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Mine Closure in Iberoamerica (Module V, Economy and Finances)

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Mine Closure in Iberoamerica

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MINE CLOSURE IN IBEROAMERICA

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MODULE V

ECONOMY AND FINANCES

IMPROVING ENVIRONMENTAL COMPLIANCE IN MINE CLOSURE: THE CASE FOR A SYSTEM OF PERFORMANCE BONDS

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I) INTRODUCTION

The mining sector presents an interesting challenge in terms of reducing its environmental impacts. Environmental impacts include the emissions of pollutants during the period that mining takes place, transformation of the landscape and the creation of conditions that can lead to environmental problems in the future. Although mining has traditionally been regulated by specifying a set of restrictions on mining activity, this system has not been particularly successful in terms of maintaining environmental quality in areas where mining is currently taking place and in areas where mining activity has been concluded. Although there certainly are examples of mining activity which has been done in a careful, environmentally protective fashion, this is generally the exception. As a consequence, it is essential that we develop a set of new environmental policy tools with which to transform mining into an activity which yields a smaller ecological footprint.

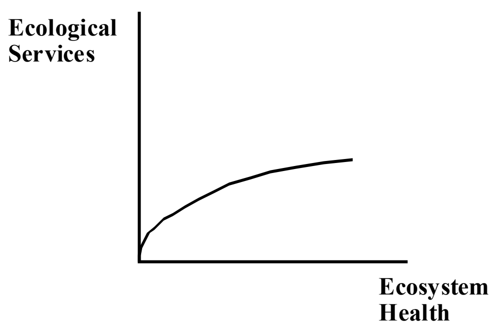
We suggest performance bonding as a policy tool that has the potential to contribute to the solution of the problem. A performance bond refers to a sum of money that is collected from the firm or individual before the potentially damaging activity begins. The money is typically held by the government or a third party (such as an NGO or in an escrow account at a commercial bank) and returned only if the activity concludes within the established restrictions. Although performance bonding has traditionally been used to ensure the restoration of surface mining areas in countries such as the United States and Canada, it has been a narrowly constructed environmental policy. First, it has only focused on the restoration of damages rather than the prevention of damages. Second, it has tends to focus on ensuring a minimum level of environmental quality rather than an optimal environmental policy. Third, it tends to be a discrete instrument, constructed as an “all or nothing” type of control. If the target or restrictions are only slightly violated, the entire bond is forfeited. In addition, there is no reward for exceeding the minimum level.

This paper develops a method which overcomes some of these limitations, transforming the performance bond into a continuous instrument that is capable of preventing damages. Section 2 discusses the structure of the proposed performance bonding system, highlighting its conceptual basis, its theoretical properties, and how it can be adapted to a broad set of environmental needs. Section 3 highlights environmental problems associated with mining in general, with a specific emphasis on mine closure. The section also shows the correspondence between these environmental issues associated with mining and mine closure and the performance bonding system outlined in Section 2. Section 4 provides a demarcation of the dimensionality of these problems both geographically and temporally. Difficulties engendered by temporal and geographical separation are solved by showing how an insurance system can be dovetailed with a performance bonding system. Section 5 details an example of the use of environmental bonding in a hypothetical mine closure example. Section 6 applies the performance bonding system to the artisanal and subsistence sectors of the economy, an area which has proved very difficult to handle with conventional environmental policies.

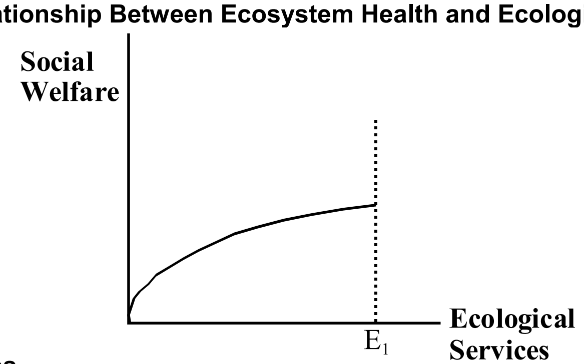
II) STRUCTURE OF A PERFORMANCE BONDING SYSTEM

The proper structure of a performance bonding system will be predicated on the relationship between social welfare and ecological services.[i] A reasonable interpretation of this relationship occurs in Figure 1, where social welfare increases at a decreasing rate as the level of ecological services are increasing. An important observation is that most of the social benefits of increasing the level of ecological services occurs before one reaches the level of services associated with a pristine ecosystem, which is E_1 in Figure 1.

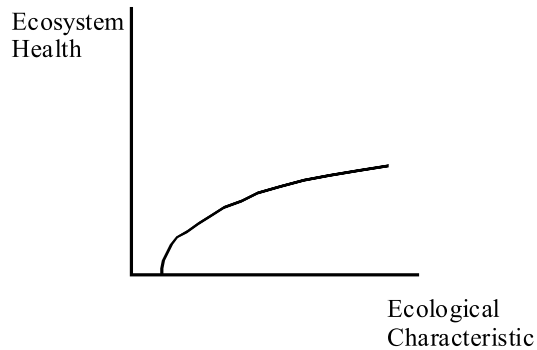
A similar relationship exists between ecosystem health and ecological services. This relationship is depicted in Figure 2. However, from a policy perspective one might want to focus on key ecological characteristics which contribute to ecological health, since ecosystem health is an outcome rather than a choice or control variable. The relationship between an ecological characteristic and ecosystem health is contained in Figure 3. Note that in this depiction, the ecosystem crashes as the level of the ecological characteristic approaches a low, but positive level[ii]. The three relationships in Figures 1-3 can be linked to derive a functional relationship between social welfare and a key ecological characteristic. This is done in Figure 4, forming the basis for structuring a performance bonding system. This relationship can be viewed as measuring the total social benefits (TB) of the ecological characteristic. TC represents the total costs of obtaining the ecological characteristic, and is presented in this graph as a linear function. The linearity of the cost function is chosen solely for ease of exposition, and does not represent a hypothesis concerning the shape of the function.



1 The Relationship Between Ecosystem Health and Ecological

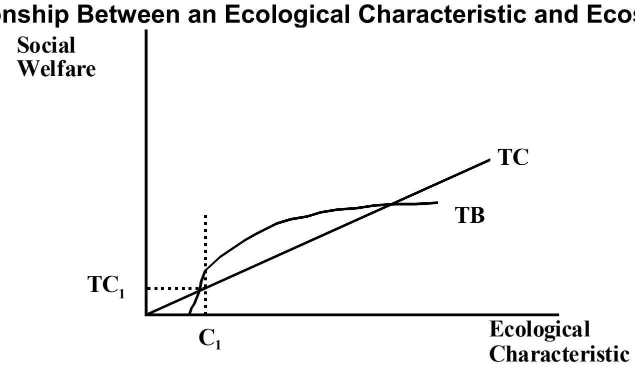


Services
2 The Relationship Between Ecological Services and Social



Welfare

3 The Relationship Between an Ecological Characteristic and Ecosystem



Health

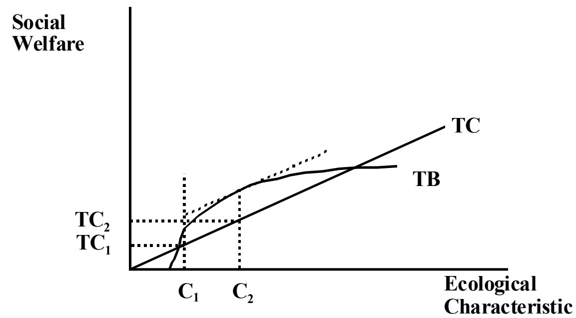
4 The Minimum Acceptable Level of the Ecological Characteristic In the traditional performance bonding system, where one seeks to stay above a minimum acceptable level of environmental quality, C_1 would make a good candidate for the definition of the standard. The definition of a level such as C_1 allows one to remain above the collapse point, with an adequate margin of safety to guard against uncertainty associated with either measurement error or stochastic events.[iii]

To assure that the level of the ecological characteristic remains above C_1, the magnitude must exceed TC_1, the cost to the firm of maintaining the ecological characteristic at a level of C_1. The amount by which the performance bond should exceed TC_1 will be a function of the firm's perception of the probability of forfeiture from violating the standard (the expected value must exceed TC_1) and also will be related to the existence of random variables or measurement error in the total cost function.

However, as mentioned in the introduction, this system does not move society towards the optimal level of the characteristic. The optimal level of the ecological characteristic would be C_2 in Figure 5, where the marginal cost of obtaining the characteristic is equal to the marginal benefit of the characteristic. In this case, the magnitude of the performance bond must exceed TC_2 in order to generate the optimal level of the characteristic.

Returning the Performance Bond

If one is only interested in maintaining the minimum acceptable level of environmental quality the procedure for returning the performance bond is relatively straight forward. The bondis returned if the minimum acceptable level is exceeded, and forfeited if the minimum acceptable level is not attained.



5 The Optimal Level of the Ecological Characteristic

Unfortunately, a corresponding procedure will not work well if the optimal level of the characteristic is the policy target. The reason for this is that if the whole performance bond is forfeited for missing the optimal level of the characteristic, the firm will have no further incentive to maintain environmental quality, and will allow it to decline towards zero. When focusing on the optimal level of quality, there should be a small penalty for being slightly below the optimal level, and large penalties for being far below the optimal level. This structuring of penalties is very important given that the total benefit function is increasing at a decreasing rate, and is likely to be relatively flat in the vicinity of the optimal level of the ecological characteristic. If the total benefit function is known (or if an estimate of the total benefit function is available) then a continuous function of returning the performance bond can be developed as in Equation (1). This function specifies the fraction of the performance bond which is returned, where TB_2 is the level of total benefits associated with the optimal level of the ecological characteristic, TB_1 is the level of total benefits associated with the minimum acceptable level of the ecological characteristic, and TB_x is the actual level of the environmental characteristic at which the firm leaves the effected area.

$$P = \frac{TB_x - TB_1}{TB_2 - TB_1} \qquad (1)$$

If $TB_x = TB_1$ (where TB_1 equals the total benefit associated with the minimum acceptable level of the ecological characteristic), then the numerator of Equation (1) will be equal to zero, and all of the performance bond will be forfeited. If $TB_x = TB_2$ (where TB_2 equals, the total benefit associated with the optimal level of the characteristic), the numerator of Equation (1) will equal the denominator, and all of the performance bond will be returned. As one moves from C_1 to C_2, the proportion of the performance bond which is returned increases at a decreasing rate, according to the slope of the benefit function, as illustrated in Equation (2).

$$\frac{dP}{dC} = \frac{dTB_x}{dC}\left(\frac{1}{TB_2 - TB_1}\right) \qquad (2)$$

III) ENVIRONMENTAL PROBLEMS ASSOCIATED WITH MINE CLOSURE

Mine closure presents a whole host of potentially long term environmental effects that must be addressed preferably prior to the beginning of mine operation. Most mining firms committed to environmental compliance have found that if the issues are identified and addressed early in the process while recovery efforts are made throughout the life of the mine, environmental mitigation costs can be minimized. In this case, if environmental compliance is sought throughout, there is no reason to believe that the environmental bond should not be returned in its entirety.

Probably the most significant environmental concern with regard to mine closure is the land surface alteration and degradation that occurs due to mining operations. Reclamation efforts vary for every mine depending on such variables as soil type, contour slope, climate, predominant ecosystem, including preexisting vegetation and wildlife, as well as others. For most mining types, many of the issues associated with mining and land alteration are caused by the mining process itself. The clearing of property and then moving of massive amounts of overburden result in a substantially different topography than had originally occurred on site. Although often times, costs prohibit returning a mine site to the original landscape, efforts are usually required of the firm to integrate the site back into the primary, self-sustaining ecosystem that existed on site before operation began. A key component of mine site reclamation is the choice of proper vegetation and medium term care of the revegetation efforts. Vegetation selection will impact almost every aspect of site reclamation, especially the mitigation of erosion and the return of wildlife.

In addition to land use, both water and air quality are of concern during the post-mining phase. After pit and plant closure, the primary source of air pollution is a result of the increase in dust particles caused by soil erosion and transport. (During mine operation, dust, heavy metal particulates, toxins and other noxious pollutants can plague mining and beneficiation processes. These emission are reduced after production ceases when studies have shown ambient concentrations to diminish.) Proper dust suppression techniques, when employed through the production and closure phases of operation can minimize the extent to which post mine damage impacts the surrounding community. Here again, proper revegetation, as well as careful slope contour, can maximize air quality.

Water quality is often compromised during mine operation on site and downstream of production facilities. Issues can vary, depending on mine type. The major problems include acid mine drainage, sedimentation, groundwater disruption, ground or surface water movement and availability disruptions, and toxic leachates. Water control and treatment can occur both in-process and/or end-of-pipe. Technology to mitigate or recycle waters contaminated by effluent wastes, e.g., simple sediment or metals, from production processes is well developed. The minimization of water discharged from the system reduces impacts by limiting either sediments or toxins from entering a local water flow. Surface water runoff can be mitigated by erosion control techniques. The issue of tailing pond leakage or evaporation however, is a more difficult problem. Potentially hazardous effluent discharge, e.g., cyanide effluent, in the case of gold mining, requires careful monitoring and quick response. Any of these issues during mine operation can cause high concentration of effluents which complicate cleanup, closure and bond return.

One of the most common post production water quality concern is acid mine drainage. Water percolates through an abandoned mine site, carrying away any number of mining related contaminants. Careful long term monitoring of the mine site and water testing is necessary to prevent heavy loads of contaminants entering local water flows. Mine site pumping to keep water from collecting in mine sites and/or treatment of the flows is sometimes required. Finally, long term impacts on underground aquifers from subsidence or backfilling post-production, are also sometimes problematic. These occurrence can be unpredicted and also very difficult to reconcile. The environmental bonding system proposed can include a lagged return period, where the bond monies are returned over the course of several years, post production, to facilitate medium and long term monitoring.

Above all the most crucial and complicated component of environmental concern associated with the mining process is the characterization and evaluation of potential impacts before they occur, prior to mine operation. The EIS (environmental impact statement), required in most countries' environmental regulations, facilitates the inventory of existing environmental assets and estimates potential problems and conflicts between the mine operation and the surrounding ecosystem This process is key to the accurate assessment of the environmental bond. In the mine closure phase of production, the challenge is to meet the prescribed environmental quality standards set out by the EIS, while still remaining within production cost limitations. Of course, the bond is designed to ensure that funds are available for clean up in the event that the firm defaults on their promise.

IV) DEMARCATION OF ISSUES

There are a set of related environmental issues associated with mining and mine closure. First, there are environmental problems associated with mining as the actual mining takes place. These include run-off of sediment, acidified waters and other types of emissions. Second, there are issues of alteration of the landscape and its impact on the ability of the impacted environmental systems to provide ecological services. Both of these types of problems can be adequately handled by performance bonds exclusively, or in combination with other environmental policies such as pollution taxes or direct controls. However, the same statement can not be made with respect to environmental problems associated with mine closure.

The reason that mine closure is more difficult to regulate is temporal in origin. The mine closure must leave the mine and the surrounding environment in a condition that minimizes present and future problems. However, this condition is not self-perpetuating and additional steps may be necessary to maintain this condition long after the mine has been closed. For example, tailing pond dams need maintenance, aquifers must be protected against leakages from waste disposal and contaminated areas, and formerly disturbed areas must be protected from invasion by exotic species.

The first step in the process is therefore to define the set of conditions at which the closed mine and the surrounding environment must be left. A performance bond can then be used to ensure that the closed mine and surrounding area are left at or near their optimal condition. However, the performance bond can not be used to assure the continued maintenance of these conditions over time, as the performance bond would have already been returned to the mining firm and could not provide any additional incentive. Since the conditions would have to be maintained in perpetuity, an additional performance bond could not work as there would be no logical termination point at which point to return the performance bond. Therefore, a second policy instrument must be developed to generate incentives for maintaining the site, protecting tailing pond dams, and rectifying any potential hazards or problems which develop over time.

There are several options which are available to provide this long term protection which are all designed to give either the mining firm or a contracted third party the incentives to provide the long-term protection. One potential policy would be just to establish liability for future environmental damages, where mining firms would be legally required to pay damages to society (through the government) and to individuals if and when future environmental damages occur. This is not likely to be a very good policy because firms may have planning horizons that are shorter than socially optimal, so they may not adequately include the possibility of future damages in today's decision to maintain the quality of the closed sight. Additionally, firms to not have infinite economic life, and if firms disappear there is no one to maintain the quality of the site. Note that this is a very different situation than that of establishing legal liability for oil spills. Since oil transportation is always a contemporaneous activity, the firms always have an incentive to maintain appropriate safety levels.

Another possibility would be for firms to be required to by a permanent insurance policy which would insure against environmental damages from the mine site. Insurance companies would then use part of the premium payments (or one time capital payment that they receive) to hire a third party to maintain the closed mine site. Note that this policy not only generates the maintenance after closure, but it also provides the mining company additional incentives to leave the mine in a good condition at closure. The reason for this is that the better the condition of the closed mine and its surrounding environment, the lower the payment that the insurance company would require.

A similar type of policy would be to require the firms to establish a fund which could then be used to pay a third party to maintain the site. This would not be as easy a process, because the government would have to estimate the potential hazards, maintenance require to minimize risk, and so on in order to determine the size of the fund. This would be a similar exercise to establishing the magnitude of the performance bond. Although this could certainly work, it might be better to rely on the market forces and the greater incentive that insurance companies would have to oversee the maintenance process in order to minimize their chances of having to pay an insurance claim from environmental failure of the closed mine.

V) An example from Mine Reclamation

In Amazonia, the concerns surrounding mining operations are much the same as in the United States. Land contour degradation, habitat destruction, water contamination and toxic soil seepage top the list. Much of Brazilian environmental policy related to mining is similar to U.S. policy. CONAMA (National Environmental Council) Resolution # 001/86 (amended 009/90 and 010/90) requires an Environmental Impact Assessment prior to commencing mining activity. Constitutional Decree # 99.274/90 authorizes state environmental agencies to obtain licenses from all mining firms regarding mine planning, environmental control planning during operation, and recovery of degraded areas. This decree also authorizes specialty agencies to license operators in highly sensitive environmental regions, e.g., IBAMA (Brazilian Institute for the Environment and Renewable Resources) has specific requirements for mining in the Legal Amazon. Finally, Decree # 97.632/89 requires all firms to submit a Plan for Recovery of Degraded Areas to be approved by the state environmental agency. Federal, state and municipal governments are charged with carrying out these regulations, however, monitoring in most cases is often difficult with agencies severely underfunded. Environmental bonds are sometimes, but infrequently used to ensure environmental compliance.

First, because of the nature of mining operations there is the potential for many more environmental damages to occur (heavy metal leachate, acid mine drainage, particulate emissions, etc.) during the period of operation than in other extractive industries. Second, because of the huge amount of land mass that is moved during a mining project, it is possible that the land area impacted can never be returned to its original ecological state or land use. Success of a reclaimed area then might be the return of as much of the land area to its initially determined baseline state before mining began, while providing some alternative ecological use with the land that cannot be completely restored.

In the rain forest, the issue of tree and vegetation clearing takes on a greater importance than in many other ecosystem types, as all of the nutrients in this type of ecosystem are stored in the living biomass. Virtually none of the nutrients are stored in the soil. Therefore, replacing the soil and haphazardly planting after mine closure is simply not enough. For a similar style of ecosystem to recover after mining activities are completed, care must be taken in both restoring the nutrient cycle and recreating a distribution of species similar to the original forest system. This is important because the correct habitat must exist to support the animals which in turn are essential to the dispersal of tree seeds that perpetuate the biodiversity of flora.

To ensure the return of environmental quality in this region, the bonding mechanism can be an extremely useful tool. First, we will assume that all of the land can be restored to forest after mining activities cease. If this is the case, a performance bond based on a specialized ecological ratio could enhance the success rate of reclamation activities. This ratio would be conceptually similar to the one defined for the forestry example, except the reclamation process would be dependent on replanting, rather than natural regeneration, because the process of mining would not leave long narrow strips of cleared area that would naturally regenerate.

Criteria used for measuring success of a revegetation project could include:

- the vegetative biomass
- the distribution of tree species
- soil quality (fertility and stability)
- general biodiversity (perhaps measured at a future monitoring date) (Leitch, 1992).
- number of days per year in which fruit can be found in the tract.[iv]

These characteristics could then be formulated into a recovery index (either weighted or unweighted) and then incorporated into a proportionality function in the fashion of Equation (1). Instead of a single ecological characteristic, the proportionality function would be based on the actual level of the recovery index (RI_x), the optimal level of the index (RI_2) , and the minimum acceptable level of the index (RI_1), as in Equation (3).

$$P = \frac{RI_x - RI_1}{RI_2 - RI_1} \qquad (3)$$

Although the above method would give a mining firm an incentive to restore the forest, in many cases, this is not technically and/or economically feasible. For example, if a large open mine pit were required to be back filled for reforestation purposes, the mine might in fact turn out to be economically infeasible. Backfilling effectively doubles the cost of a mining project. Instead, a restoration plan could construct an alternative land use for the portion of the mine land that is not recoverable to the baseline state.

Perhaps the largest pit in a project is slated to become a natural lake, allowing it to fill with seasonal rain water that over time will accumulate. With careful, periodic monitoring of the water quality in the lake, this source of water could provide a set of ecological services (albeit different from those provided by the rainforest) as well as economic services (tourism, commercial fishing, irrigation) and recreational services to area residents.

In the area that is not thought to be recoverable back to the forest baseline, a functionality index will weight the potential of this land's contribution to the forest ecosystem, based on possible ecological values of the area and/or anthropocentric use values. This functionality index would vary substantially based on potential alternative uses. In this example, functionality indicators could include

- water quality of the lake (dissolved oxygen, pH, absence of toxic metals and other contaminants)

- water quality downstream of the lake (dissolved oxygen, pH, absence of toxic metals and other contaminants)

- reproductive success of aquatic organisms

- growth rate of aquatic organisms

- biodiversity of flora and fauna in the area surrounding the lake

- aesthetic value and cohesiveness with original ecosystem of the surrounding area

-recreational quality of the area

The functionality index can be similarly incorporated into a proportionality function:

$$P = \frac{FI_x - FI_1}{FI_2 - FI_1} \quad (4)$$

Implementation of a Performance Bonding System in Mining

The first step in the process of implementation of a performance bonding system in a mining context is for the government to decide upon (or the government and the mining firm to agree upon) a restoration plan. This plan would determine which areas of the mining tract would be restored to its original state, and which areas would be restored to some other function.

For the area that is designated to be restored to forest, the first step would be to identify the components of the recovery index, and weights (if any) to be assigned to these components. Next, a performance bond would be established of a magnitude equal to the cost of obtaining the optimal level of the recovery index, RI_2. The performance bond would then be returned based on the proportionality function of Equation (3).

For the area that is designated to be an alternative land use, the first step would be to identify the components of the functionality index, and associated weights (if any). Similarly, a performance bond would be established equal to the cost of attaining the optimal functionality index, FI_2. As with the recovery performance bond, the functionality bond would be returned according to the proportionality function, in this case, Equation (4).

Monitoring

In the United States, the Surface Mining Control and Reclamation Act of 1977 establishes a system of enforcement and monitoring of environmental compliance both during mine operation and after mine closure. During the environmental inspections, all environmental damage mitigation techniques and environmental recovery indicators are inspected for quality. In the reclamation phase, the factors listed above included in the reclamation quality index can be easily tested as the reclamation process moves forward. Usually, a lag of five years or so is added to the end of mine closure in determining the date for full bond return. This allows environmental auditors to determine if the revegetation procedures have resulted in the beginnings of a healthy recovery of the surrounding forest and vegetation.

This type of hands-on monitoring, however effective, is understood to be a costly aspect of enforcement. These additional costs are the primary reason that environmental monitoring and compliance is so sporadic in many parts of the world. However, if the costs of monitoring are incorporated into the original license fee or into royalty payments, the system can work even in developing countries that typically have under-funded enforcement agencies.

VI) USE OF PERFORMANCE BONDS IN THE SUBSISTENCE AND ARTISANAL SECTOR

We define subsistence activities to include economic activities conducted by families primarily to provide goods for their own consumption. Although some of the production my be sold in markets, the market activity represents a small proportion of total production. In contrast, market sales are the primary focus of artisanal producers. Artisanal producers tend to be small scale operators, with low stocks of capital and unsophisticated technologies in comparison to the corporate sector. Entry and exit from the artisanal industries can be very rapid, for example, the number of artisanal gold miners in the Amazon region varies from 100,000 to 800,000, depending on the price of gold. Examples of artisanal activities include quarrying activities, production of gem stones, gold mining activities, small dairies and ranches, and fabrication of products from recycled materials.

Although subsistence activities and artisanal activities are quite different, they share some common characteristics which increase the difficulty of enforcing environmental policy. For example, both subsistence and artisanal activities often don't appear on the economic "radar screen" and thus are extremely difficult to monitor. In addition, this lack of visibility and extreme mobility in combination with an absence of, or small amount, of fixed assets makes enforcement of environmental fines quite difficult, as it is difficult to fine someone who has no money or visible assets to seize. In addition, there is the very difficult ethical issue of penalizing people who already suffer from poverty. These same characteristics also make the development of a performance bond (with the structure suggested above) very difficult.

However, rather than focusing on penalizing these small scale producers for improper environmental performance, the system we are proposing in this section of the paper would reward these producers for proper environmental performance. The proposed system, which we will call a performance bonus system, can be structured to reduce the problem of encouraging entry.

First, let's look at the case of an artisanal activity, such as the mining of ornamental stone for building facades[5] or wildcat (garimpo) mining of gold.[6] Quarrying activities can lead to environmental impacts such as water pollution associated with residues from stone cutting, dumping of waste rock, and noise pollution, while garimpo mining of gold can lead to mercury pollution, sedimentation of the water, and other pollution problem. Yet these artisanal firms are difficult to regulate because of the characteristics described above. A performance bonus can be established as follows. First, decide the periodicity and magnitude of the bonus. The bonus should exceed the cost of environmental compliance, and we will call this level, "Z." Instead of requiring the firm to post a bond equal to Z, the firm is required to post a bond equal to Z (where 0<Z<1) and the government and/or NGOs contribute an amount equal to (1-)Z to an escrow account. This contribution is called the performance bonus.

Then, a proportionality function analogous to Equation (1) should be chosen based on the environmental risks associated with this mining activity. Performance will determine both the amount of the bond which is returned to the firm and the amount of the bonus which is awarded to the firm. For example, if environmental performance is below the minimum acceptable level of performance, the firm forfeits the Z it provided as a performance bond and also forfeits access to the (1-)Z that the government and/or NGOs have made available as a performance bonus. If the artisanal firm's environmental performance is at the optimal level, it receives all of the Z bond back, plus all of the (1-)Z that is available as a performance bonus. For levels of environmental performance between the minimum acceptable level and the optimal level, a proportionality function of the nature of Equation (1) can be used to determine the proportion of both Z and

(1-)Z that is awarded for the firm.

Additional discussion is needed of the proper determination of the magnitude of Z. Two factors can be identified which should be considered in the determination of this level. First, the greater the value of the firm's assets, the greater should be Z. Second, there is the need to discourage the entry of firms who enter the industry for the purpose of collecting the performance bonus. The greater the potential for the performance bonus system to encourage the entrance of firms, the greater should be to provide a corresponding disincentive.

VII) Conclusion

Performance bonds can be very useful tools for achieving specific environmental quality standards if constructed properly. We have discussed a methodology that provides those using performance bonds more precision in the disincentives they give to those creating environmental damages. The approach taken here is directed at promoting environmental damage prevention activities since many damages are irreversible and since prevention of damages is often less costly than restoration. It also strives to achieve the optimal level of environmental quality, as opposed to the typical minimum acceptable level. This base minimum level is often the goal of restoration activities as it ensures complete return of the bond. However, there is no incentive (and in fact likely that additional costs would be incurred, a significant disincentive) in meeting any higher environmental standards with this system. Additionally, structuring this mechanism as a continuous tool so that action can be taken and compensation can be paid according to a variety of different levels of mitigating activity creates a clearer incentive system allowing for a balance between the marginal costs and benefits of environmental preservation (or restoration, where that is the goal).

Although traditionally performance bonds have been used most frequently and somewhat effectively in the mining industry, with a few adjustments bonds can be an effective regulatory tools in many other applications. By instituting a bonding system before disturbance activities begin, regulatory agencies can provide strong assurance that steps will be taken to either prevent damages or restore an area, depending on the policy goal.

The efficiency of the system of performance bonding described above increases with the more that is known about the relationship between social welfare and ecological indicators. While we have good knowledge of this for some ecosystems, more research must be done before the system can be widely employed in its most efficient form. The performance bonding system can still be employed without a knowledge of this functional relationship (based on Equation (1)) but it is less efficient in maximizing social welfare. Even with the current gap in scientific knowledge, integrating estimates of these more comprehensive characteristics of the relationship between social welfare and ecosystem health into performance bonding systems makes bonding a more effective and readily evolving regulatory tool.

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Endnotes:

Ecological services are functions produced by ecosystems such as nutrient cycling, soil formation, carbon sequestration, maintenance of atmospheric chemistry, biodiversity, watershed protection, and so on.

See Kahn and O’Neill (1999) for a discussion of the policy relevance and ecological origins of this type of bifurcation or threshold.

See Bishop (1978) for a discussion of the concept of a minimum safe standard.

Presence of fruit during the whole year is necessary to provide sufficient habitat for large mammals such as monkeys and fruit bats. These large animals are essential to the dispersal of the large seeds (in large fruits) of many rainforest trees. If there is a protracted period without fruit, the mammals will migrate to another area, leaving the area without a seed dispersal mechanism.

See C. Peiter, R.C. Villas Boas and W. Shinya, “The Stone Forum: Implementing a Consensus Building Methodology to Address Impacts Associated with Small Mining and Quarry Operations, Natural Resources Forum 24, 2000, pp.1-9.

See Maria Laura Barreto, “Garimpo de Ouro no Brasil:Desafios da Legalizacao, PhD thesis, Escola Politecnica da Universidade de Sao Paulo, Sao Paulo, Brasil.