Managing partially protected resources under uncertainty: an application to antibiotic resistance

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Abstract

The existence of well-defined and enforceable property rights is widely acknowledged as a necessary precursor to the optimal use of resources. However, the impact of enclosure and efficient management of some resource pools on other resource pools that are open-access is poorly recognized. The problem is common to most congestion-prone facilities including roads, parks, fisheries, grazing lands and wilderness areas, and is especially germane to the problem of growing antibiotic resistance where patented drugs (whose effectiveness is privately owned) are typically underused relative to generics, (whose effectiveness may be considered an open-access resource.) In this paper, we analyze the optimality of price and quantity instruments in regulating resource use when there is uncertainty about congestion costs. Price instruments are found to preferable when the overall demand for the resource is perfectly inelastic, and quantity instruments are favored when demand is perfectly elastic. The effect of market power by resource owners on the optimality of the two instruments is also explored.

Key Words: regulation; antibiotic resistance; congestion

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Regulating private decisions to enforce property rights under uncertainty

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Introduction

It is widely acknowledged that the existence of well-defined and enforceable property rights is a necessary precursor to the optimal use of resources, and common ownership leads to over congestion. Although Frank Knight argued that private ownership could achieve optimal congestion, the limited applicability of this argument has long been known (Knight 1924). Buchanan was the first to show that that private ownership could achieve efficient resource use "only in those cases where the extent of commonality of usage is limited to a relatively small proportion of the total resource supply…" and there was no monopoly power associated with private ownership (Buchanan 1956). However, a second drawback of private ownership; the adverse impact of enclosure and efficient management of some resource pools on other resource pools that are open-access is poorly recognized.

In an important paper, De Meza and Gould showed that if property owners must incur costs to enforce their rights, then the level of enforcement could be more or less than is socially optimal (de Meza and Gould 1992). An example they describe is that of burglar alarms. If no house in the neighborhood has alarms then a single homeowner's decision to install an alarm may reduce that homeowner's risk of being burgled, but could leave everyone else worse off by diverting burglars to unprotected houses. The two socially optimal stable equilibria may be that either all houses have alarms or that none have alarms, and any intermediate solution may be sub-optimal to these equilibria[1].

One can see the relevance of this problem of "externality-spillovers" to the optimal management of resources for which some pools are privately owned, while others are open access. Regulating any single fishery may displace fisherman who may move to (and congest)

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[1] This situation also arises in the case of road tolls. Institution of a toll on a highway could reduce the number of commuters on the highway and reduce congestion, but would push some of them onto side roads where there is no toll, thereby inefficiently congesting these other roads. In this case too, the toll may ensure the optimal use of the highway, but may be an inferior solution when the congestion on all roads is considered.

other fisheries that are open-access, potentially leaving society worse off compared to the pre-privatization equilibrium. The problem of effort displacement is familiar to those charged with regulating fisheries. For instance, concerns that institution of gear restrictions on pelagic line[2] fisheries would encourage fishermen to relocate to other sensitive fishing areas, jeopardize sea turtles and dolphins, or increase bottom line fishing of grouper, snapper and tilefish, constituted roughly a third of all comments sent in response to a NOAA ruling (Federal Register 2000).

Another important application of externality spillovers of great contemporary relevance is in the case of bacterial resistance to antibiotics. Bacteria have evolved to be resistant to antibiotics and the pace of this evolution is directly correlated with the quantity of antibiotics used. Some of the most powerful antibiotics are under patent and effectively enclosed. Other antibiotics, such as penicillins and first- and second-generation cephalosporins, have long been in use and are no longer under patent. In the case of antibiotics, patents could give a single firm the incentive to care about resistance to a drug. However, the patentee is likely to ignore the effect of her pricing decision on exacerbating resistance to antibiotics that may be in the generic (i.e. open-access) domain and may overprice or underuse her antibiotic relative to the socially optimal level.

A possible regulatory response to this cross-resource spillover problem may be to subsidize the use of patented drugs that might otherwise be underused, or to tax the use of generic drugs to ensure that they are not overused. Alternatively, quantity instruments can be used to ensure that patented drugs are used more often. Currently price instruments are under consideration, and quotas are already being used. For example, proposals are underway to increase the cost of antibiotics faced by patients by increasing co-payments for certain types of patented antibiotics prescriptions, a form of price regulation. Quantity instruments are already being applied in the form of formulary restrictions on antibiotic usage imposed by hospitals. Paradoxically, such formulas restrict the use of powerful, patented antibiotics to a second line of defense—a backup should all cheaper drugs fail—even though they are already potentially underused because of their high cost.

In this paper, we compare the optimality of price and quantity instruments in regulating for across-antibiotic spillovers, when the path of evolution of resistance to antibiotics is uncertain. We consider optimal policy responses in the face of uncertainty in the path of

[2] Pelagic or long line gear is the dominant commercial fishing gear used by U.S. fishermen in the Atlantic Ocean to target highly migratory specifics such as Atlantic swordfish and tunas.

evolution of resistance. Two cases are considered. In the base case, where the demand for antibiotics is perfectly inelastic, and patients are forced to choose between the two antibiotics being offered, one generic (and open access) and the other patented (and privately managed). In the second case, demand elasticity is assumed to be perfectly elastic, which allows for entry and exit of patients in response to the imposition of a tax or a subsidy on antibiotics. Finally, we compare the competitive market equilibrium to a market in which enclosure also confers monopoly advantages.

When demand is fixed, we identify a superiority of taxes even if the slope (and expected position) of the MC curves is identical. The intuition arises from the fact that the tax still allows both markets to adjust to the cost shock, while the quota does not. This result differs from the Weitzman case, in which the externality is independent of the marginal abatement cost curve, and the relative slopes drive the preference for a tax or quota. Here, since the externality for the open-access supply is the difference between marginal and average costs, a shock shifts that market supply curve in the same direction as the social marginal cost curve. Thus, while the tax fixes the price signal for producers in the Weitzman case, here the tax is not the price; rather, it influences the price, as do the cost shocks. A quota, on the other hand, makes supply invariant to shocks, as in the Weitzman case. As a result, the relative tradeoff is not between a too-rigid price and a too-rigid quantity, but a flexible, suboptimal price and a too-rigid quantity.

On the other hand, when demand is perfectly elastic, we find a clear superiority of quotas. Despite the flat marginal benefits of the resource, the damages from overharvesting the open-access resource increase with harvesting. Thus, the additional losses when a negative cost shock induces too much production and the tax is too low outweigh the losses from underproduction with a positive cost shock, while the quota impacts are roughly symmetric.

The two cases addressed earlier are then explored under the case where the private resource owner has monopoly on the resource.

Model

Our model reframes and extends the model of De Meza and Gould (1992) in the following ways. First, we focus on the product market equilibrium, rather than the labor market equilibrium. Since congestion arises from use of the product, we prefer to focus on the product price impacts of enclosure, assuming instead that this industry is too small to influence the prevailing wage rates.[3] Second, we consider the scope of the congestion externality, and whether it applies within or across resource pools. Third, we compare the competitive market equilibrium to a market in which enclosure also confers monopoly advantages. Fourth, we consider optimal policy responses. Finally, we examine how those responses might be affected by uncertainty in the congestion parameter.

We assume two types of resource pools, one enclosed and the rest open access. The quantity from each pool q_i is produced at cost $C^i(q_i, \theta_i)$, which is convex in q_i and shifted by an uncertain parameter θ_i. Marginal production costs may be increasing due to diminishing returns to harvesting effort or, for the antibiotic case, decreasing quality of effectiveness. The uncertain parameter may represent susceptibility to antibiotic resistance, for example. The market price of the product is the inverse demand function $p(Q)$, where Q is total production.

Z is the fixed cost of enclosure—such as the costs of protecting a patent. In the case of antibiotics, one firm (or set of firms representing a fixed share of the market) enjoys patent protection, while the remaining firms produce drugs for which the patents have expired, resulting in an open-access pool of antibiotic effectiveness. These firms do not have the option to enclose the resource; hence, we largely abstract from the enclosure decision itself, treated by De Meza and Gould, and focus on the questions of allocative efficiency.

Profits for an enclosed ("Private") pool are $\pi_P = p(Q)q_P - C^P(q_P, \theta_P) - Z$. We allow the private resource pool owner to have the potential to exert some monopoly power, so profit-maximizing extraction for this owner solves

$$MR(Q) = C_q^P(q_P, \theta_P) \tag{1}$$

where $MR(Q) = p(Q) + p'(Q)$.

Firms using the open-access pool are price-takers in the product market. Profits for an open-access ("Free") pool are by definition zero, as effort and extraction occurs until the average marginal product equals the cost:

$$p(Q) = \frac{C^F(q_F, \theta_F)}{q_F} \tag{2}$$

[3] De Meza and Gould assumed product prices were fixed while wages were endogenous; in a sense, we reverse this normalization.

Market clearing occurs when $Q = q_P + q_F$ and, from combining equations (1) and (2),

$$MR(Q)/C_q^P(q_P, \theta_P) = p(Q)q_F / C^F(q_F, \theta_F) \qquad (3)$$

Since C is convex in q, average product is higher than marginal product, given any level of extraction; therefore, with equal θ, $q_P < q_F$. To the extent that marginal revenue is lower than the price, this difference is further exacerbated.

A firm will enforce its patent as long as $pq_P - C^P(q_P, \theta_P) \geq Z$, and we assume that this holds. In a model of price-taking firms (i.e., $MR = p$), enclosure of part of the market has two effects on allocative efficiency. On the one hand, enclosure improves the efficiency of extraction in the private access pool; on the other hand, it exacerbates the over-exploitation of the open-access pool, as the private pool supply contracts. When enclosure also confers monopoly powers, it leads to an under-exploitation of the private access resource, and further over-exploitation of the open-access resource.

Policy Options with Perfect Competition

Given incomplete enclosure, what policy instruments might best improve welfare, particularly if the production cost function is uncertain? Should we tax open-access production, put a quota on one or the other, or subsidize enclosed production?

This problem offers an important twist on the classic Weitzman "Prices v. Quantities" question. In that model, the externality is independent of the marginal abatement cost curve, and the relative slopes drive the preference for a tax or quota. Here, the externality for the open-access supply is the difference between marginal and average costs; consequently, the production supply curve is correlated with the depletion externality.

Perfectly Inelastic Demand

Consider the case of perfectly inelastic demand for the antibiotic: all patients are treated with one or the other of the drugs. This basic model can be represented intersecting MC, AC and MB curves. The MB curve is downward sloping and represents the benefit of use of antibiotic A on averting resistance to antibiotic B. It is essentially the MC of using antibiotic B but drawn in mirror fashion from the right axis.

The planner problem is to minimize total production costs, such that $Q = q_P + q_F$. Thus, the planner wants $C_q^P(q_P, \theta_P) = C_q^F(q_F, \theta_F) = p(q_P + q_F)$. In a decentralized program, the planner uses a tax or permit price to achieve this allocation subject to $C_q^P(q_P, \theta_P) = p, \quad C_q^F(q_F, \theta_F)/q_F = p - t$.

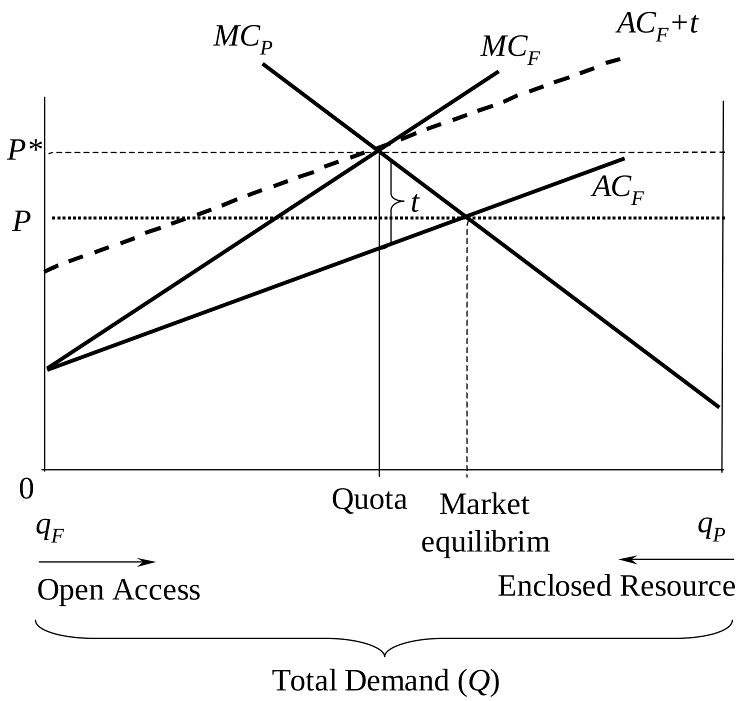
Suppose first that all firms are price takers, implying $MR = p$. Furthermore, let us define the optimal price $p^*(\theta_P, \theta_F) = C_q^P(q_P, \theta_P) = C_q^F(q_F, \theta_F)$. This equation represents the balancing of marginal costs and benefits, given uncertainty in each. Consequently, the optimal tax (or permit price) *ex post* is $t^* = p^*(\theta_P, \theta_F) - \frac{C^F(q_F, \theta_F)}{q_F}$. Under certainty, both instruments achieve the same outcome. However, a tax or equivalent quota policy set *ex ante*, before the values of θ_i can be resolved, may not have the same effects *ex post*.

In the Weitzman problem, setting an optimal *ex ante* tax fixes the price or marginal benefit of supply. In contrast, the optimal tax here fixes a wedge between the supply curves, and the price still requires equilibration with the alternative antibiotic's supply curve. A quota policy, on the other hand, fixes the quantity supplied, just as in Weitzman. This different functioning of the tax leads to different relative preferences for instrument choice. For the enclosed property firm q_P satisfies $p = C_q^P(q_P, \theta_P)$. For the open-access resource, q_F is a response function satisfying $C^F(q_F, \theta_F)/q_F = p - t$.

Ex ante, the policy maker want to set the tax $\bar{t}$ (or quota $\bar{q}_F$) such that marginal costs are equalized in expectations. This implies that the tax should reflect the expected difference between marginal and average costs in the open-access resource:

$$t = E\left\{C_q^F(\bar{q}_F, \theta_F) - \frac{C^F(\bar{q}_F, \theta_F)}{\bar{q}_F}\right\} \qquad (4)$$

Figure 1: Optimal Tax and Quota



With fixed demand, resource payments are transfers between consumers and producers, so any changes in welfare depend only on the total production costs:

$$TC = C^P(q_P, \theta_P) + C^F(q_F, \theta_F)$$

To consider how these costs change *ex post*, we assume a quadratic cost function

$$C(q_i, \theta_i) = \theta_i q_i + c_i q_i^2 \tag{5}$$

where q_i is the quantity of regulated good (antibiotics), $2c_i$ is the slope of the marginal cost curve and θ_i is a shock to the marginal cost function. This functional form is appealing for two reasons. First, as Weitzman shows, the quadratic function in the neighborhood of the optimal quantity is a justifiable second order approximation following a Taylor's series expansion (Weitzman 1974)[4]. Second, the quadratic approximation can be justified on the basis of a simple Poisson-probability based mechanism for selection of drug resistance (Laxminarayan and Weitzman 2002).

For the private resource,

[4] Since the constant term disappears when the approximation is written in terms of deviations from the optimal level, we can omit it from the quadratic form (Newell and Pizer 2003).

$$p = \theta_P + 2c_P q_P \tag{6}$$

For the open access resource with a tax t imposed,

$$p - t = \theta_F + c_F q_F \tag{7}$$

From the above two equations, and from $\sum_i q_i = Q$, we have

$$q_F = \frac{2c_P Q - t - (\theta_F - \theta_P)}{c_F + 2c_P} \tag{8}$$

and

$$q_P = \frac{c_F Q + t + (\theta_F - \theta_P)}{c_F + 2c_P} \tag{9}$$

We can solve for the optimal tax by setting expected marginal costs for the two resources equal to each other,

$$t = E\left\{\frac{(\theta_P - \theta_F)c_F + 2c_F c_P Q}{2(c_F + c_P)}\right\} = \frac{(\mu_F - \mu_P)c_F}{2(c_F + c_P)} + \frac{c_F c_P Q}{(c_F + c_P)} \tag{10}$$

where μ_i is the mean of each shock term, representing the expected intercept of the MC curve.

Similarly, we can solve for the optimal quota for the free-access pool:

$$\begin{aligned} \bar{q}_F &= E\left\{\frac{2c_P\left((\theta_P - \theta_F) + 2c_P Q\right) + c_F\left(2(\theta_P - \theta_F + c_P Q) + \mu_F - \mu_P\right)}{2(c_F + c_P)(c_F + 2c_P)}\right\} \\ &= \frac{(\mu_P - \mu_F) + 2Qc_P}{2(c_F + c_P)} \end{aligned} \tag{11}$$

Expected total costs with the quota are

$$\begin{aligned} E\{TC_{quota}\} &= E\left\{\theta_P(Q - \bar{q}_F) + c_P(Q - \bar{q}_F)^2 + \theta_F \bar{q}_F + c_F \bar{q}_F^2\right\} \\ &= \frac{4Q(c_P\mu_F + c_F\mu_P) + 4c_F c_P Q^2 - (\mu_F - \mu_P)^2}{4(c_F + c_P)} \end{aligned} \tag{12}$$

Since quantities do not change with the quota, these expected total costs also equal the total costs at the expected values of the shock parameters.

Meanwhile, expected costs under the tax are

$$E\{TC_{tax}\} = E\left\{\theta_P q_P + c_P {q_P}^2 + \theta_F q_F + c_F {q_F}^2\right\}$$
$$= \frac{\left(4Q\left(c_P\mu_F + c_F\mu_P\right) + 4c_F c_P Q^2 - (\mu_F - \mu_P)^2\right)(c_F + 2c_P)^2 - c_P({\sigma_P}^2 + {\sigma_F}^2 - 2\sigma_{PF})}{4\left(c_F + c_P\right)(c_F + 2c_P)^2} \qquad (13)$$

where σ_i^2 is the variance of θ_i and σ_{PF} the covariance.

The difference in expected costs depends on the relative responses in production:

$$E\{TC_{quota}\} - E\{TC_{tax}\} = E\left\{\theta_P(q_F^{tax} - \overline{q}_F) + c_P\left({\overline{q}_F}^2 - q_F^{tax2} + 2Q(q_F^{tax} - \overline{q}_F)\right) + \theta_F(\overline{q}_F - q_F^{tax}) + c_F\left({\overline{q}_F}^2 - q_F^{tax2}\right)\right\}$$

Since $\overline{q}_F = E\{q_F^{tax}\}$, this expression simplifies further to

$$E\{TC_{quota} - TC_{tax}\} = E\left\{(c_P + c_F)\left({\overline{q}_F}^2 - q_F^{tax2}\right)\right\} \qquad (14)$$

Substituting and simplifying, we see that expected total costs are higher with the quota than the tax if

$$E\{TC_{quota} - TC_{tax}\} = \frac{c_P\left({\sigma_P}^2 + {\sigma_F}^2 - 2\sigma_{PF}\right)}{\left(c_F + 2c_P\right)^2} > 0 \qquad (15)$$

The larger the variances and the smaller the covariance of the uncertain terms, the greater is the superiority of the tax instrument. In the limiting case where the covariance offsets the variances ($(\sigma_P - \sigma_F)^2 = 0$), price and quantity instruments are equally efficient. Equation (15) thus implies a general superiority of taxes—when demand is fixed.

The intuition arises from the fact that the tax still allows both markets to adjust to the cost shock, while the quota does not. This result differs from the Weitzman case, in which the externality is independent of the marginal abatement cost curve, and the relative slopes drive the preference for a tax or quota. Here, since the externality for the open-access supply is the difference between marginal and average costs, a shock shifts that market supply curve in the same direction as the social marginal cost curve. Thus, while the tax fixes the price signal for producers in the Weitzman case, here the tax is not the price; rather, it influences the price, as do the cost shocks. A quota, on the other hand, makes supply invariant to shocks, as in the Weitzman case. As a result, the relative tradeoff is not between a too-rigid price and a too-rigid quantity, but a flexible, suboptimal price and a too-rigid quantity.

Figure 2 and Figure 3 illustrate the market responses to unexpected cost shocks in the open-access resource and the privately owned resource, respectively, when demand is fixed. They reveal that the tax preference does not depend on the source of the cost shock in this case.

Figure 2: Response to Unexpected Cost Shock in Open-Access Resource with Tax v. Quota

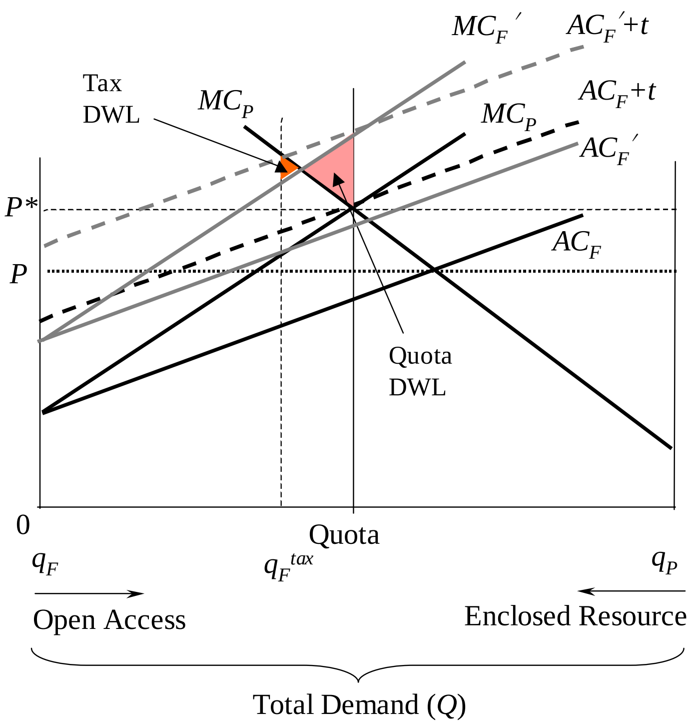
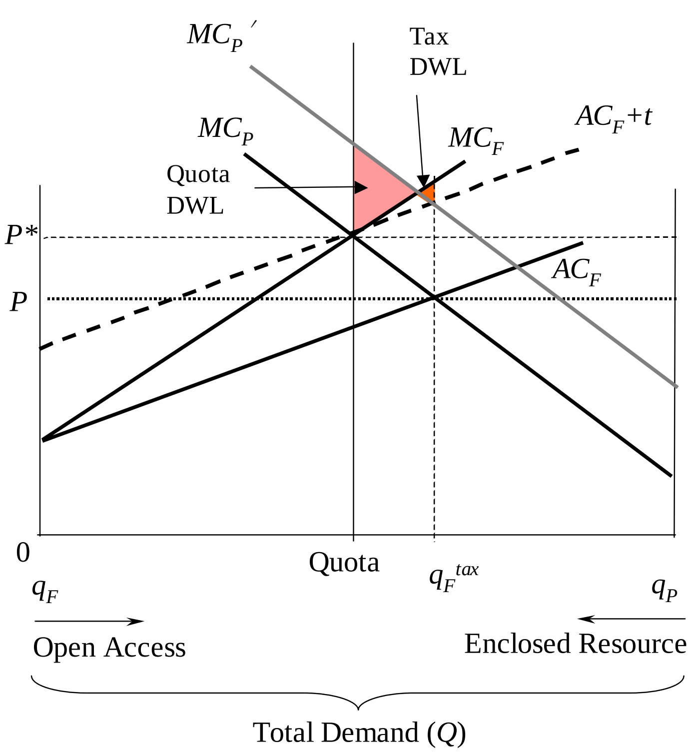


Figure 3: Response to Unexpected Cost Shock in Enclosed Resource with Tax v. Quota



In the fixed demand case, we note that a subsidy on *P* equal to the aforementioned tax would produce an equivalent result. However, in the case of elastic demand, a tax on *F* is not equivalent to a subsidy on *P*. Unless there exists an incentive to underproduce the privately owned resource (as in the monopoly case), a subsidy would encourage overuse and would be less efficient than a tax that targets overproduction in the open-access sector

Perfectly Elastic Demand

Consider the extreme case of perfectly elastic demand, such as if a perfect substitute is available. In this case, there is no externality spillover between the two resource pools, since any change in production of one is met by the substitute technology, not by putting pressure on the other resource. (For this reason, a subsidy to the enclosed resource would only encourage overproduction there and do nothing to crowd out production in the open-access resource).

Solving as before, we see that production from each pool is independent of the costs in the other:

$$q_F = \frac{p - t - \theta_F}{c_F} \tag{16}$$

and

$$q_P = \frac{p - \theta_P}{2c_P} \tag{17}$$

The optimal tax then also depends only on the expected cost shift in the open-access sector:

$$t = \frac{p - \mu_F}{2} \tag{18}$$

Similarly, we can solve for the optimal quota for the free-access pool:

$$\overline{q}_F = \frac{p - \mu_F}{2c_F} \tag{19}$$

Although there is no change in consumer surplus in this scenario, total production costs must also include the costs of the available substitute:

$$TC = \theta_P q_P + c_P {q_P}^2 + \theta_F q_F + c_F {q_F}^2 + p(Q - q_P - q_F) \tag{20}$$

The expected difference in total costs then depends on the difference between production of the open-access resource in the tax and quota scenarios, since the private-access response is identical:

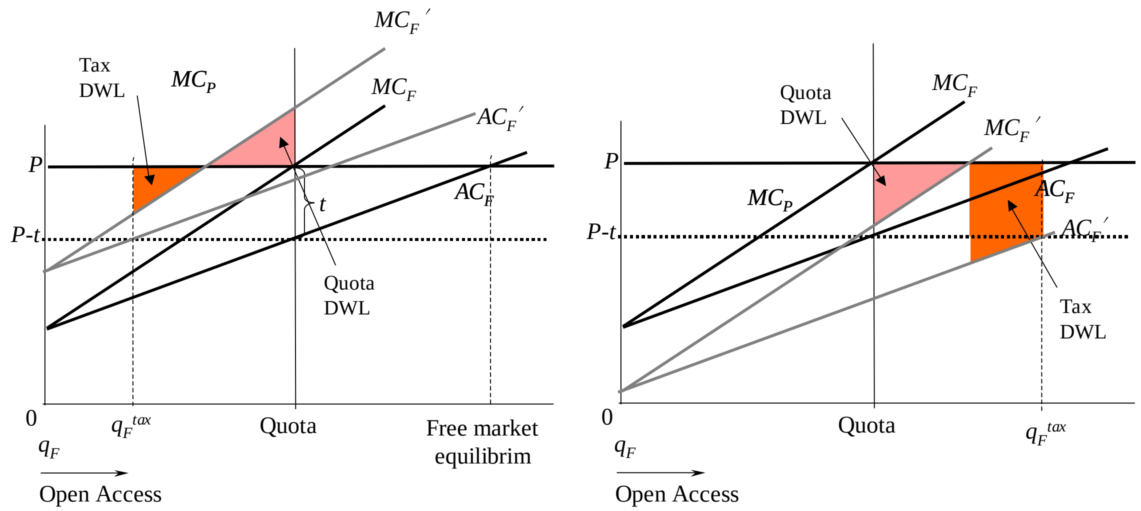
$$E\{TC_{quota} - TC_{tax}\} = E\{\theta_F(\bar{q}_F - q_F^{tax}) + c_F(\bar{q}_F^{\,2} - q_F^{tax2}) + p(q_F^{tax} - \bar{q}_F) \qquad (21)$$

Substituting and simplifying, we find that

$$E\{TC_{quota} - TC_{tax}\} = -\frac{\sigma_F^{\,2}}{4c_F} \qquad (22)$$

In other words, with perfectly elastic demand, the quota performs better than the tax. This result implies that the overresponse of the open-access pool to cost shocks under the tax is costlier than an inability to respond under the quota.

Figure 4: Responses to Positive and Negative Cost Shocks in Open-Access Resource with Perfectly Elastic Demand



This result is particularly interesting, given that the marginal benefits of the resource are flat in this case. In the Weitzman problem, flat marginal benefits imply that a tax should dominate. The important distinction here is that the marginal damages in this case—the loss from overharvesting the open-access resource—are not flat. Rather, they increase with harvesting. Thus, the additional costs in situations in which the tax is too low outweigh the costs when the tax is too high; meanwhile, the quota impacts are roughly symmetric for upward and downward cost shifts, since production does not vary.

Downward Sloping Demand

Given the divergent results for the preceding extreme cases, we can intuit a new kind of prices-versus-quantites rule for cross-resource spillover problems. When overall resource demand is steep, meaning spillover issues dominate, price policies are preferred. When demand is relatively flat, limiting spillover effects, policies to limit production of the open-access resource are preferred.

Policy Options with a Monopolist

When the enclosed firm is a monopolist, twin problems emerge: underproduction of the privatized resource and overproduction of the open-access resource. If demand is responsive, a simple tax on the open-access resource does not address the former problem; twin instruments may then be necessary.

With perfectly elastic demand, the monopolist cannot exert any market power, so that case is not relevant for further consideration. With fixed demand, the optimal quota does not change; however, the optimal tax must adjust when the private resource owner behaves like a monopolist. Furthermore, marginal revenue is a function not only of demand, but also of the open access cost—and whether the policy instrument is perceived to be flexible. This begs the question of whether the relative policy preference changes with strategic behavior.

Perfectly Inelastic Demand

With a quota, the private resource owner faces a fixed residual demand. Theoretically, the monopolist could charge as high a price as desired; however, since that is a transfer, we can focus on the costs, which the monopolist has the same incentive to minimize. Consequently, the results for the quota policy are the same as with price-taking private producers.

However, with the tax, the monopolist's residual demand curve is a function of the open-access behavior. From the open access response with a tax t imposed (7):

$$p = \theta_F + c_F(Q - q_P) + t \tag{23}$$

Consequently $MR = p - c_F q_P$, and from the first-order condition,

$$p - c_F q_P = \theta_P + 2c_P q_P \tag{24}$$

Solving for output, we have

$$q_F = \frac{(c_F + 2c_P)Q - (\theta_F - \theta_P) - t}{2(c_F + c_P)} \tag{25}$$

and

$$q_P = \frac{c_F Q + \left(\theta_F - \theta_P\right) + t}{2(c_F + c_P)} \tag{26}$$

We solve for the optimal tax by setting expected marginal costs for the two resources equal to each other, yielding

$$t = c_F Q \tag{27}$$

This tax is unaffected by the expected cost shocks. Furthermore, it is generally larger than the tax in the price-taking firms case:
$c_F Q - \frac{(\mu_F - \mu_P)c_F + 2c_F c_P Q}{2(c_F + c_P)} = \frac{c_F\left(2c_F Q - (\mu_F - \mu_P)\right)}{2(c_F + c_P)}$. Since the monopolist's supply curve is steeper than the price-taking firm's, the higher tax raises the open-access supply curve to induce the monopolist to produce more.

Substituting and simplifying, we see that expected total costs are higher with the quota than the tax if

$$E\{TC_{quota} - TC_{tax}\} = \frac{\left(\sigma_P^{\ 2} + \sigma_F^{\ 2} - 2\sigma_{PF}\right)}{4(c_F + 2c_P)} > 0 \tag{28}$$

This result is similar to that with price-taking firms: the superiority of the tax instrument increases the larger the variances and the smaller the covariance of the uncertain terms. Moreover, the tax preference is even stronger in the monopolist case, since
$\frac{1}{4(c_F + 2c_P)} - \frac{c_P}{(c_F + 2c_P)^2} = \frac{c_F^{\ 2}}{4(c_F + 2c_P)(c_F + 2c_P)^2} > 0$.

Downward Sloping Demand

It is unclear whether this stronger relative preference for taxes continues to hold when demand is downward sloping. The monopolist's incentives to withhold production mean the optimal quota and tax both differ from the price-taking ones when demand is responsive. Furthermore, a policy to subsidize privately owned resource production would offer yet different results from the tax. Unfortunately, in this example, allowing for demand response is not conducive for deriving useful analytical results. Numerical modeling would be required to explore these issues further.

Further Issues

The insights that emerge from this analysis are broadly applicable to situations where the optimal management and harvesting of any single natural resource pool increases the risk of over-exploitation of other unprotected resource pools. Our initial results point to interesting questions for extensions of the model.

For instance, although in the case of antibiotics, enclosure (through patents) is accorded to most new products entering the market[5], the choice of which resources to enclose and privately manage may be endogenously determined. For instance, a drop in the price of enclosure facilitated by the introduction of barbed wire was posited to be responsible for greater private management of prairie farmers in the American West (Anderson and Hill 1975). One possible extension would be to explore the effect of changes in the price of enclosure on the order in which properties are likely to be enclosed and the associated effect on social welfare.

Another question is whether the cost shocks might shift the slope rather than (or in addition to) the intercept of the marginal cost curve. While our representation may be appropriate for the antibiotics case, applications to other resource problems may test this assumption.

The partial equilibrium model in this paper can be derived from a general equilibrium framework, with an assumption that utility for this product is separable from utility from all other goods, and that those goods exhibit constant returns to scale, which determines the wage rate. Relaxing these assumptions allows some of the incidence of effects in this market to spread to other markets (as through the labor market in De Meza and Gould). The intuition for policy is similar, but additional interactions arise, as is well known in the literature on optimal taxation in the second-best.

[5] A notable exceptions is the class of artemisinins - antimalarials developed through public-private partnerships and in the public domain.

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