Multi-Market Trading for Cooperative Resource Management: An Application to Water Pollution and Fisheries

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Introduction

Increasingly, environmental problems are recognized to involve linkages across multiple environmental variables (Walker et al. 2004; Crepin 2007; Horan et al. 2011). Examples include interactions between pollution and a fishery, between valuable indigenous and invasive species, and between land use and wildlife (or, more broadly, biodiversity). Prior work on managing these complex, linked systems generally focuses on efficiency rather than implementation (e.g., Brock and Xepapadeas 2002; Crepin 2007). However, implementation is important and also may be complex owing to the linkages across environmental variables. Indeed, solutions to these complex environmental problems will generally involve changing human behaviors within the multiple economic sectors that impact upon the multiple environmental variables.

In principle environmental management can be implemented in a variety of ways where the only required coordination across environmental sectors involves setting the policy tools at levels reflecting linkages within the complex environmental system. For instance, when jointly managing pollution and an impacted fishery, one could use taxes on emissions and taxes on harvest landings. The optimal tax rates would be calculated jointly and would optimally encourage individual polluters and anglers to consider their impacts upon the fishery. However, these approaches do not encourage polluters to respond directly to angler behaviors, and vice versa. This would not matter in a first-best setting where environmental managers can be certain to set the policy tools at levels to generate the correct response. The same cannot be said for a real world (second-best) setting where managing human and environmental responses is imperfect. In such a setting, there may be benefits from using policies that elicit responses to behavioral choices within the alternative sector. The reason is that the value of environmental resources – and hence the value of the linkages being managed by environmental policies – depends on how agents are using the resources in each sector (Horan et al. 2011).

Tradable permit markets are generally seen as a coordinating mechanism, within a particular regulated sector (e.g., a polluting sector), that enhances efficiency by incentivizing agents to respond to behavioral choices of others within the sector. In a pollution permit market, for instance, increased emissions by one polluter must be offset by reductions in emissions from another polluter. Polluters therefore respond to each other through the market, resulting in cost-effective allocation of control among the sources.

Economists have examined the creation of pollution permit markets that incorporate multiple pollutants (e.g., multi-pollutant markets, Montero 2001; or point-nonpoint trading, Shortle 1990) as a way of extending policy coordination to further improve the efficiency of pollution control. In these markets, permits are defined for each pollutant type, and trading can occur across types using a trading ratio that defines how many permits for one pollutant can be traded for permits for the other pollutant. However, prior work on permit markets stops short of coordinating behaviors across multiple sectors for cases where society benefits from regulation in both sectors and one sector harms the other. For instance, permit markets are traditionally developed either for polluters or for a fishery, but not for both – even in cases where the fishery is damaged by pollution.

This paper extends the concept of multiple permit types to a problem involving both the externality-generating sector and the affected sector. This multi-sector market provides a mechanism for agents in one sector to respond to environmental behaviors made within the other sector. Moreover, unlike traditional permit markets in which the regulated externality sector incurs only costs, we show that the multi-sector market generates efficiency gains that may be redistributed using appropriate allocations of initial endowments. Accordingly, the multi-sector market may generate gains that benefit both sectors, resulting in a win-win outcome for both sectors. We use a simple example of a polluted fishery to illustrate the approach, but note that it could be applied in a variety of different settings.

Polluted Fishery

Suppose a commercial fishery is polluted by emissions from local industry. Denote the fish stock by x and the stock of ambient pollution affecting the fishery by a. The fish stock grows according to:

(1) $$\dot{x} = g(x,a) - h$$

where g is net growth prior to harvesting, and h is the aggregate harvest. For a given a, g takes the usual shape with respect to x: $g_{xx} < 0$ (where subscripts denote partial derivatives), and $g(0,a)=g(X(a),a)=0$, where $X(a)$ is the carrying capacity of the fishery for a given value of a. We assume pollution reduces both total and marginal growth of the fishery ($g_a(x,a) < 0$, $g_{xa}(x,a) < 0$), which yields $X_a(a) < 0$. The reduction in fishery productivity is the only way in which pollution damages the fishery in the model (e.g., the value of fishery harvests are not reduced due to pollution, though we could model this).

The stock of ambient pollution grows according to

(2) $$\dot{a} = z - \gamma a$$

where z is current emissions and γ is the decay rate of pollution in the fishery. We have specified a linear relation in (2) for simplicity, but more generally the relation could be nonlinear.

Damages other than those to the fishery are given by the increasing, convex damage cost function $D(a)$.

The Social Optimum

We illustrate the multi-sector trading approach by focusing on a first-best setting. Though the real power of trading likely comes from second-best settings, the first-best approach is simpler to present and is easily expanded to second-best settings.

For simplicity, polluting firms and anglers are all price takers operating in a competitive setting, with neither sector being large enough to affect input or output prices. These assumptions imply that it is equivalent to focus on aggregate choices and welfare measures, as opposed to the choices and welfare of individual firms. We focus on aggregate measures, for now, to simplify the analysis. Implicitly (for now, explicitly later), we assume the number of firms and anglers is fixed, so that the optimal choices are derived for fixed industry structures. This is not a necessary assumption, but again it simplifies the exposition.

Denote polluters' net benefits of generating emissions in a particular period by the concave function $\pi(z)$. Denote anglers' net benefits of harvesting in a particular period by the concave function $B(h,x)$, where $B_x(h,x) > 0$ to reflect the fact that net benefits generally increase when the resource stock is larger (as harvest costs are smaller when fish are abundant). Accordingly, if ρ is the social discount rate then the planner's problem is

$$(3) \qquad \underset{z,h}{Max} \quad \int_0^\infty [B(h,x) + \pi(z) - D(a)] e^{-\rho t} dt$$
$$s.t. \quad (1), (2), x(0) = x_0, a(0) = a_0$$

The current value Hamiltonian associated with this problem is

(4) $$H = \pi(z) + B(h,x) + \lambda[g(x,a) - h] + \eta[e - \gamma a]$$

where $\lambda>0$ is the co-state associated with x and $\eta<0$ is the co-state associated with a. The necessary conditions for this problem are (1)-(2) along with

(5) $$\frac{\partial H}{\partial h} = B_h(h,x) - \lambda = 0$$

(6) $$\frac{\partial H}{\partial z} = \pi_z(z) + \eta = 0$$

(7) $$\dot{\lambda} = \rho\lambda - B_x(h,x) - \lambda g_x(x,a)$$

(8) $$\dot{\eta} = \rho\eta + D_a(a) - \lambda g_a(x,a) + \eta\gamma$$

The solution to conditions (5)-(8), described at length by Tahvonen (1991), can be written in feedback form as $h^*(x,a)$, $z^*(x,a)$, $\lambda^*(x,a)$, and $\eta^*(x,a)$.

Multi-Sector Permit Trading

Though a decentralized market consists of interactions involving many firms, we continue to simplify the exposition by focusing on the two aggregate sectors. We begin by specifying how decisions are made prior to regulation. Unregulated polluters choose the emissions level z^0 such that $\pi_z(z^0) = 0$, yielding $\pi^0 = \pi(z^0) > 0$. Unregulated anglers choose the harvest volume $h^0(x)$ such that rents are competed away $B(h^0(x), x) = 0$.

Now consider the design of the decentralized multi-sector permit market. This market is based on a single category of permits to be allocated between the two sectors. Without loss of generality, permits are denominated in terms of emissions. Permits are denoted $\hat{z}$ and are sold at a price of q. A cross-category trading ratio, denoted τ, defines how many harvest permits count for one emissions permit. This ratio ensures that an increase in ecological pressure from one sector is accompanied by a decrease in ecological pressure from the other sector. For instance, fishing firms (anglers, indexed by *f*) holding $\hat{z}^f$ permits are allowed to harvest $\tau\hat{z}^f$ fish. Anglers can only increase their aggregate harvests, increasing stress to the fishery, by removing 1/τ emissions from the system and offsetting some degree of stress on the fishery. In purchasing these permits, it is as if anglers are making an investment in pollution control. Alternatively, polluters can only increase their aggregate emissions if they purchase permits from the fishery. In purchasing these permits, it is as if polluters are making an investment in conserving the fishery.

Consider the problem faced by polluters (indexed by *p*), who are initially allocated $\hat{z}^{p0}$ permits. Polluters will choose emissions levels, *z*, and emissions permit holdings, $\hat{z}^p$, to maximize their net benefits of emissions, $\Pi = \pi(z) - q[\hat{z}^p - \hat{z}^{p0}]$, given that their total emissions cannot be greater than their permit holdings, $z \leq \hat{z}^p$. Assuming the emissions constraint is satisfied as an equality, then $\hat{z}^p$ can be eliminated as a choice variable so that $\Pi = \pi(z) - q[z - \hat{z}^{p0}]$. The resulting first order condition is

(9) $\partial\Pi / \partial z = \pi_z(z) - q = 0$.

Now consider the problem faced by anglers, who are initially allocated $\hat{z}^{f0}$ permits. Anglers will choose harvest levels, *h*, and permit holdings, $\hat{z}^f$, to maximize their net benefits of harvesting, $B(h, x) - q[\hat{z}^f - \hat{z}^{f0}]$, given that their total harvests cannot be greater than their permit holdings, $h \leq \tau\hat{z}^f$. Assuming the harvest constraint is satisfied as an equality, then $\hat{z}^f$

can be eliminated as a choice variable so that anglers' net benefits can be written as $B(h,x) - q[h/\tau - \hat{z}^{f0}]$. Anglers' necessary condition for optimal harvests is

(10) $\quad B_h - q/\tau = 0$

The market solution is characterized by the necessary conditions (9) and (10) along with the market clearing condition

(11) $\quad \hat{z}^{p0} + \hat{z}^{f0} \geq z + (1/\tau)h$

In particular, conditions (9) and (10) together imply that the market equilibrium results in indifference at the margin between using permits for emissions or harvests, with the technical rate of permit substitution being equal to the economic rate of substitution:

(12) $\quad \tau = \pi_z(z)/B_h(h,x)$.

The Economically Optimal Multi-Sector Permit Market

An optimal permit market is designed by choosing the aggregate number of permits (in either denomination) and the trading ratio to maximize the present value of social net benefits, subject to polluters' and anglers' behaviors in the market as given by conditions (9)-(11). As market behaviors do not constrain a first-best trading program, we can derive the first-best program by simply analyzing how the solution to the planner's problem (3) relates to the market solution.

First consider the optimal choice of trading ratio. Comparing condition (9) with condition (6), we see that an optimally designed market will yield $q^*(x,a) = \eta^*(x,a)$.

Conditions (5) and (12) then imply the optimal state-dependent trading ratio is

(13) $\quad \tau^*(x,a) = -\eta^*(x,a)/\lambda^*(x,a) > 0$,

The trading ratio, which defines how a harvest volume substitutes for one emissions permit, is larger the larger are the marginal damages of pollution (-η) relative to the marginal value of the fishery (λ). Greater reductions in harvests are required to increase emissions the larger are marginal damages, *ceteris paribus*, implying emissions increases are costly in this setting. Fewer reductions in harvests are required to increase emissions the larger is the marginal value of the fishery, *ceteris paribus*, implying emissions increases are cheap in this setting.

Alternatively, more emissions permits must be removed from the system to increase harvests, the larger is the marginal value of the fishery, *ceteris paribus*, implying harvest increases are expensive in this setting. The reason is that more harvests would depress resource rents and reduce the value of the fishery. Fewer emissions permits must be removed to increase harvests, the larger are marginal damages, *ceteris paribus*, implying harvest increases are cheap in this setting. The reason is that the fishery has incentives to take more emissions permits off the market, to reduce pollution, when pollution is heavily damaging to the fishery and/or society at large.

The adjoint condition (8) can be used to rewrite the optimal trading ratio as

$$\tau^*(x,a) = -\frac{g_a(x,a)}{\rho+\gamma} + \frac{d\pi_z(z^*(x,a))/dt}{B_h(h^*(x,a),x)[\rho+\gamma]} + \frac{D_a(a)}{B_h(h^*(x,a),x)[\rho+\gamma]} > 0, \tag{14}$$

The first right-hand-side (RHS) term, which is positive, is the discounted marginal impact of pollution on fishery growth, where the discount rate is ρ+γ to reflect the persistence of pollution. The second RHS term is the discounted capital gain associated with pollution, normalized by the marginal value of fish. This second term vanishes in the steady state. The final RHS term is the discounted marginal damage costs accruing outside the fishery, again normalized by the marginal value of fish. The larger are marginal damages outside of the fishery, the larger the trading ratio and hence the price of emissions permits relative to harvest permits.

Now consider the optimal number of permits. Denote the total number of permits by Z^*. The optimal state-dependent number of permits is then specified as

(15) $$Z^*(x,a) = z^*(x,a) + \left(1/\tau^*(x,a)\right)h^*(x,a)$$

We now turn to the issue of allocating these permits.

Choosing the initial permit allocation: creating a win-win solution

Once the trading ratio and the number of permits are chosen, the permit market is implemented by choosing a method to allocate permits among polluting firms and anglers. We analyze an approach in which the permits are freely allocated (as opposed to auctioned off). In this setting, the regulatory authority chooses some combination of $\hat{z}^{p0*}$ and $\hat{z}^{f0*}$ such that the aggregate permit cap is attained in each period. Specifically, if we specify the initial allocation in state-dependent form, then the allocation in each period must satisfy the following relation

(16) $$\hat{z}^{p0*}(x,a) + \hat{z}^{f0*}(x,a) = Z^*(x,a)$$

It is well-known that the initial allocation of permits does not affect market efficiency, provided transactions costs are negligible and markets are competitive (Montgomery 1972). The initial allocation of permits does affect the ex post (i.e., post trading) distribution of welfare, however, as firms initially allocated with permits will be better off than firms that do not hold permits initially but must instead purchase them from the initial permit holders. The initial allocation is typically approached as an equity issue (Kampas and White 2003).[1] However, we argue that the allocation could have welfare implications, making it also an efficiency issue.

In a traditional pollution permit market where pollution-related costs are external to all

[1] The initial allocation has been shown to have efficiency implications when there are transactions costs (Stavins 1995).

permit market participants, all economic surplus created by the permit market accrue to non-polluters whereas economic costs arise as the net impact to polluters in the permit market. Polluters endowed with a relative abundance of initial permit holdings may gain from the pollution market, as they can sell some of their permits to others. However, these gains only result from an income transfer that does not affect economic surplus among polluters; as indicated above, polluters are collectively worse off after the imposition of the permit market and the initial endowment only redistributes these costs. Indeed, Kampas and White (2003) analyze a variety of allocation approaches for a traditional pollution permit market and find that the gains to one sub-group of permit traders is always offset by losses to another sub-group.

The multi-sector permit market described here differs from traditional permit markets in that the multi-sector market generates economic surplus for the fishery. Absent other external damage costs (i.e., if $D(a) = 0$), or when these other damage costs are sufficiently small, the gains to the fishery must outweigh abatement costs in a first-best market. Moreover, the proper redistribution of this additional surplus could leave all market participants better off than if the permit market had not been implemented, so that the permit market yields a win-win outcome. In what follows, we simplify matters by assuming $D(a) = 0$.

The redistribution of additional surplus that is required for a win-win outcome may be accomplished via the choice of initial permit endowments, provided such a redistribution lies in the core. A minimum condition for such a redistribution to lie in the core is that both polluters and anglers can be better off when all permits are initially allocated to polluters. The reason is that all economic surplus is generated by the fishery, and so a win-win outcome will only arise if surplus in excess of polluting firms' abatement costs can be transferred to the pollution sector. Assuming polluters receive all permits initially, they will be better off than in the unregulated scenario whenever the following condition holds:

$$(17) \qquad \int_0^\infty q^*(x,a)[h^*(x,a)/\tau^*(x,a)]e^{-\rho t}dt > \int_0^\infty \left[\pi^0 - \pi(z^*(x,y))\right]e^{-\rho t}dt > 0 .$$

The RHS of (17) represents the present value of abatement costs. The left hand side (LHS) of (17) represents the present value of total revenue that polluters receive from selling permits to anglers. Note that anglers are collectively always better off under the permit market, even if all permits are initially allocated to polluters. Anglers' permit purchases in this case, as given by the RHS of (17), equal $B_h(h^*(x,a),x)h^*(x,a)$ after using condition (10). Anglers' post regulatory net benefits are then $B(h^*(x,a),x) - B_h(h^*(x,a),x)h^*(x,a)$, which is positive by the concavity of *B*. Finally, note that condition (17) implies

$$(18) \qquad \int_0^\infty B(h^*(x,a),x)e^{-\rho t}dt > \int_0^\infty \left[\pi^0 - \pi(z^*(x,y))\right]e^{-\rho t}dt$$

which must hold in a first-best outcome in which the surplus gained by the fishery exceeds abatement costs. Hence a win-win situation is not inconsistent with a first-best outcome.

Allocations based on Shapley values

Assuming (17) holds, a win-win outcome is possible. Though many initial allocations may result in a win-win outcome, a particularly interesting allocation is based on Shapley values. Shapley values describe how surplus can be redistributed among all participants in such a way that the participants would voluntarily choose to participate in the regulatory program (Shapley 1972; Petrosjan and Zaccour 2003). That is, using Shapley values to allocate surplus results in the permit market also being a cooperative solution: all participants would choose to participate in the permit market if given a choice between participation and going unregulated. Such an outcome is neither a requirement of a permit market nor of a win-win outcome. But, as we describe below, this outcome does lead to a desirable, and perhaps efficiency-enhancing, property.

Shapley values have a dynamic interpretation in the current context, and so we use the dynamic approach developed by Petrosjan and Zaccour (2003) to derive these values. It now becomes necessary to consider individual firms and anglers. Index individuals by $i \in (1,I)$, with polluting firms taking index values $i \in (1,p)$ and anglers taking index values $i \in (p+1,I)$. Individual polluters' emissions are denoted z^i, with $\sum_{i\in(1,p)} z^i = z$. In particular, denote z^{i0} to be the unregulated emissions level for firm *i*, with $\pi^i(z^{i0})$ being the corresponding profit level. Individual anglers' harvests are denoted h^i, with $\sum_{i\in(p+1,I)} h^i = h$. Denote $h^{i0}(x)$ to be the unregulated harvest level for angler *i*, with $B^i(h^{i0}(x),x)$ being the corresponding profit level. Taking others' choices as given, the present value of net benefits to individual *i* at time *t* is

(19)
$$
\begin{aligned}
F^i(x,a,t) &= \int_t^\infty \pi^i(z^{i0}(\tau))e^{-\rho(\varsigma-t)}d\varsigma, \qquad i \in (1,p); \\
F^i(x,a,t) &= \int_t^\infty B^i(h^{i0}(x,a),x)e^{-\rho(\varsigma-t)}d\varsigma, \qquad i \in (p+1,I).
\end{aligned}
$$

The value functions F^i are expressed in terms of both the current state and the current time, as Petrosjan and Zaccour (2003) indicate it is necessary to keep track of all these variables to ensure the derivation of a dynamically consistent allocation of economic surplus. We can also define the present value of net benefits, at time *t*, for any coalition $K \subseteq I$:

$$\underset{z,h \in K}{Max} \quad F(K,x,a,t) = \int_t^{\infty} \left[B(h,x) + \pi(z)\right] e^{-\rho(\varsigma - t)} d\varsigma$$

(20) $$s.t. \quad (1),(2), x(t) = x^I(t), a(t) = a^I(t),$$

$$z^j = z^{j0} \text{ or } h^j = h^{j0}(x,a) \text{ for } j \in I \setminus K$$

where $x^I(t)$ and $a^I(t)$ are the values of the states at time *t* when an efficient solution has been followed from the initial period until time *t*. That is, these values represent the solution to (3), evaluated at time *t*, or equivalently are the solution to problem (20) for the special case of the grand coalition *K=I*. Given these definitions, the characteristic function of the cooperative game is:

(21) $$\begin{aligned} &v(\{i\},x,a,t) = F^i(x,a,t), \qquad i = 1,\ldots,n \\ &v(K,x,a,t) = F(K,x,a,t), \qquad K \subseteq I \end{aligned}$$

The Shapley value is then

(22) $$\phi^i(v,x,a,t) = \sum_{K \ni i} \frac{(n-k)!(k-1)!}{n!}[v(K,x,a,t) - v(K \setminus \{i\},x,a,t)]$$

where *k* is the number of members of coalition *K*. The Shapley value represents the present value of surplus that will be allocated to individual *i* from time *t* onwards, with $\sum_{i \in I} \phi^i(v,x,a,t) = F(I,x,a,t)$. Unlike static models, the dynamic Shapley value in (22) is not the current allocation of surplus to individual *i*. Rather, the amount of economic surplus to be allocated to individual *i* at time *t* is based on the dynamic Shapley value:

(23) $$\beta^i(t) = \rho\phi^i(v,x,a,t) - \frac{d\phi^i(v,x,a,t)}{dt}$$

The allocation $\beta^i(t)$ represents a share of the efficient, current-period surplus $\sum_{i \in (1,p)} \pi^i(z^{i*}(x,a,t)) + \sum_{i \in (p+1,I)} B^{i*}(h^{i*}(x,a,t),x)$. To see this, sum expression (23) over all $i \in I$ to obtain

$$(24) \qquad \sum_{i \in I} \beta^i(t) = \rho F(I, x, a, t) - \frac{dF(I, x, a, t)}{dt}$$

The Bellman's equation associated with problem (20) for the case of the grand coalition, which holds along an efficient solution path, is

$$(25) \qquad \rho F(I, x, a, t) = \left[\sum_{i \in (1,p)} \pi^i(z^{i*}(x, a, t)) + \sum_{i \in (p+1, I)} B^{i*}(h^{i*}(x, a, t), x) \right] + \frac{dF(I, x, a, t)}{dt}.$$

Rearranging (25) and comparing the result with (24), we find the following relation must hold

$$(26) \qquad \sum_{i \in I} \beta^i(t) = \sum_{i \in (1,p)} \pi^i(z^{i*}(x, a, t)) + \sum_{i \in (p+1, I)} B^{i*}(h^{i*}(x, a, t), x)$$

Hence, current-period surplus is fully allocated in each period.

The surplus allocation indicated by (23) is achieved by setting the following initial permit allocations at time *t*

$$(27) \qquad \begin{aligned} \hat{z}^{i0*}(x, a, t) &= \frac{[\beta^i(t) - \pi^i(z^{i*}(x, a))]}{q^*(x, a)} + z^{i*}(x, a), \qquad i \in (1, p) \\ \hat{z}^{i0*}(x, a, t) &= \frac{[\beta^i(t) - B^i(h^{i*}(x, a), x)]}{q^*(x, a)} + h^{i*}(x, a) / \tau^*(x, a), \qquad i \in (p+1, I) \end{aligned}$$

It is easily verified that the initial permit endowments in (27) sum up to the efficient permit cap $Z^*(x,a)$:

$$
\begin{aligned}
\sum_{i\in I}\hat{z}^{i0*}(x,a,t) &= \sum_{i\in(1,p)}\left[\frac{[\beta^i(t)-\pi^i(z^{i*}(x,a))]}{q^*(x,a)}+z^{i*}(x,a)\right] \\
&\quad+\sum_{i\in(p+1,I)}\left[\frac{[\beta^i(t)-B^i(h^{i*}(x,a),x)]}{q^*(x,a)}+\frac{h^{i*}(x,a)}{\tau^*(x,a)}\right] \\
&= \frac{\sum_{i\in I}\beta^i(t)-\left[\sum_{i\in(1,p)}\pi^i(z^{i*}(x,a))+\sum_{i\in(p+1,I)}B^i(h^{i*}(x,a),x)\right]}{q^*(x,a)} \\
&\quad+\sum_{i\in(1,p)}z^{i*}(x,a)+\sum_{i\in(p+1,I)}\frac{h^{i*}(x,a)}{\tau^*(x,a)}=Z^*(x,a)
\end{aligned} \tag{28}
$$

where the first equality comes from (27), the second equality comes from rearranging the RHS terms, and the third equality comes from applying the relations in (26) and (15).

Given the initial permit levels in (27), firms and anglers would cooperatively participate in the permit market even if the market was not formally regulated. This has potentially important efficiency implications. Traditional permit markets are deemed beneficial because, even with an inefficiently large permit cap, i.e., $Z>Z^*$, the solution is still cost-effective. Here, having an inefficient permit cap results in less surplus to be distributed, leaving market participants worse off than in the efficient outcome. Accordingly, when aggregate permit levels are suboptimal, all market participants will have a private incentive to coordinate on requesting *additional* regulation, i.e., a lower Z, so as to move to the efficient intertemporal allocation. Thus, there is private inertia for more efficient regulation.

Discussion

We have shown that it is possible to develop and implement environmental markets to link sectors that interact ecologically, but which have not previously interacted economically. Such markets lead agents in each sector to both affect and respond to behaviors and ecological changes in the other sector, extending and enhancing economic feedbacks in ways that can improve efficiency. While our focus was on a first-best multi-sector market, for which there would be no efficiency gains relative to first-best traditional (single-sector) markets, the real power of the approach likely comes in second-best settings. Indeed, second-best single-sector markets are likely to be less responsive to ecological and behavioral changes than second-best multi-sector markets in which economic signals about environmental pressures and ecological health are transmitted across sectors.

An added benefit of multi-sector markets, which arises even in the first-best case, is the possibility of a win-win outcome in which both sectors gain from regulation. This is not true of single-sector markets, in which the externality-generating sector only incurs costs while the gains in economic surplus are external to this sector. The multi-market approach internalizes these gains and, via the initial permit allocation, can reallocate these gains to the various market participants. Indeed, we have shown that it is possible to create a market in which all participants would voluntarily choose to be regulated at efficient levels. If regulations are too lax, all participants would have incentives to demand more!

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