – original draft, Writing – review & editing, Project administration. Graham A. Davis: Methodology, Formal analysis, Writing – review & editing.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Fig. 3. Government net revenue under different elasticities of entry in response to bonding, $f(0) = 10%$

Fig. 4. Project entry elasticity and the revenue-maximizing bond rate, $C = 0.2$

References


